G.N.L. in Marine Propulsion

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September 2020

TABLE OF CONTENTS

ILUSTRATIONS

G.N.L. IN MARINE PROPULSION

ABSTRACT

This paper reviews the reasons why the LNG is becoming the new fuel in marine propulsion, it illustrates how the LNG is employed on board and it analyses how its employment in the Hidrovía Paraguay Paraná region shall be implemented.

The experience can be very well extrapolated to other similar environments.

The first titles introduce certain specificity of the marine sector, for those not familiar with them.

A proposal of a Master Plan and the adoption of a regulation frame is introduced.

Finally, there is a guidance for the design of a prototype and an evaluation of the need for such a course of action.

Conclusions point out the opportunities derived from LNG in innovating with equipment and conducts that remain anchored in the past due to lack of adequate policies. It is up to us, to respond to the requirement with a minimal reaction, or in use of our best capabilities, take the opportunity to move towards the state of the art of this technological era.

1 INTRODUCTION

LNG is becoming steadily the propulsion fuel for the marine industry worldwide.

This process is introducing mayor changes in design and operation of all vessels.

No country will be excluded from these changes that we can see happening now.

1.1 BACKGROUND OF MARINE PROPULSION

The origin of marine propulsion goes back to the beginning of the XIX century. Coal fuelled boilers and Watt's simple expansion steam engine where adapted successfully for use on board.

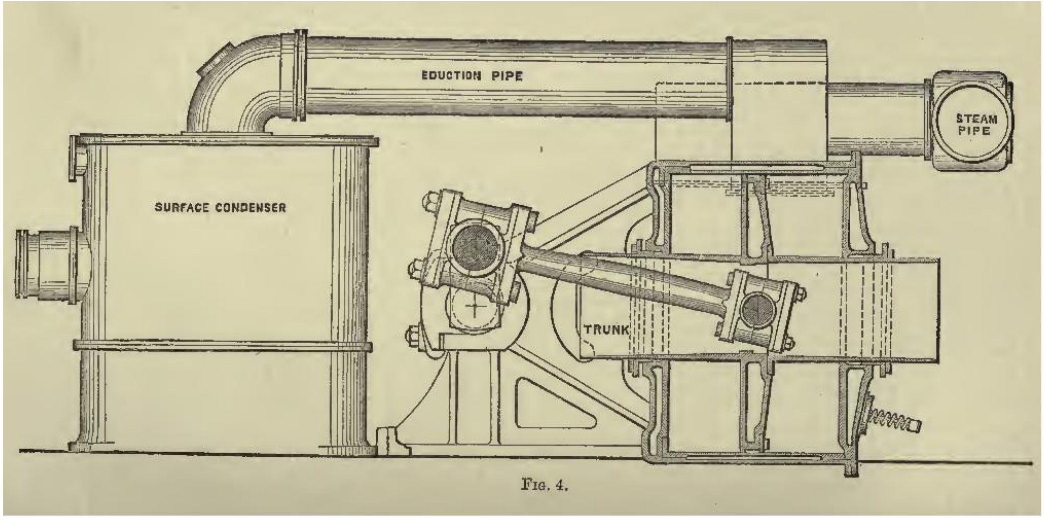
The concept developed along the XIX century to more efficient engines, although always based on coal burning boilers. The Fuel Oil was introduced at the end of the century together with the new "Parsons" steam turbine.

This scheme dominated the industry until after WWII.

The diesel engine was introduced in the 30s by the Germans. During WWII only German vessels employed diesel propulsion.

After WWII, the world fleet swapped to diesel propulsion, except for US vessels which delayed some time in doing so, mainly for military reasons.

This was, beyond the expansion in size, the last major technological global change until the present time.



1 - Sennet Engine (Naval-History.net)

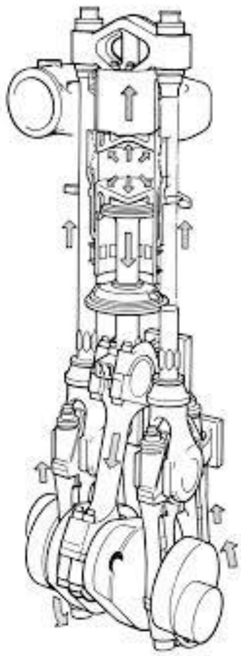
1.1.1 Diesel engines

Diesel engines went through several improvements since they were first used on board.

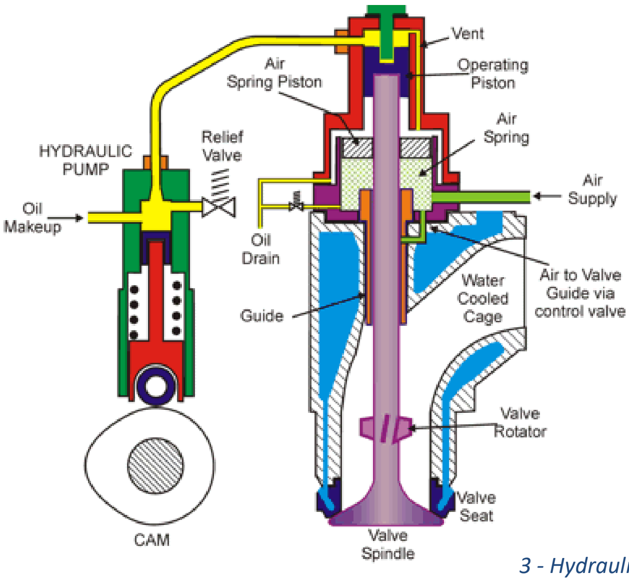
The use of turbocharger made it feasible by improving the power/weight ratio to a value which allowed the installation on board.

Thereafter, many improvements have been introduced in the scavenge process, e.g. cross scavenge, loop scavenge, uniflow, all with the objective of improving combustion.

In the same line, there was a very interesting development, the opposed pistons engine shown in figure 2, produced by Doxsford in the UK, that could be defined as an engine with a big exhaust valve. It was a very economic engine, but produced out of time, when oil was cheap.



2 - Opposed pistons engine (Jorn Dragsted).



3 - Hydraulic exhaust valve (marinediesels.info).

The last significant development is the hidraulic/electronic control of the exaust valves which allows a very good control of the combustion at variable regimes.

1.2 THE ORIGIN

The LNG was used as fuel on board for the first time in LNG transportation vessels. They were built from the mid-60's in France and USA.

The concept is that the boil of gas build up on the top of the tank as a result of the leak of heat towards the inside of the tank, raises the internal pressure and must be either vented (acceptable in those times) or otherwise consumed for propulsion. The gas is burned in steam boilers and the prime mover is a steam turbine.

This fuel remained only available for those vessels in the LNG trade until the global acceptance of new regulations to mitigate atmospheric contamination and greenhouse effects contribution by the maritime business.

In conjunction with the regulation requirements, engines manufacturers developed the dual engines, LNG and/or diesel, which gives great flexibility to the operation, especially considering the scarce availability of LNG bunkering stations. The second important development is the small or micro LNG liquefaction plants, which allows liquefaction anywhere and, in a scale suitable to any requirements, not being anymore bound to large LNG production plants.

1.3 THE REGULATIONS

Regulations applicable to maritime transportation must be global to result efficient (IMO).

The marine industry has a long story of international regulations.

1.3.1 History

The first Construction Rules go back to the early times of the insurance market, in second half of the XVIII century. Ships were classified within a scale (1, 2, 3 …) based on the quality of the construction and condition of her gears, at the discretion of the surveyor. The XIX century gave origin to the classification societies as we know them today, with a set of rules and formal procedures to be accomplished. The first was the Bureau Veritas in Antwerp followed almost simultaneously by the Lloyd's Register in London.

4 - Samuel Plimsoll monument. London (tripadvisor).

By 1870, we see the outcoming of the first "operational" regulations, the load line regulations limiting the amount of cargo to be taken on board by establishing a minimum distance between the deck of the vessel and the water surface. This is known as the "Plimsoll Mark". At that time, Owners tended to have their vessels overinsured and then overload them, producing numerous incidents and loss of lives. The strong presence of the owners in the parliament made Samuel Plimsoll's life quite difficult. He ended menacing the Prime Minister Mr. Disraeli with his fist. The Bill finally passed and was enforced by the Chamber of Commerce, but poor Samuel destroyed his political career.

His legacy got to our days.

The **Plimsoll Mark** is part of the **International Load Line Convention** (ILLC), still valid.

The first international convention adopted by mostly all countries having a significant fleet, is **SOLAS**, **Safety of Life at Sea**. It was adopted in 1914 as a consequence of the sinking of the Titanic in 1912. With successive updates, it also remains valid to the present time. It covers aspects such as subdivision and stability, construction of the hull and the machinery, firefighting system, radio communications, etc.

WWII led to the formation of the United Nations, and within this organization, the **IMO**, **International Maritime Organization** (formerly called differently) since 1958. The SOLAS was incorporated and issued in a new revision in 1960. Also, the Load Line Convention, ILLC, and Rules to Avoid Collisions at Sea, COLREG, were adopted by IMO.

MARPOL, the convention of our present concern, was adopted in 1973, in good part because of the stranding of the M/T “Torey Canon” in the southern coast of England. The oil spill reached France, and all the English Channel was covered with 120 000 tons of crude oil, the largest environmental incident in the history of shipping. Furthermore, in 76 and 77, there were several incidents with tankers, and the convention was not yet in force, so the amendment of 1978 was adopted and went into force. The Annex VI, concerned with air pollution, came into force in 2005.

Another significant incident which impacted the pollution prevention, was the stranding of the Exxon Valdez in 1989 in Alaska, in a very fragile and hard to clean area. The clean-up cost more than 2.5 billion USD and the claims exceeded 7 billion. Oil companies decided to get rid of their fleets, to charter form 3rd parties and focus in controlling the condition of those ships (also thrusted to outsiders). The US government unilaterally issued the oil pollution act of 1990, known as OPA90, that made double hull mandatory in US waters, regardless of other measures being studied by IMO at the time. The OPA90 was practically adopted by most vessels, and other interesting options under study were abandoned.

1.3.2 Marpol

The Marpol convention is structured in six chapters that regulate the prevention of both incidental and operational incidents.

We hereby illustrate the structure of those annexes:

5 - MARPOL Structure.

Annex I

•Pollution by Oil

Annex II

•Noxious Liquid Substances in Bulk

Annex III

•Harmful Substances Carried by Sea in Packaged Form

Annex IV

•Sewage from Ships

Annex V

•Garbage from Ships

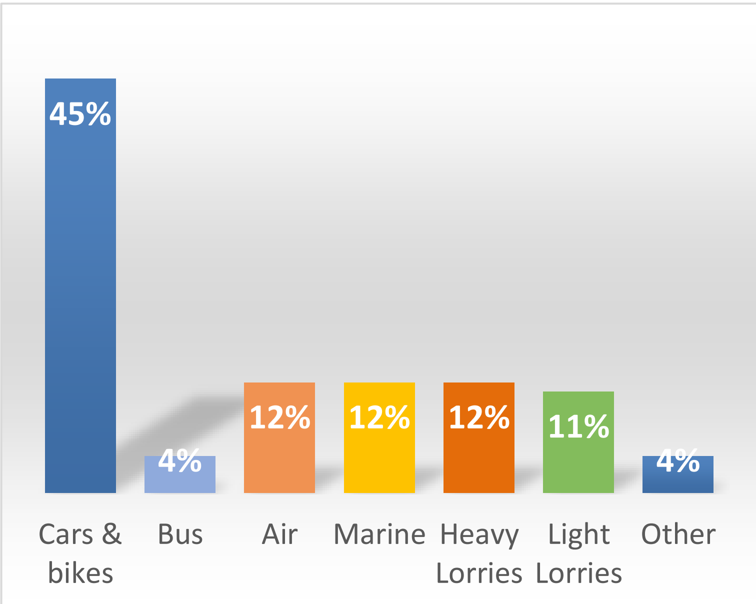
Annex VI

•Air Pollution from Ships

1.3.3 The Environment

Let us have a view of contamination attributable to our industry within the overall transportation rates.

We will quote statistical information from: *the US Energy Information Administration. International Energy Outlook 2016*.



6 - World use of energy in Transportation.

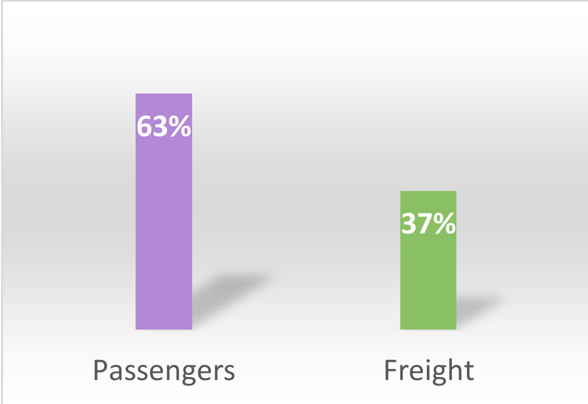
The chart beside represents the use of energy for the worldwide transportation.

Cars and motorbikes pop up with an extraordinary number, 45%; that should move us to reflexion.

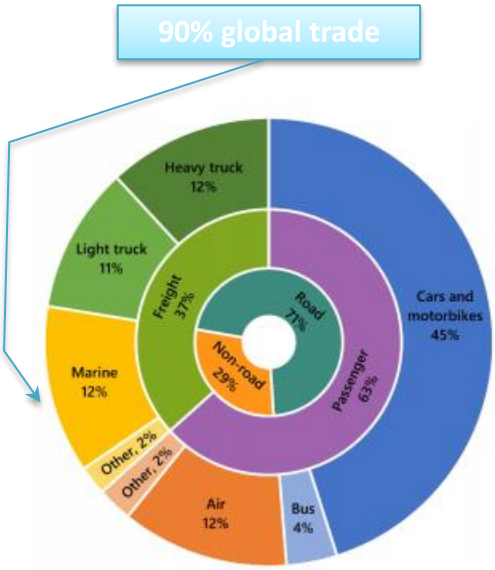
Marine employs 12%, which seams not much in proportion, but is very significant in absolute numbers (especially for the riparian population).

Another view of the same data is this one; only 37% of the energy is employed in the transportation of cargoes.

The movement of passenger in the modern world, pays a very high toll in contamination. Another number that should move us to reflection.



7 - World use of Energy: Cargo and Passengers.



8 - Use of Energy in Transportation (US energy Dep.).

This final graph includes the former ones in the two outer rings.

Note that shipping moves about 90% of the world trade, consuming only 12% of the transportation dedicated energy. However, the impact in the **shore populations is very important**, as has been quantified by thorough European studies.

1.3.4 The Requirements

What are the requirements imposed by MARPOL Annex VI?

Basically, these are the items covered:

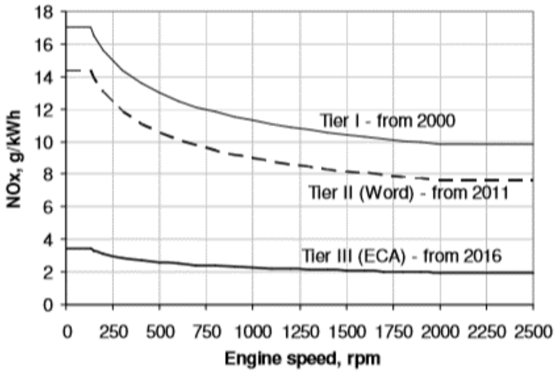
- SO_x (*Sulphur oxides*) and PMs, Particulate Matter from ships (Reg. 14).
- NO_x (*Nitrogen oxides*) emissions from diesel engines (Reg. 13).
- Marine Fuels quality (Reg 18).
- Greenhouse Gases through energy efficient ships (Chapter 4).
- VOC (*Volatile Organic Compounds*), emissions from tankers cargo tanks (Reg 15).
- Emissions of ODS (*Ozone Depleting Substances*).
- Shipboard incinerators emissions (Reg 16).

Furthermore, Annex VI defines de ECAs (*Emission Control Areas*).

Of all, we will concentrate on the first two and make some comments on the 3rd, because of their impact in the ships design.

1.3.4.1 NO_x

Nitrogen oxides (NO_x) as compounds contained in the exhaust gases of marine diesel engines are the result of fuel oil combustion. Their emission into the atmosphere affects the formation of smog and contributes to global warming and acid rains (Overview of MARPOL ANNEX VI; Leo Campara).



9 - NOx regulations (Chorowski).

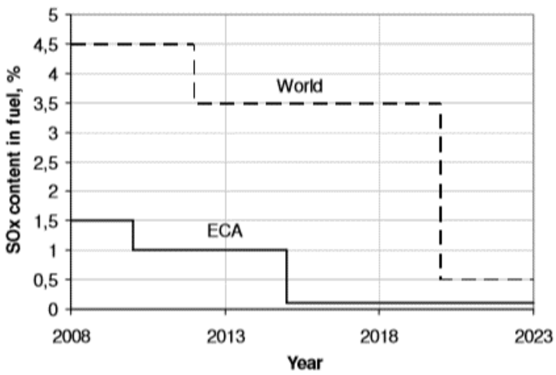
Shipping is responsible for 7% of the world's NO_x emissions; which translates to 5 million tons. The regulation sets a series of goals to be achieved by steps, based on the engines' rpms. The requirements in the chart are associated to age and time since built of the vessels.

1.3.4.2 SO_x

SO_x and PMs are regulated jointly in Rule 14. Different to NO_x, which is regulated for diesel engines, SO_x and PM are controlled no matter the source, as a content in the fuel.

Sulphur oxides (SO_x) are a collective name for sulphur dioxides (SO_2) and sulphur trioxides (SO_3). These compounds are known as "acidic gases" because its transformation results in the formation of acidic components that separate from the acid rains causing land acidification. They potentially have a detrimental effect on human's health, vegetation and building constructions.

Particulate Matter (PM), is a complex mixture of very small particles of soot and ash formed from fuel combustion products and liquid droplets. The higher the fuel sulphur content, the greater is the particle formation. As they are extremely small, these particles can be inhaled and cause serious health problems. Particles less than 10 microns in diameter pose the greatest problems, because they can get deep into the lungs, and some may even get into the bloodstream (*Overview of MARPOL ANNEX VI; Leo Campara*).



10 - SOx regulations (Chorowski).

Shipping is responsible for 4% of the world's SOx emissions, this is equivalent to about 6 m tons.

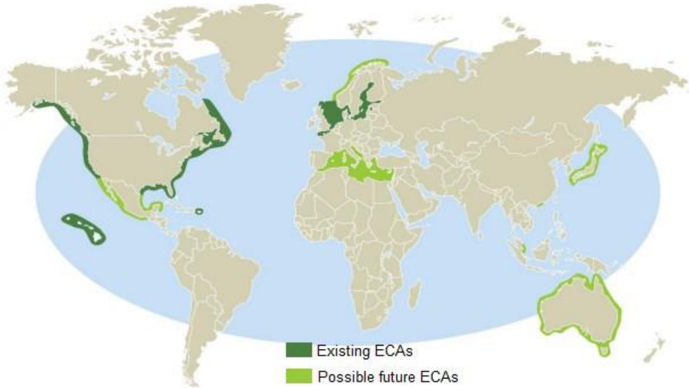
1.3.4.3 CO_2

CO2 and greenhouse effect gases are indirectly covered in Chapter 4, where an “efficient” design is required.

In few words, a hydrodynamically efficient design will consume less fuel, and therefore reduce the emission of greenhouse effect gases.

We will cover this thoroughly in the item “prototype” at the end of this paper.

1.3.4.4 ECA



11 - ECA Areas (Campara).

The Emission Control Areas are defined in Annex VI. They allow imposing stricter requirement in certain more fragile or more transited areas. The initial ECA were the Baltic and the North Sea for SOx and E an W coast of the USA for NOx & SOx.

1.3.5 The Solutions

Now we will review the main technical options to achieve the Annex VI objectives.

- **SCR** (Selective Catalytic Reduction)
  NO_x reduction by chemical recompositing to Nitrogen and water with the catalyst.
  They consume Ammonia or Urea. Ammonia slip must be prevented.
  CO_2 is produced as residue.
  It is very effective for NO_x, but for NO_x only.
- **EGCS** (Exhaust Gas Cleaning System) or **Scrubbers**
  They basically wash the exhaust gases that are forced to pass through.
  They are effective in eliminating SO_x and Particulate Matters.
  They mitigate NO_x and consume lime or caustic soda. They discharge unharmful sulphur base salts. They do not eliminate other contaminants.
  They are huge in size and quite heavy.

***12** - Scrubber - (Shipinsight.com).*

Note in the sketch the dimensions of the scrubber in a large vessel, and the height of the weight.

- **EGR** (Exhaust Gas Recirculation)
  By reinjecting part of the exhaust gases in the air intake, NO_x production is reduced (or mitigated), however it increases unburned Hydrocarbons, PMs and CO_2 as well as fuel consumption.
- **Emulsion**
  The employment of emulsifiers or emulsified stabilized fuel has proven efficient in improving fuel consumption and additionally in the reduction of PM and NO_x. Though the reduction of PMs is quite effective, the reduction of NO_x is below the regulations requirements.
- **Gas Engine - LNG**
  NO_x and SO_x as well as PM emissions are reduced below the regulations most strict requirements.
  CO_2 is reduced in about 25%, though this is referred to the vessel funnel, and being a greenhouse effect gas we are interested in the overall balance. It will be vented in the liquefaction plant. In any case separated and vented is a better situation that throwing it in the funnel, because at least it is available to be recovered / processed when the time comes that there is a suitable recovery process.

LNG is the overall solution to all the requirements.

1.4 LNG - BASIC CONCEPTS

Hereby we review and list some basic concepts concerning the LNG:

- LNG is replacing coal as the second fuel most used worldwide. It has an extensive and complex supply chain.
- LNG is basically natural gas in a liquid state. It is composed of several gases, about 90% is Methane, depending on the field of origin.
- It is stored as a liquid, in thermally insulated tanks, mostly of stainless steel, at very low pressure.
- It is transported in LNG tanks and must be gasified for its use.
- Methane is combustible in concentrations between 5% and 15% in volume, and explosive if within a confined space in such concentrations.
- It is cleaner than other hydrocarbons.
- It has been subjected to a liquefaction process that drops its temperature to -160°C reducing the volume to 1/600. This makes transportation feasible.
- In the liquefaction process, contaminant gases like CO2, H2S, SOx NOx, etc. are eliminated.
- From the point of view of handling, it is a safe fuel. All cares required by cryogenic liquids handling must be followed.

2 THE LNG ON BOARD

The use of LNG on board, impacts mainly in three areas or systems: the **engines**, the **tanks**, and the **gas plants**, though we will also refer to the boil-off recovery system. Of course, there are other areas like Fire Fighting, Ventilation, etc., that are also affected, but we will focus on those highlighted.

2.1 THE ENGINES

As mentioned, the development that gave the most significant impulse to the growth of the LNG as fuel on board is the dual fuel concept. Though the origin goes back to the 80's, it is by the end of the 90's that the first commercial dual engines are delivered. Only in the last couple of years we see a worldwide involvement in these developments.

In the field of the slow speed two stroke diesels, the first steps were given by MAN. These are the large engines employed as prime mover in large vessels. A significant number of orders followed the first delivery engine in 2015.

But we will focus now in the medium and high-speed engines, of about 1500kW.

We are currently in the beginning of the commercial development of such engines. The ranges or families of engines offered are still limited.

2.1.1 Otto vs Diesel cycle

In the Diesel cycle, the air in the cylinder is compressed over fuel ignition point before gas and pilot fuel are injected at very high pressure. In the Otto cycle, gas and air are mixed during compression and ignited by the injection of pilot fuel upon completion of the injection.

We could therefore say this is about: **High pressure vs low pressure**.

The difference in injection pressure affects mainly the complexity of the gas plant required. High pressure = high cost.

The high temperatures required for the diesel cycle combustion, result in a higher NO_x content in the funnel. A diesel cycle engine might require some after treatment to comply with tier III NO_x requirements.

On the other hand, Otto cycle requires a more precise control of the mix to avoid knocking (too lean) or misfiring (too reach). However, current technology offers a variety of solutions to this problem. The use of precombustion chambers have proved of high efficacy to concentrate there the ignition of the diesel oil.

Diesel cycle engines adapt better to the varieties of LNG compositions and conditions that need to be employed mainly in engines burning gas recovered from the cargo boil-off process.

2.1.2 2-stroke vs 4-stroke

Two stroke engines have been traditionally preferred in push boats for their fast response when manoeuvring and maintenance simplicity. Four stroke engines however, are in general more efficient and technology has developed to an extent were maintenance issues are more predictable.

There is a wide variety of engines being offered in the 4-stroke medium size engines (around 1500 kW), in contrast very little is available in the 2-stroke engine market.

We can mention engines from: Yanmar, Daihatsu, Wartsila, MAN, Caterpillar, and others.

2.2 THE TANKS

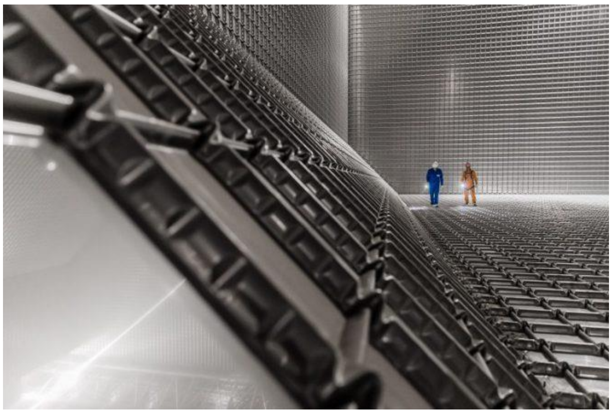
There are two concepts of cryogenic tanks for LNG, **membrane**, and **structural tanks**. For the latter, there are 3 subgroups which we will describe now:

2.2.1 Membrane Tanks

The membrane forming the barrier is not self-supporting, it lays over the insulation that covers the structure. It is so designed as to take the large dimensional variations resulting from temperature drops from ambient to cryogenic -160° C.

The material used is often either stainless steel or aluminium.

They normally work at no more than 0.25 bar, though in some cases design can reach a working pressure of 0.7 bar.



13 - Membrane tank (GTT).

These tanks are typical in LNG cargo vessels.

2.2.2 Structural Tanks

Structural tanks are classified in 3 groups which we hereon describe.

These tanks are required to sustain a 2 g acceleration load as protection in the case of a collision.

Sloshing must be considered in the calculation, as it might be a very significant load.

2.2.2.1 Type "A"

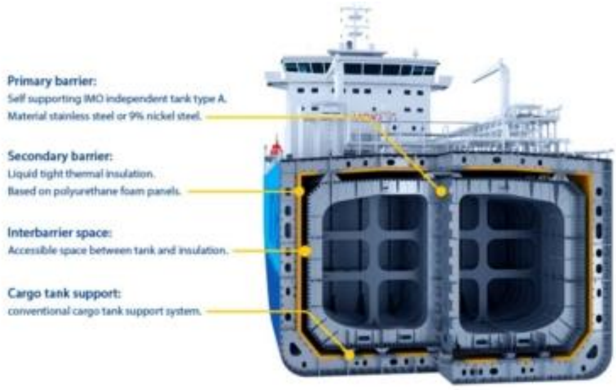
Requires a full secondary barrier.

The structural design follows standard rules for tanks.

The MWAP (Maximum Working Allowable Pressure) is 0.25 bar, and in special cases up to 0.7 bar.

There is an accessible insulation space between tank and insulation.

Materials are also mainly stainless steel.



14 - Type "A" tank (LNT).

It is a tank within a tank, with the internal tank supports in key places to minimize heat exchange.

2.2.2.2 Type “B”

They are of a more sophisticate design.

Geometry is usually cylindrical or spherical. In the illustration we see a sphere with a cylinder body that improves the cargo capacity

In these cases, only a spill collection tray is required.

The MWAP is same as for type “A”.

15 - Type "B" tank (KHI).

2.2.2.3 Type “C”

Type “C” are self-supporting tanks that can be considered “pressure vessels”.

They are independent tanks, usually shaped “C” or “D”

MAWP is over 0.7 bar, limited within the possibilities of a pressure vessel.

They are available in certain sizes, in general not over 600 m^3.

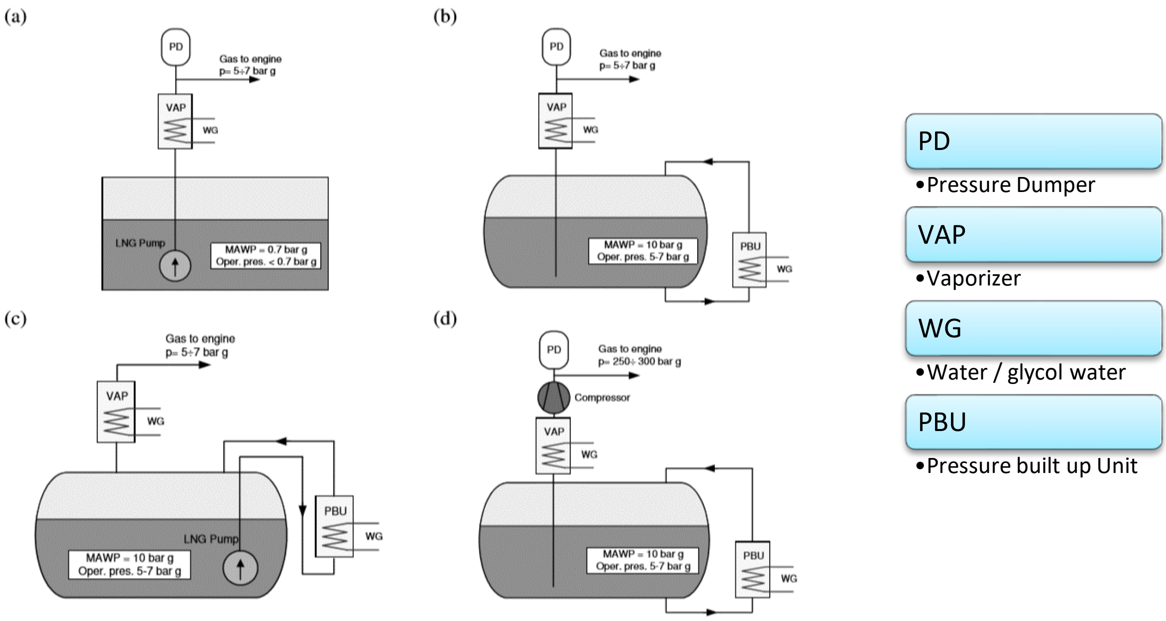
16 - Type "C" tank (Gloryholder).

This is the type of tank we are more interested from here, on in view of the application we will explain in the following sections.

2.3 THE GAS SYSTEMS

Different schematics can be considered for the LNG regasification process, depending in the type of tank, position on board, characteristics of the engine, etc.

We will present the schemes together, for better comparison between them:



17 - Gas Systems (IOP Chorowski).

a) **With pump**:
When we have a low-pressure tank (MAWP < 0.7b, membrane or "A" or "B" types), a submersible pump is required, to pump the liquid out of the tank and to build up the pressure to what is required by the engine. These pumps are quite sophisticated (and expensive); however, they are very reliable, and manufacturers claim they are more and more competitive, even in arrangements in which their use is not mandatory.
The gas is warmed/vaporized in the VAP, where heat is provided by suitable intermediate fluid, like water + glycol.
The PD is a damper necessary to compensate for pressure fluctuations. In many cases, with a suitable design of the piping, this PD can be avoided.
This arrangement is adequate for low pressure engines.

b) **By heating**
In this case, the tank allows for a certain pressure to build up inside. The PBU, Pressure Build Up Unit, makes this by warming the gas. Heat is received through WG.
The fluid is conducted out of the tank simply by hydrostatic conditions.
From there on, the system is the same as a).

c) **Combined**
This option is the same as b), but with the tank in a low position, like e.g. a double bottom, therefore the PBU cannot be always below the liquid level and a small pump is required to ensure that liquid goes through the PBU.

d) **With compressor**
This one is like b), but after the VAP a compressor rises the gas pressure to that required by the engine, say 300 bar.

Other combinations are possible, but these cases mostly illustrate all the basic concepts.

2.4 The recovery of the Boil Off

Recovery of the boil-off is a very important process. Venting methane to the atmosphere should not be a possibility in circumstances other than an emergency, otherwise we will be giving up our main goal.

Marine tanks are subjected to thermal losses to a higher degree than those ashore. Their structural complexity derived from the loads to be resisted, especially those to ensure integrity in case of a collision and those derived from the sloshing effect, requires internal structures.

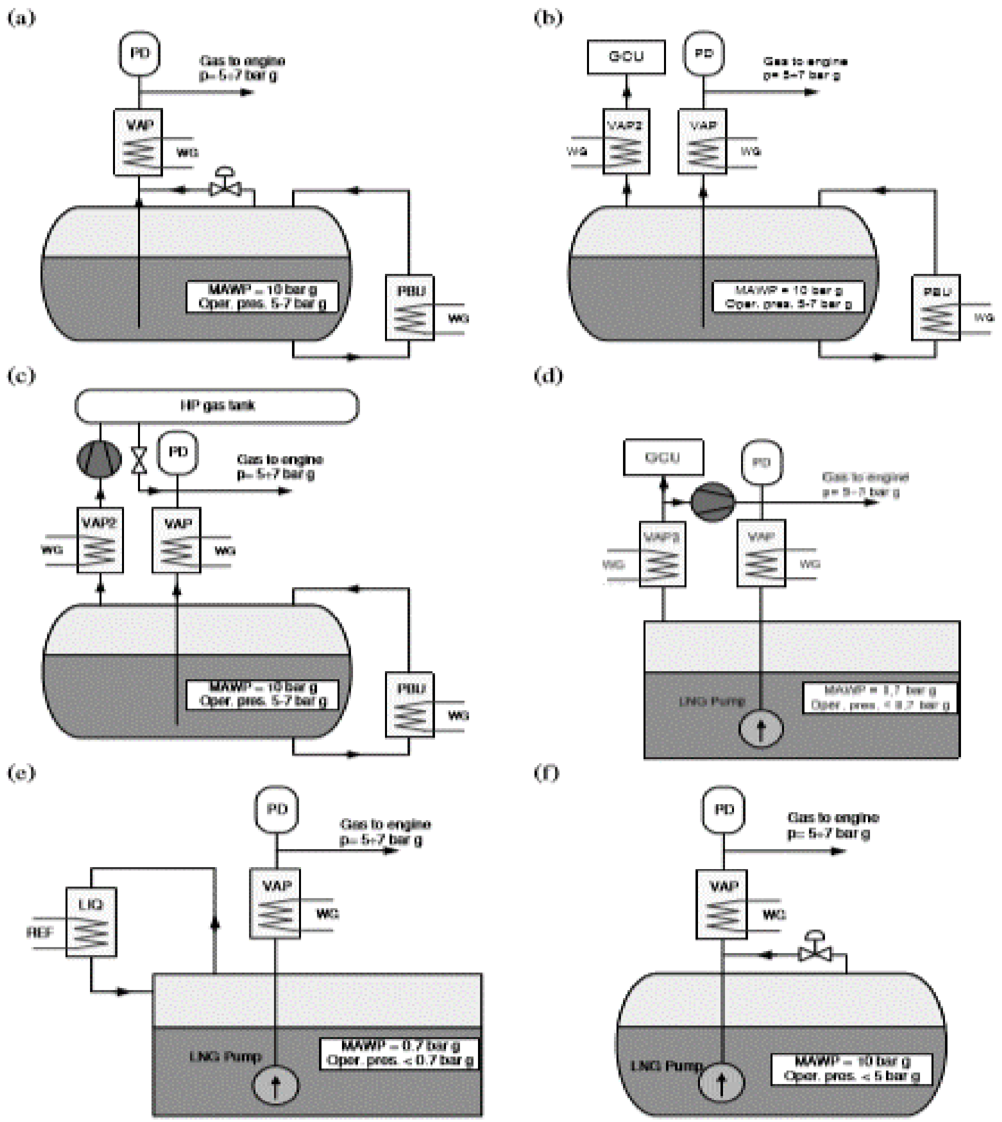
The classification societies demand that a tank should remain without opening the safety valve for at least 15 days. This might require some intervention depending on the type of tank, the atmospheric conditions, etc.

Different systems can be adopted to "consume" this gas, in general derived from the previously described gas system.

The general concepts are the following:

a) Consumes the gas build up in the tank, in the engines. It requires the engines running to consume and the tank rising the pressure to quite a high level.
b) The gas is consumed in a GCU. It can be employed in any service on board; heating, VAP, etc.
c) The boil off is compressed and stored in a pressure tank, at high pressure, and then employed in the engines in due time.
d) Similar for a low-pressure tank. Requires a compressor.
e) In this case, the boil off is liquified and returns to the tank liquid at cryogenic temp.
f) Like a) for the pump situation.

A good boil off handling system ensures a clean and green vessel.



PBU
- Pressure Built Up Unit

GCU
- Gas Combustion Unit

REF
- Cryogenic cooler

18 - Boil Off systems (IOP Chorowski).

PD
- Pressure Dumper

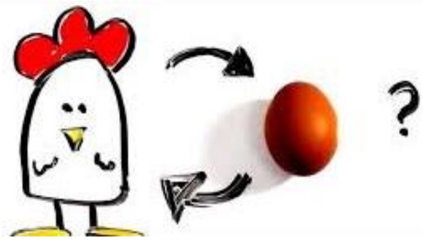
VAP
- Vaporizer

WG
- Water / glycol water

3 THE IMPLEMENTATION OF GNL USE IN THE REGION

3.1 INTRODUCTION

In order to review the best options to develop the use of LNG in the region, we will refer to an article we published in 2015 titled "*LNG the fuel to recover the HPP (Hidrovía Paraná Paraguay)*".We evaluated why this fuel could allow Argentina to reconstruct its historical inland waters fleet. The article concluded that this was the dilemma of ***the chicken and the egg***.



In that article we pointed out the following:

- The **development of the use of LNG** in all the basin and the potential expansion to other traffics like the coastal, regional, fishing, requires of **large investments in studies and plans** that are difficult to be accomplished without the intervention of the government.
- The **implementation** of this technology **by the owners** requires their changing over to new high-tech units. Suitable aids in credits or other means must be provided, at least for the initial investments.
- **Bunkering services** must be available in reasonable cost and operational conditions.
  Without **seasonal limitations** or shortages and with a **steady price**, or at least an even relation of the price with that of the MDO.
- In the **USA, the MARAD program** offers 900 000 USD in subsidies to promote the conversions of existent port tugs to GNL.
  The aim is to create a data base to facilitate future conversions. The owner using the subsidy must make public all the technical information derived from the project.
- The **European Master Plan** for the Rhin-Moss-Danube that studied the use of LNG in that basin, invested 34 million euros in very thorough research, regulations, training, etc. This plan could be considered as a model for ours.

These terms remain valid today, the needs persist, the financial issues are the same, and the conclusion is the same: the **need for a plan to organize our regional development**.

3.2 PUSHER BOATS

Pusher Boats are the key to implementation of LNG in marine propulsion in the region.

Why pusher boats?

The main reasons are four:

- **Availability of space on deck.**
  The tug's deck is not busy with cargo, ore cranes, or nets. It is fully available to place the LNG tanks. This makes the design simpler, there is no requirement to

place gas tanks below main deck, with the associated extra costs and technical hurdle.

- Small impact of the **principal dimensions** in the design. The dimensions of the tug can be adjusted when in the drawing board without inconveniences, the deck is available to receive the fuel tanks. The tug sketched in this item is suitable to make the round trip Zárate - Corumbá (over 7500 km) with adequate margin and on a single load of LNG.
- Strong impact of the **fuel oil use** in the operational costs. If compared with, e.g. a port tug in which the fuel is of minor incidence in the costs, in a river push tug, fuel is of great importance.
- No **stability** problems. Stability requirements due to the high emplacement of the tanks, can be corrected very easily with little changes in the dimensions.

3.3 Impacts in the Region

The use of LNG in the Hidrovía Paraguay Paraná has three main areas of impact:

19 – Impacts in the Region

- **Environmental**:

The use of LNG will significantly improve the environmental conditions in our main basin, especially in the riverside.

- **Economic**:

The improvement in the economic conditions, namely the reduction in OPEX, should allow us to recover the HPP as a cheap and efficient means for the transportation of our goods and those of the region, to the export ports.

***20** - LNG Push boat by ConsulMar SRL.*

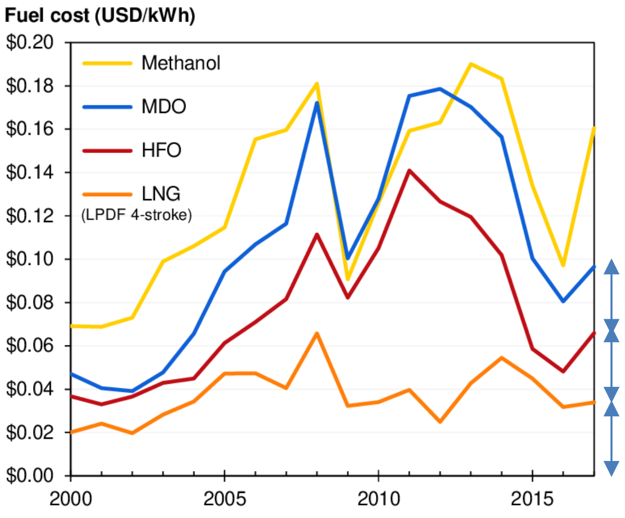
- **Social**:
  The fleet renewal plan will create many high-quality jobs in the shipyards. The same will happen with the merchant marine jobs that will increase not only in number, but in quality. Also, the living conditions on board should improve considerably.

3.4 AVAILABILITY

- **Natural gas is abundant in our country**. The "Vaca Muerta" formation is the 2nd largest in the world and the only shale in production outside the USA.
- Presently we have a floating **regasification and storage plant** in a key position in the south of the HPP.
- We have **gas ducts** along most of the HPP in the Argentinian section, up to Reconquista.
- With gas being available in gas ducts not only along the HPP, but also along all the Atlantic coast, it will be possible to install **liquefying plants in any location** required.

3.5 COSTS

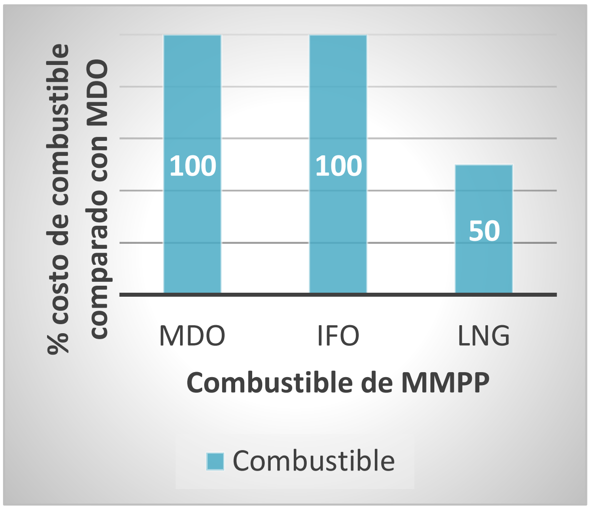
The world cost for different fuels has been synthesized by the US Sec. of Energy in the graphic below.



21 - Fuels World Costs. (US Sec. of Energy).

In 2016 the relation between LNG, IFO and MDO cost was of about 1/3, 1/3, 1/3 in comparable terms.

The operational cost of using the different fuels in our cost environment is approximately the following:



22 - Relative Cost of Fuels

The cost of MDO and IFO can be levelled, depending on the prices, this is due to the technical aspects of the plant.

The 50% cost of the LNG (operational, excluded of capital extra expenses) is no doubt significant, and can impact in the overall costs differently depending on the cost composition for each flag. In the Argentinean flag, this incidence will be smaller because of the high cost of the crew and taxes.

Another very important aspect of the cost is the fuel **robbery**. This is a substantial component of the cost that we have not been able to quantify.

Robbing in MDO is very high, in IFO is small, **with LNG is impossible**.

3.5.1 Operation

- The operation of an LNG plant on board, requires highly skilled personnel.
- These personnel need to be specially trained and supervised.
- The demanding working conditions raise the general level of all those participants in the operation. The European program has created training centres for both land and onboard personnel.
- The access of merely fit personnel, without a suitable education, shall be limited or excluded.
- On this respect we refer to YPF's experience with their regasification plants, in which the general level of all the crew raised to the highest qualifications. The training in performing a complex task, makes the individual improve all his work in general.
- The operational costs were observed to reduce as the personnel performed better due to a higher training level.

3.5.2 Environment

3.5.2.1 What do we have?

- Most engines now in use in the HPP do not comply with any emissions regulations.
- The import of obsolete second-hand units brings together engines of very old conception and in dubious condition.
- If this is not stopped, these engines will continue to pollute for decades.
- So far, we do not have rules that regulate air pollution by ships in the HPP.

3.5.2.2 What do we do?

- Even in new units, we are not being better than Marpol tier II.

- IFO engines do not even reach this standard.
- The use of liquid fuel represents an additional contamination danger in case of spill. Oil spills in the river produce damages very difficult to be repaired or cleaned. Most of the tugs do not have double hull protection.

3.5.2.3 What can we do?

- LNG fully complies all the requirements presently imposed to international trade, with margin. Adopting this fuel in inland navigation is quite simple.
- Rules must be adopted. Owners need to have standards that level all players to remain competitive.

> The main reason why shipping is changing engines and fuels worldwide,
> **is because it is imposed by the rules.**

3.6 FEATURES CONTRIBUTING TO THE IMPLEMENTATION

Several features are presently contributing to the implementation of the use of LNG in Argentina:

The Energy Secretary has declared the use of GNL in propulsion as a policy, as well as the development of use of LNG in areas not served by gas ducts.

The undersecretary of Hydrocarbons is executing the program with active promotion measures.

YPF, the national oil company, is part of the program, and has expressed firm interest in distributing and installing bunkering stations.

The Secretary of Industry is working in facilitating finance access for the program.

The IDB bank is involved in the development of LNG use in the region.

Provincial governments in the way are most interesting in the program.

There are at least three LNG push boat projects at different development stages being elaborated by; a group of private interests, a state-owned yard and a union.

3.6.1 Three Projects

From the industry perspective, the program comprises three projects with combined effects:

- The construction of LNG propelled push boats.
- The construction of LNG barges.
- The transportation of GNL in the HPP.

3.6.2 Master Plan

A Master Plan has been proposed by the University of Buenos Aires, Faculty of Engineering.

The Plan will cover all issues related to the availability, transportation consumption and distribution of LNG in the region.

It will study present time situation and projections.

It will also evaluate the before mentioned three areas of impact, environment, economics and human.

The proposal for the Master Plan includes a detailed methodology to ensure the composing of a uniform data base and coordinated reports.

We hereon quote the Plan’s bullet list to show the scope proposed:

3.6.2.1 **GNL in PROPULSION**

- The Waterway
  - General description.
  - Outstanding characteristics.
  - Operation conditions.
  - Future conditions.
    Improvements that can be expected.
- The Cargo
  - Types:
    - Bulks.
    - Ores.
    - Liquid.
    - Containers.
    - Others.
  - Transportation:
    - River/barges.
    - River /self-propelled.
    - Railways.
    - Lorries.
  - Projections:
    - LNG
- The Fleet
  - Existent:
    - Argentina.
    - Foreign.
  - The condition and the particulars.
  - LNG vessels:
    - Particulars.
    - Local building capabilities.
- The Equipment
  - Engines
    - Types
  - Gas equipment.
  - Storage of LNG on board.
  - Availability,
    - Financing,
    - After sales service.
  - Local capability for manufacturing.
- El L.N.G.

- Availability.
- Key places for bunkering:
  - Downriver.
  - Upriver.
- Best ways to supply the bunkering stations.

3.6.2.2 IMPACTS

◆ ECONOMIC IMPACT

- Infrastructure costs.
  - Liquefaction plants.
  - Link to gas pipes.
  - Piers.
- Equipment costs, CAPEX.
  - Tugs.
  - LNG transportation/supply vessels.
- Operational expenses OPEX.
  - LNG price on board
    construction
    structure.
    taxes.
  - Customs condition/dues.
  - Costs of the crew.
  - Projections.
- Financing.
  - International promotion credits.
  - Local financing.
  - Tax structure.
  - Import taxes and dues.
  - Other advantages: Promotion laws etc.
- New Business
  - Oil & Gas activities.
  - Freight gains in the HPP
  - Regional production, improving relative prices due to lower freight.
  - Shipbuilding Activity.
  - LNG transportation for local consumption; relative advantages.

◆ ENVIRONMENT IMPACT

- Fuel.
  - Diesel & IFO vs GNL.
  - Clean fuel/ low emissions.
- Associated technologies.
  - Hydrodynamic improvement:
    Hull lines
    Propellers
  - Manoeuvring improvements.
  - Other improvements.

◆ SOCIAL IMPACT

- Shipbuilding industry.

- Crews.
- Population:
  - Ports
  - Riverine

3.6.2.3 **LNG Distribution to the NEA**

- OFFER
  - Availability in the basin.
  - Gas pipes.
  - Bahía Blanca.
- CONSUMPTION
  - National
    - Urban areas
    - Industrial clusters.
  - Exports
    - Regional.
    - Bi-ocean corridor.
- DISTRIBUTION
  Alternatives
  - LNG Barges.
  - ISO Containers.
  - Lorries.
  - Railways.
  - Combinations.
  - Gas pipes:
    - NEA
    - Bolivia Brazil.
- Environmental Impact
  - According to the way of transportation.

3.6.2.4 **REGULATION FRAME**

- CONSTRUCTION of the TUGS
  - Construction of the vessels.
  - The gas equipment on board.
- CONSTRUCTION of the BARGES
  - Construction of the vessels.
  - The gas equipment on board.
- LOADING and UNLOADING OPERATIONS
  - From the receiving side.
  - From the supplying side (floating or ashore).
  - Contingency plans.
- TRAINING
  - Crew.
  - Shore personnel.

3.6.2.5 **METHODOLOGY**

- DATA BASES
  - They must cover the necessary to plan the policies and to guide the investors.
  - The data must be reliable, originated in dependable sources.

- The presentation shall be, systematic, analysed by means of charts and sketches.

- RECOMMENDATIONS
  - Alternative tracks must be proposed for the development of the project
  - It must evaluate the necessity of promoting the development of prototypes.
- CONCLUSIONS
  - Type of equipment to be used.
  - Positions for the bunkering stations.
  - Advantages of promoting a LNG Technological Cluster.
  - New business to be expected.

This is a comprehensive proposal, that requires the intervention and consultation of offices and institutes like e.g.: ENARGAS, PNA, CEARE, IGP-UBA, etc. The project can be handled in different ways. The University of Buenos Aires stimulates multidisciplinary thesis on these disciplines, which in due time, could be integrated into the Master Plan.

The unavailability of good statistics and trustworthy registers imposes a challenge that can be overcome at this instance by the cooperation with other universities in the region.

3.7 PROTOTYPE

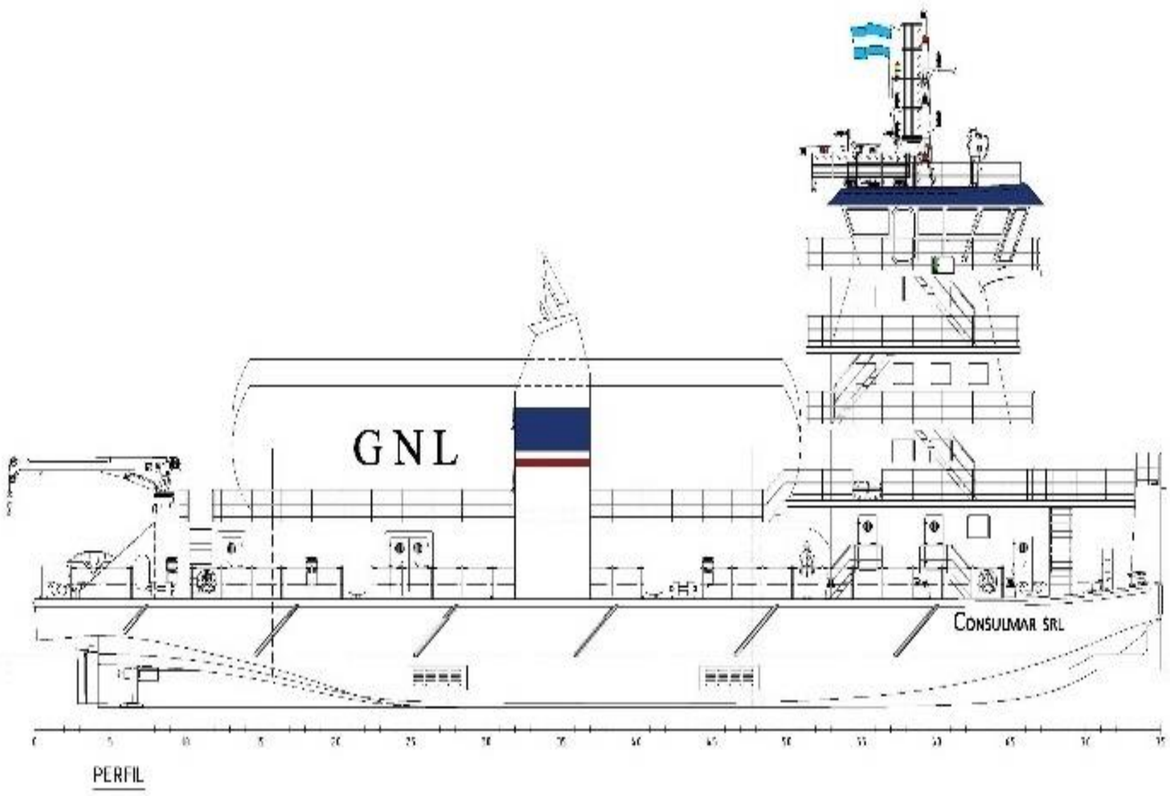
3.7.1 Why a Prototype

The prototype will provide information in areas such as:

- Technical
  - Confirm the ideal gas system.
  - Confirm the correct selection of type and number of storage tanks.
  - Check the performance of the fuels.
  - Check the performance of the improvements introduced in steering, hydrodynamics, etc.
- Economics
  - Check all variables against the predictions.
    (Numbers in the predictions against numbers in the accounting books).
- Human resources
  - Crew training. Establishing the difficulties.
  - Shore personnel training.
- Production
  - Adjustment of production parameters to move towards chain production.

3.7.2 Requirements for the Prototype

The prototype is not a Mississippi pusher tug of the fifties converted to GAS.



23 - Profile of LNG pusher Tug by Consulmar SRL.

One of the great advantages of this renovation of the fleet is the possibility of significantly improving the performance of the tug. This means NOT ONLY converting to LNG but REDUCING CONSUMPTION SIGNIFICANTLY. This reduction is the one that will give a sensible reduction in the greenhouse effect gases in addition to the overall reduction in emissions.

Let us go through the main items where substantial improvements can be made, aft to fore:

- **Rudders**

There are many improvements in rudder design which affects not only the hydrodynamic of the rudder itself, directly related to the resistance and therefore fuel consumption, but also, and mainly those relate to the improved manoeuvrability.

Better manoeuvring characteristics allow better performance in each bent of the river, following a shorter path and less disturbing the engine regime, resulting in a reduced consumption of fuel. In the case of our rivers, which differently from the Mississippi or Rhine, have not been intervened, bents are abundant and this phenomenon is therefore of paramount importance.

- **Propellers / Nozzles**

Kaplan propellers have proved to be a very good option for work horses like push tugs or trawlers, nevertheless technology has evolved, and we have improvements to introduce.

Propellers with more areas in the right place, with less tendency to induce vibrations. Small changes that add to the shopping basket.

- **Flanking rudders**

Flanking rudders are a pain in the neck of the naval architect. They disturb the flow towards the propeller so much, that anything we can do in improving this situation, or better yet, eliminating it, is welcome.

There is a very interesting proposal from a Dutch yard to replace them by retractable flaps. It looks like a very smart and not complicated approach. There are also possibilities of eliminating them, by a radical redesign of the manoeuvring system.

- **Shafts, seals, bearings.**

These items, well designed, will not impact the fuel consumption, but they will impact the maintenance bill.

We see push boats docking regularly just to replace bearings or, less often, to renew seals. This is not acceptable. We see systems that turn out to be a collection of opinions issued by superintendents, yards masters, inspectors, etc. along the vessels life. We, naval architects must provide a safe and satisfactory performing system that shall not be intervened but when regular dry dock is scheduled. The market provides a collection of very fine devices, suitable for the harsh environment we are called to live with.

- **Hull appendix**

The underwater stern of certain boats looks like a Christmas tree when on stocks. This is money in the fuel bill. Stern lines must be as clean as possible. Any item located in this area must be scrutinized by the naval architect responsible for the hydrodynamic performance of the vessel. A wrongly located heat exchanger, can be very expensive along the life of the boat. If a good location is not available, there are suitable replacement for this element. Same for sea chests, struts, etc.

- **Stern lines**

Push boat lines are inherited from the barge industry. It has been demonstrated the significant improvement that can be obtained by directing the water flow smoothly towards the propeller disk. This can be done without making the yards life difficult at the time of erecting shaped bodies.

The result in this item will have a significant and direct impact in the fuel bill.

- **Structure**

The structural design of the push boat is quite simple, mainly because it is built by barge building yards. We have means today to calculate far beyond the basic rule proposed structures at very affordable costs. Stems shall not vibrate; structures should be lighter and safer.

- **Accommodation**

The living conditions for the crew must be improved. These vessels are highly powered, with a small mass and therefore high tendency to vibrate. We have now all the means to significantly improve the life on board by a scrupulous design. Crew members should not be condemned to living in conditions that could have been acceptable in the post WW I times.

- **Navigation bridge**

The navigation bridge must have ample visibility 360 degrees, and down, towards the manoeuvring areas of the deck. The information must be ample and readily available to the pilots, radar screens suitable for river navigation, electronic charts, communications, all at the reach of the hand together with good information from engine, rudders, etc.

This technology is available off the shelf. No reason not to incorporate it improving the safety of the system and the life of the pilot.

4 CONCLUSIONS

- LNG is the **global tendency**, other means of propulsion less contaminant, do not offer adequate autonomy, are expensive or are far from being available in a commercial scale.
- **Riverine populations** are the principal **victims of the pollution** resulting from the inland water navigation vessels. We have the means to avoid this damage.
- We are being required to **supply LNG to the vessels operating in our waters.** We should not only satisfy this demand, but we should **encourage it**. It should become an **advantage to sail our waters with a clean vessel**.
- The global change has been fundamentally motorized by the requirements in the international regulations. Let us **not be naive** believing that in our region **we can attain such change without strong and strict regulations**.
- The way to start any LNG use program in our country **must start** with inland water **pusher tugs**. These are the simplest vessels where to adapt such technology, there is where we will learn, allowing us to incorporate this technology.
- Argentina must take advantage of its privilege situation regarding LNG.
- It is important to produce **prototypes** to attain **high efficiency** in the design of the large series to come right after.

The best way to reduce greenhouse gases is by NOT producing them.