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LIQUEFIED NATURAL GAS AS A MARINE FUEL OPTION IN THE AMAZON

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SUMMARY

The use of liquefied natural gas(LNG) as fuel in vessels is already a reality in the world and is consolidating increasingly as a booming industry. In Brazil, we observe a series of obstacles that discourage the adoption of LNG as a naval fuel to be used in the river fleet in the Amazon Basin in the short term, highlighting among them the war scenario in Europe that generates shortages of the product for import and prices in elevation, the small share of LNG in the Brazilian energy matrix, generating a lack of capillarity and difficulty in obtaining the product for refueling in the various ports and terminals in the interior, the relatively new fleet of vessels designed to operate with diesel and not subject to conversion. On the other hand, there is an increase in perception public awareness of the environmental impacts of transport activities, with the international agenda seeking a low-carbon economy, thus leading to intensified efforts to adopt policies that minimize these impacts. this one job analyze aspects technical and regulatory in systems in supply of small scale liquefied natural gas (LNG-PP) with a focus on its application in navigation interior at amazon Brazilian. It takes as a case study the operations of the fleet of vessels of Transporte Bertolini, the largest shipping company operating on the main routes of the Amazon Basin, and thus proposes a model conceptual of a network logistics for gas supply. this network, formed per one fleet in ferries in storage and supply in LNG, seeks to have the capacity to provide supply to vessels operating on the main commercial routes in the Amazon.

Keywords : inland navigation; vessel supply; LNG in Small Porte; Amazon.

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

ABS	*American bureau of Shipping*
AHTS	*anchor handling tug supply*
AJB	waters jurisdictional Brazilian
ANP	agency National of Petroleum, Gas Natural and Biofuels
ANTAQ	agency National in Transport waterways
ATB	*articulated tug and Barge*
PUB	Barcarena (SHOVEL)
BHP	*break horse power*
BOG	*boil-off gas*
BV	*bureau Veritas*
CAPEX	*capital Expenses* , expenses in capital
CNG	*Compressed Natural gas*
DNV GL	*det norsk Veritas Germanischer Lloyd*
CPD	board in Ports and Coasts
DWT	*Deadweight*
IN	pusher
ETC	Season in Transshipment in Loads
FLNG	*floating Liquefied Natural Gas*
FRU	*floating regasification unit*
FSRU	*floating storage regasification unit*
FSU	*Floating Storage unit*
GHG	*Greenhouse gas*
GN	Gas Natural
CNG	Gas natural pill
LNG	Gas Natural liquefied
LNG-PP	Gas Natural liquefied in small bearing
CNG	Gas Natural vehicular
GTL	*Gas to liquids*
GTW	*Gas to wire*
HBSA	Hidrovias do Brazil SA
HFO	*Heavy fuel oil*

hp	*horsepower*
IBAMA	Institute Brazilian of Quite Environment and From Resources Natural renewable
IMO	*International Maritime Organization*
IFO	*Intermediate fuel oil*
IRP	*Inventory Routing Problem*
ITA	Itacoatiara (AM)
LCNG	*Liquefied-Compressed Natural Gas*
LDC	Louis Dreyfus Commodities
LNG	*Liquefied natural gas*
MAO	Manaus (AM)
MATOPIBA	Maranhao, Tocantins, Piauí and bahia
MDO	*Marine diesel oil*
MGO	*Marine gasoil*
MSC	*Maritime Safety Committee*MTPA *Million Tons per Annum*
MTT	Miritituba (SHOVEL)
MW	megawatt
Natural NGV	*Gas Vehicle*
NO_x	Oxides in nitrogen
OPEX	Operating *Expenses* , Operating Expenses
PPI	Program in Partnerships in Investments
VRP	Vehicle Routing Problem (or Routing)
PSV	*Platform supply vessel*
PVH	Porto old (RO)
SAN	Santana (AP)
FSMS	*The Society for gas as The Marine Fuel*
SIGTTO	*The Society of International Gas Carrier and Terminal Operators*
SIN	System Interconnected National
SO_x	Oxides of sulfur
SPC	*Soy protein concentrate*
SSLNG	*Small Scale Liquefied Natural Gas*
STM	Santarém (SHOVEL)
STS	*Ship to ship*
TEN-T	Trans-European Transport networks

TERFRON	Terminal port Border north
TGPM	Terminal in grains tip of mountain
TPB	tones in size gross
TPS	*Terminal to ship via pipeline*
TKU	tone per kilometer useful
TTS	*truck to ship*
TUP	Terminal in use private
TWP	*Technology Warming Potential*
UHE	power plant hydroelectric
UTE	power plant thermoelectric
VOYEX	*voyage Expenses* , costs in travel
WTI	*west texas Intermediate*

SUMMARY

INTRODUCTION

Presentation

Historically, the propulsion of vessels was carried out by sustainable means, either by human effort when rowing, or by harnessing the energy of the winds. with the revolution industrial, The energy propulsive passed on The to be provided per firewood, per coal and, us last100 years, for petroleum derivatives. However, with the growing environmental awareness in societies caused for the perception of miscellaneous shapes in pollution and of heating global,the world today is in a period of transition (MACLEAN et al., 2016).

Before new viable sustainable solutions are found, it is necessary to adopt energy sources that, although still finite and polluting, may reduce O impact environmental of transport maritime and inland, at competitive costs (THOMSON et al., 2015; XU et al., 2015). in the future maybe The little distant, at vessels will use installations propelling most efficient and environmentally responsible, such as solar energy, electric batteries and hydrogen cells (ROYAL ACADEMY OF ENGINEERING, 2013; LLOY'S REGISTER BR ONE, 2017).

Until then, it is in society's interest to reduce dependence on the heavier fractions of the petroleum, which pollute more and compete with more noble applications, such as the manufacture of plastic materials. One of the sources that has progressively assumed this role is natural gas. Natural.

Natural gas is a mixture of light hydrocarbons with other molecules such as carbon dioxide, nitrogen, helium, among others (IMO, 2009). However, its main component It is ever O methane, CH_4. Per to be O hydrocarbon most simple, It is O what provides the greatest amount of energy per unit mass (WORLD NUCLEAR ASSOCIATION, 2016).

that efficiency energetic It is one in your properties most attractive. There is, although,others four reasons for your growing adoption at fuel in transition: prices structurally competitive in relationship to the derivatives in Petroleum; pressures marketing and regulatory for the adoption in fuels what manage any less emissions in pollutants; maturation of the natural gas market with the development of new technologies to its production, transport, storage and consumption; and its increasing availability due to discoveries of giant reserves in the most diverse regions of the planet (EL GOHARY & SEDDIEK, 2013; WANG & NOTTEBOOM, 2013; WAN et al., 2015).

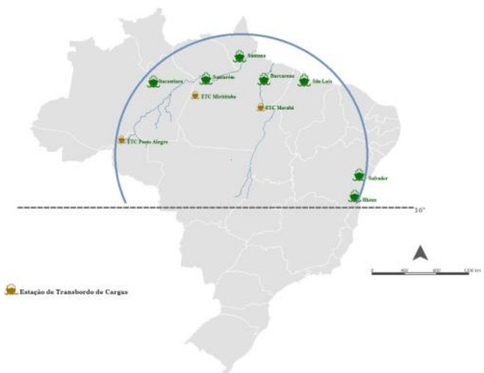
In this context, a problem that emerges is how to provide the adequate infrastructure for O consumption most broad of gas Natural in propulsion naval. Relatively common in infrastructure development, this problem is often illustrated by the “egg and gives hen" (AHLFELDT et al., 2014; GNANN et al., 2015; PETERS BR WAINWRIGHT, 2017).

In the case under study, it is necessary to ask the question: what should develop first? THE supply infrastructure or fuel demand? governments and investors fear to bet sums bulky in resources in one network in supply fearing at thethere will be adequate demand for the new fuel in the future. The logistics operators, for On the other hand, they are afraid to invest in vessels able to burn the new fuel and, therefore, most faces initially, without The Warranty what there will be The infrastructure to supply them.

O This work will seek to contribute with the support to the planning and sizing of the infrastructure for transporting natural gas on vessels. By association with experiences (WAN et al., 2015; KHAN, 2017), it is understood that the demand, potentially repressed, will bloom in then.

In Brazil, gas as a naval fuel could be used in different regions. THE inland navigation in the Brazilian Amazon, however, has grown enormously in relevance in the last decade, especially due to the so-called “Arco Norte”. (FOLHA DE S. PAULO, 2016; PEREIRA, 2017). Arco Norte is the set of Brazilian ports responsible for flow in bulk solid and what meet above of the 16th parallel South, as shown in Figure 1.

Figure 1: north arch



Source: ministry gives Agriculture, livestock and Supply (2017).

Adding to the secular navigation that has been developed in the north region to the transport in passengers and of most miscellaneous loads, O bow north has if tornado Therelevant foreign trade corridor, with the export of grains (especially soy and corn) and the import of fuels and fertilizers.

Between 2011 and 2021, the movement of I am at the bow north increased 88.5% and The in corn, 174.8% (ANTAQ, 2021). In addition, interminals at region North East of Brazil (Are Luís, savior and Ilhéus), of of bow you portsserving long haul ships from Itacoatiara (AM), Santarém (PA), Barcarena (PA) and Santana (AP). Three road-water transhipment ports (Cargo Transhipment Stations, ETC´s), located in tributaries of the Amazon River, are also included in the system: Porto Old (RO), Miritituba (SHOVEL) and Marabá (SHOVEL). THE navigation The leave in Marabá, at the river Tocantins, was not included in this work, as it depends on a large work in charge of the public still with no prospect of materialisation: the demolition and dredging of Pedral do Lawrence (G1 PARÁ, 2020).

Goals

- Propose an initiative that understands LNG as an Amazon Naval fuel option;
- Understand where it will be available on which routes it can be used in the medium term.
- Propose a supply logistics solution for the routes it will be used

Justification

Although we are aware of the current uncertainties regarding the availability of LNG in the international market, the region amazonian it has abundance of Natural Gas and low or no demand, as these deposits are located in the middle of the jungle, far from any potential consumer. This creates opportunities for future installations of liquefaction units, making it possible to exploit this resource, including for naval propulsion.

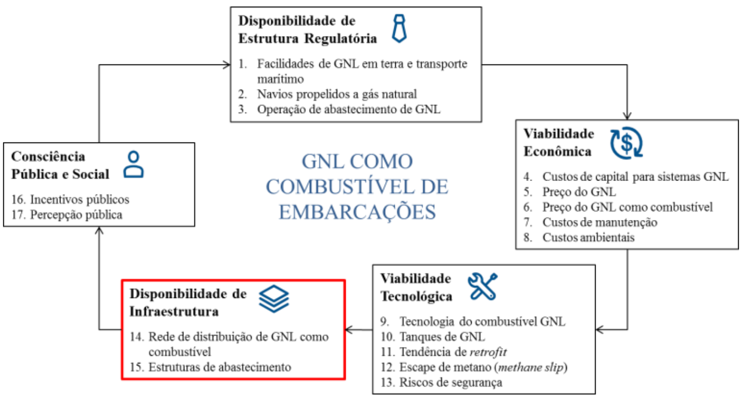
Even after massive investments in a gas pipeline slinging Natural Gas deposits from the field of annatto, at the Amazonas to Manaus, the state capital, more than 60% of the gas produced is reinjected due to lack of demand (ANP, 2021).

Therefore, there is a surplus of natural gas in the northern region, but this offer is poorly distributed, as it is available today only for consumption in Manaus. Per other side, The demand per fuels in vessels has grown sharply, especially due to the large volume of cargo transported by the new port terminals of Arco Norte (SANTIAGO, 2015; ZAPAROLLI, 2016; PEREIRA, 2017).

Navigation, both nationally and internationally, is under constant pressure to reduce your costs and to minimize your environmental impact (BRYNOLF, 2014). THE use of natural gas liquefied (LNG) in marine propulsion, in the paper of fuel any less polluter, can supply this demand (LLOYD'S REGISTER, 2015).

Wang and notteboom (2014) made one revision systematic in studies and articles published about O job in LNG at fuel naval, identifying 17 factors, which affect the success or failure of the development of the propulsion market shipbuilding to LNG in 33 studies. From each study, then, the identification of the state in the which is found each factor: if affects positively to evolution of marketplace, or if affects negatively. All studies that addressed the issue of infrastructure availabilityunderstood as a factor still far below their minimum conditions for favoring of LNG as fuel as shown in figure 2.

Figure 2: Factors associates I'm success of LNG at fuel naval



Source: Adapted from wang and Night Boom (2014)

The present work is justified, therefore, as it allows a deepening in the search for solutions to the problem of oversupply and poorly distributed, along with the meeting a repressed demand due to the lack of a distribution network. So, through the planning gives infrastructure in transport, it will be then possible foment one new alternative energetic at Amazon region.

Delimitation of job

of Score in view space, O job is limited The region north of Brazil, most specifically to the Amazon, Madeira and Tapajós.

From the temporal point of view, the work is part of a planning horizon of transport in medium and far away deadline. At O team expected in construction in each vessel (both supply barges and pushers that will use LNG as fuel) the construction and maturation of a minimum fleet can take from 5 to 10 years.

From the point of view of dimension, the work is restricted to an analysis of a proposal for a distribution network. However, discussions in the bibliographic review show that there is a strong social and environmental appeal in a successful transition to more sustainable navigation (BUREL et al., 2013; VIANA et al., 2014; ANDERSON et al., 2015).

From a technological point of view, the work is part of a new and fast-paced industry. expansion, in which innovations are constant (INTERNATIONAL GAS UNION, 2015-a/b; DAMEN, 2017). However, it will not be part of the scope of the study in-depth discussions on O project from equipment with tanks, terminals, systems in liquefaction, regasification and loading, vessels, on-board machinery, etc. In this regard, will be presented only the basic concepts necessary to understanding of the problem.

From the point of view of the natural gas supply chain, the work is restricted to distribution of LNG to final consumers, ie to the *downstream market.* In addition, the method in supply considered if restrictions I'm STS (ship *I'm ship*). For bigger details, to see item 2.7.

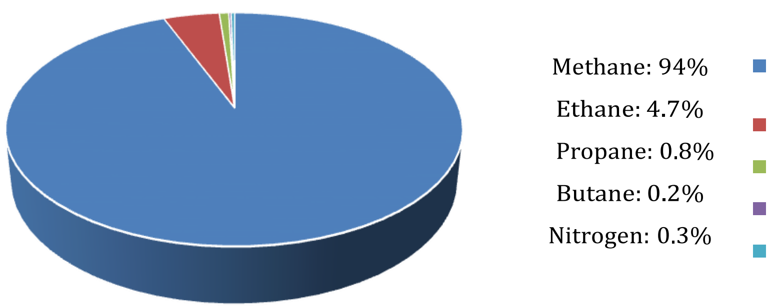
LITERATURE REVISION

Natural Gas: properties

O gas Natural it has features what O become even attractive because it presents elevated temperature in self-ignition: 595 °C (MOKHATAB et al., 2014). At comparison,diesel is approximately 210 °C. Natural gas contains virtually no sulfur (therefore at the issues gases SO_x). Your combustion issue, in relationship to the fuels traditional (HFO and MGO), approximately 20-25% less CO_2, 85-92% less NO_x gasesand 98-100% less particulate matter (STUER-LAURIDSEN, 2010; BIZI & TISCHER, 2012; EL GOHARY BR SEDDIEK, 2013; TZANNATOS BR NIKITAKOS, 2013; HARVEY GULF, 2017).

The composition of natural gas varies according to its origin. geology and its processing, but the typical mixture considered by the Maritime Organization International (International *Maritime Organization* , IMO) evidence what your contents It ismainly methane, with 94% by mass (IMO, 2009). In the Brazilian Amazon, today there are only availability of natural gas from the production of onshore fields in the Basin of Urucu, with subsequent transport by gas pipeline to Manaus, in the Amazon. The composition of natural gas from the Urucu Basin is a little poorer, with a higher concentration of Nitrogen (~14%) and lower concentration of methane (~74%), as shown in figure 3.

Figure 3: composition typical of gas Natural



Source: Adapted in IMO (2009)

Because it is mostly composed of methane, a simple molecule, natural gas it burns quite efficiently, both economically and environmentally. Your storage and distribution take place in two ways: compressed natural gas (CNG) and natural gas

(LNG). English acronyms are also widely used: CNG and LNG, respectively. CNG is processed at pressures between 200 and 250 bar, requiring for that, tanks and piping suitable The tall pressures. already O LNG It is processed at very low temperatures (below -162 °C), requiring tanks and piping cryogenics (IOGP, 2013). Both interventions are necessary because the low density of the gas(between 0.7 and 0.8 kg/m ^{3} , depending on the composition) requires a lot of space for its storage at ambient temperature and pressure, when you want to get the same energy equivalent in their competitors, you fuels liquids derivatives inPetroleum. Therefore, although the gas is transported by gas pipelines at low pressures and intermediate, When It is considered your application in vehicles and vessels (supply and storage), the only viable alternatives are through GNC or LNG.

THE insertion of gas Natural at headquarters in transport

The first developments in the use of natural gas as a transport fuel occurred from the opportunity that arose with its transport over long distances by ships and trucks. Although the most efficient way to transport natural gas is through pipelines, for your transport in between continents were developed ships tank Specialized ships , called LNG ships or methane tankers. For transport within continents in order to overcome long distances with sparse infrastructure, tank trucks were developed also specialized.

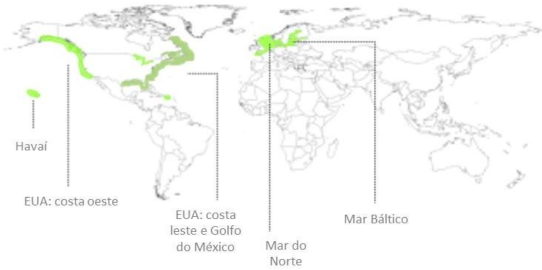
Under these conditions, where natural gas is transported as cargo, part of the LNG returns to the gaseous state inside the tanks (this gas is *called boil off gas*), being then necessary to open exhaust valves, so that the pressure inside the tanks at the overtake you values maximums allowed. One form alternative in use of this gas is precisely to use it for propulsion and energy consumption on board vehicles and ships. With the maturity of embedded technology, it became possible use also O gas Natural at fuel, regardless gives cartoon transported. in that marry, O gas Natural need to be stored in tanks segregated.

still what O use of gas Natural at fuel in vessels at the be essentially new – the first methane tanks date back to the 1950s and the use of natural gas for power generation on board offshore oil platforms dates back to the 1960s (PETROBRAS, 1991) BR It is The leave From years old 2000 what has occurred one constant intensification in the researches and investments in marketplace at area (BUREL et al., 2013; WANG & NOTTEBOOM, 2013).

Regulation in emissions

O constant increase from problems environmental and in health public associates at emissions in gases polluting issued per engines The combustion has taken you countries Theestablish increasingly strict regulation of the transport industry. The materials particulates, sulfur oxides (SO_x) and nitrogen oxides (NO_x) are related to a long list of damages, such as acid rain and various respiratory diseases. In the cities coastlines, it is estimated that thousands of deaths are caused annually by fleet emissions world of ships. Therefore, there is an urgent need to properly study the impact of navigation on air quality (ZHANG et al., 2017; VIANA et al., 2014; MULLIGAN & LOMBARD, 2006). In this context, the IMO has added tougher limits for emissions within the Annex 6 of MARPOL 73/78 (International Convention for the Prevention of Pollution by ships). Annex 6 recognizes, firstly, two Emission Control Areas (*Emission Control Areas* , ECA's) in the coastal zones of North America and two in Europe , as shown in figure 4 .

Figure 4: areas in Control in emissions, ECA's



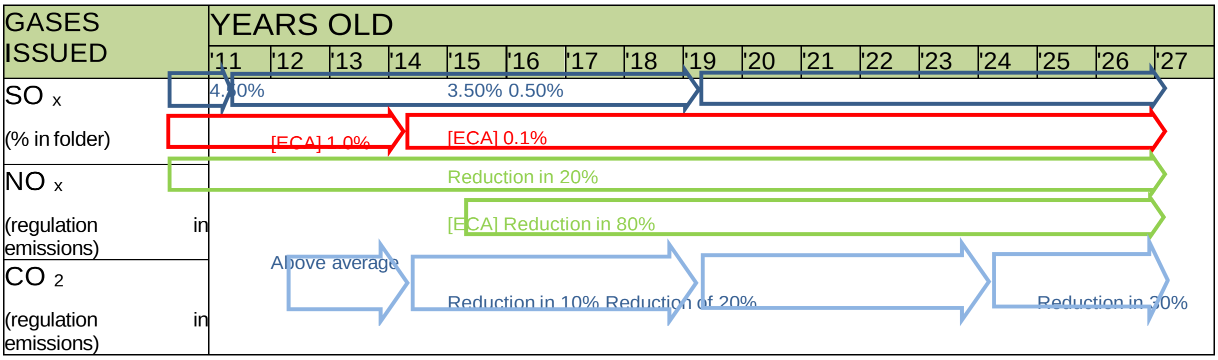
Source: Adapted in SGMF, 2014

In these areas, stricter rules apply than in the rest of the world. For nitrogen oxides, since 2011 global emission limits apply according to the ship's engine power, and since 2016 even stricter limits have been applied to American ECA's , also known as " *Tier III* ". For sulfur oxide emissions, as of 2020, a sulfur content limit will be established in fuels for 0.1% in bulk to all ECA's and 0.5% in bulk to the rest of the world.

additionally to the gases polluting, has matured The discussion about you gases greenhouse *gases* , *GHG* 's. Although there has not yet been a global agreement on how limits will be implemented for the emissions of these gases, among which stand out CO_2 and CH_4 , the expectation is that by 2020 there will be global regulation in this regard under the auspices of the IMO. Today, merchant navigation is the only transport that still does not have limiting rules for GHG's , I try to stay out of the agreement of Paris 2015, although it is responsible for approximately 2.33% of global emissions of CO_2 (IMO, 2015-b).

The consolidation of the evolution of the IMO emission regulations, including new restrictions what will enter in force in the future, it can be contemplated in figure 5.

Figure 5: Evolution of regulations in emissions gives IMO



Source: port of Yokohama, 2016

THE consequence direct of these rigid news restrictions It is what, for to fulfill The legislation, shipowners will need to adapt. There are different adaptation strategies, each with their different costs and associated risks. The attractiveness of using natural gas in propulsion naval lies in the fact that it allows the ship to suit both GHG's , NO_x and SO_x tosame time.

Although there are several regional initiatives aimed at regulating natural gas, such as marine fuel, it is The IMO the responsible for publish a globally valid code. As this is still a relatively recent subject, the entity, after a meeting of the Maritime Safety (*MSC – Maritime Safety) Committee*) at its 86th Session (2009), published the "Interim Safety Guidelines for Gas-Fed Propulsion Installations in Ships" (IMO, 2009).

These guidelines, although not mandatory, remained as a guide for design, construction and operation of gas-powered vessels until IMO published the

International Code for the Safety of Ships using Gases or other Fuels of Low Flash Point (*International Code of Safety for Ships using Gases or other Low - flashpoint Fuels -IGF Code*), in 2015. The code was adopted in 2015 and entered into effective for signatory countries from January 2017, applicable both to new ships Such as converted ships.

Analysis of national scene

At the Brazil, O gas Natural pill he eats being used since you years old 70 at vehicle fuel (BRASIL ENERGIA, 2015-b), under the name of Gas Natural Veicular (CNG). In naval propulsion, its use has not yet been disseminated, for regulatory reasons, techniques, economical and logistics (HAÏDAR, 2015).

At limitations regulatory they are related The absence in standards incorporated Thelegislation Brazilian what regulate The installation in systems in propulsion naval whatuse natural gas as fuel. In fact, the use of this fuel is prohibited in inland navigation by the Directorate of Ports and Coasts (DPC) of the Brazilian Navy, according to with The NORMAM-02/2005, then it presents score in glow below in 60 °C.

IT IS needupdate so much The NORMAM-02 at your related for navigation in sea open (NORMAN-01), including chapters what enable O use of gas Natural and in others low flash point fuels.

Therefore, it would be necessary to verify and review the related Brazilian standards (mechanical installations, CNG installations, engines for generation thermoelectric, etc.), The The end in accommodate The new reality of gas Natural at shipped fuel. In addition, the main Classification Societies in the world have already published rules updated for vessels propelled The gas Natural (BUREAU VERITAS, 2011; AMERICAN BUREAU OF SHIPPING, 2011).

The ANP in recent years has published resolutions (ANP, 2008; ANP, 2015) what regulate installations in gas Natural for vehicles and energy production, as well as the production of gas from renewable sources (the called biomethane). Per to have potential in generate gas Natural in regions close of consumption, the biomethane has potential in impacts positively O marketplace in gas Natural in vessels, but still only in a scenario of far away deadline.

Finally, limitations logistics also has barks O development of gas Natural at navigation amazon. These limitations they say respect The unavailability innatural gas supply systems for vessels, which in a way is a global phenomenon, as this is a fairly new industry. potential investors at the build The infrastructure, then still at the there is vessels what have in equipment for processing natural gas (engines, tanks, piping, etc.).

Already the shipownershesitate to invest in vessels, as there is no infrastructure. In other words, a classic mentioned deadlock of the type "which comes first: the chicken or the egg"? as it happened in the adoption of new fuels in the past (such as the transition from coal to derivatives in Petroleum and now at transition for vehicles electrical), are needed initiatives coordinates not only to provide adequate equipment and vessels, but also for provide for infrastructure logistics.

Despite the limitations described, in 2014 and 2015, when Transportes Bertolini Ltda converted the “Bertolini LXXVI” river pusher in its BECONAL shipyard for tests with propulsion also *dual-fuel* . The pilot project was supervised by the Directorate of Ports and Coasts of the Brazilian Navy. Per at the be space The board, for storage of CNG were used two cards of 5,000 Nm^3 of natural gas, positioned on the deck of the ferry (*deck*).

the set pusher – ferry normally operates with 35 trailers, but for the test trip between Manaus and Belém, two *slots* were occupied by trucks. The tests were successful technically, by having been obtained rate in replacement usual of Marketplace: 70% gas Natural and 30% diesel, as shown in figure 6.

Figure 6: Arrangement in tests of pusher Bertolini LXXVI

Source: BERTOLINI, the author.

However, at the time, it was not feasible to continue the studies, which could include LNG vessels. Among other reasons, one of the main was the lack of infrastructure liquefaction (at -162 °C, in the case of LNG) and CNG vessels would require storage space not compatible with the size of the vessels, that is, there was not yet the supply network, what could include at plants in LNG, associates The terminals in mooring,trucks or ferries from supply.

offer of gas Natural at fuel at amazon

Amazonas has the second largest Brazilian proven reserve of natural gas, with the country's largest *onshore* (in land): the basin of Urucu, according to figure 7.

Figure 7: Base in production of Petrobras in annatto, AM

Source: See (2011).

Of the 14 million m ^{3} averages per day produced in 2021, 60.3% was reinjected into the wells due to excess gas in the regional market (ANP, 2021). In fact, since the inauguration of the Urucu-Manaus gas pipeline, in 2009, the surplus of natural gas in the Amazon is acute and has even received press attention place (SEVERIANO, 2015). At projections future, although, point still great day off.

THEBased on ANP data (ANP, 2021), it appears that the proven reserves in the state there are 50.5 billion m ^{3} . Maintaining the current demand for natural gas in Amazonas (5.6 million m ^{3} /day) and without new discoveries, the reserves will allow production for another 25 years old.

that scenery still if show conservative, one turn what there is reservations still in phase of exploration in the basins of Solimões and of amazon (BRASIL ENERGIA, 2014) and one vast area not surveyed, which can substantially increase the supply of natural gas at region.

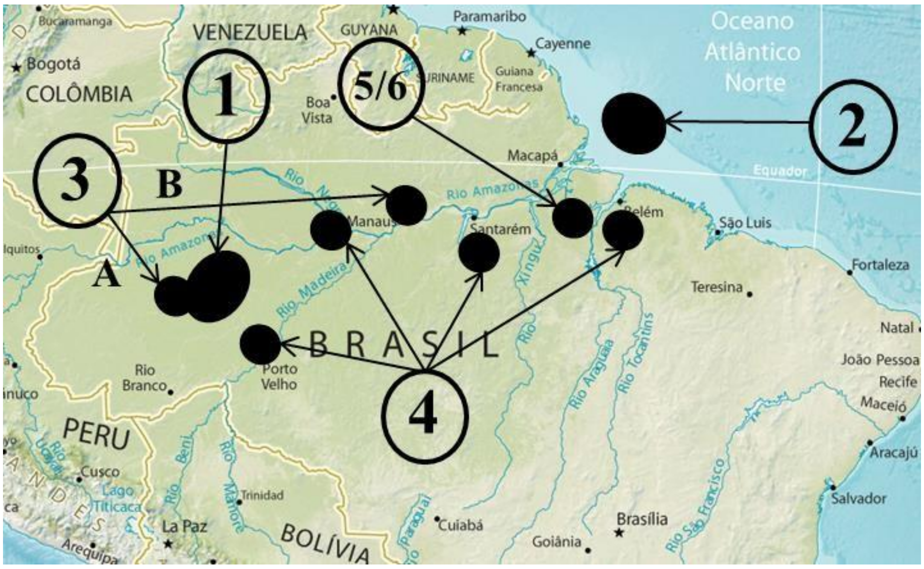
However, the abundance of surplus natural gas in the Amazon, although it constitutes a opportunity, still it is associate The relevant obstacles in transport and distribution. Today,the only relevant market served is the city of Manaus, where the gas is consumed mainly in thermoelectric generation, industrial consumption (as raw material or for energy generation) and, residually, in commercial, residential and power consumption applications. CNG.

Of the Gas coming from the Urucu Gas Pipeline, there is no distribution to the few and scattered urban centers in the interior of the state, with the exception of *citygates* installed in four of the crossings by the gas pipeline Urucu -Manaus: Anamã , Anori , Caapiranga and Codajás. In these municipalities, oil generation fuel he was replaced by natural gas, generating earnings environmental and economical.

Another point to be observed is that the large commercial navigation, target of the work, does not circulate through the channels of the rivers where these municipalities are located and, therefore, far from the availability of Gas from the Urucu Gas Pipeline.

Urucu production is not, however, the only possible source of natural gas in the Region. North. Other sources at different stages of maturity are described below and illustrated in the figure 8 .

Figure 8: Spots in potential offer in gas Natural gives amazon



BR

Source: See (2011)

At point 1, you can see the natural gas fields in Baixo Juruá discovered by the then HRT Oil and Gas (now PetroRio), later sold to Rosneft , an oil company Russian. Such fields, although shut down reservations proved relevant, are located in areas far from consumer centers. Point two is relevant to exploration blocks with high seismic potential at Foz do Amazonas, which meet in phase in studies in impact environmental .

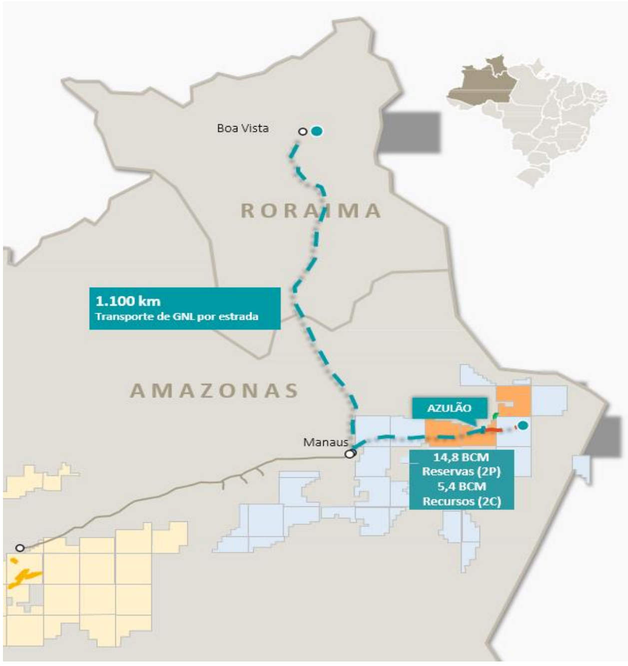
Signal number 3 is consistent with other Petrobras exploration blocks in less accessible regions, such as inAmazon Basin and the Solimões Basin . The fourth point is about Biogas generated The leave in waste agroindustrial (at The vinasse or treated poultry and swine excrement) and urban (sanitary landfills).

The fifth signage makes up the potential availability in LNG The leave in your transport per ships methane tankers designed to bring in imported gas or distribute gas from northeastern *hubs of Pecém (CE) and Salvador (BA), where there are already terminals* operational. And the sixth point is the potential availability of an LNG regasification terminal in the region of Barcarena, Pará (Figure 11 , 5/6), to meet the industrial demands of bauxite and alumina refining, as well as for thermoelectric generation.

On the other hand, there is currently something more tangible and that can change the scenario regarding the availability of LNG. Approximately 3 years ago , the operation of the first LNG liquefaction plant of the company ENEVA began in the Azulão fields, the first in the north of the country. This plant is located about 70 kilometers from the city of Itacoatiara, the point of confluence between two important waterways: the Madeira River, a tributary of the south bank of the Amazon River that connects the state of Rondônia and its capital Porto Velho and the Amazon River itself. having the capital of the state of Amazonas, Manaus, upstream.

The availability of LNG so close to such important shipping lanes opens up the real possibility of supplying this fuel for naval propulsion. This plant today is intended to provide LNG for the supply of the Jaguatirica II thermoelectric plant, located in the state of Roraima and which is being supplied with LNG transported by road for more than 1100 km, however the company already indicates that it intends to expand the liquefaction to naval follow-up service from Itacoatiara, as shown in figure 9.

Figure 9: Provision of LNG from Roraima to Amazonas



Source: the author

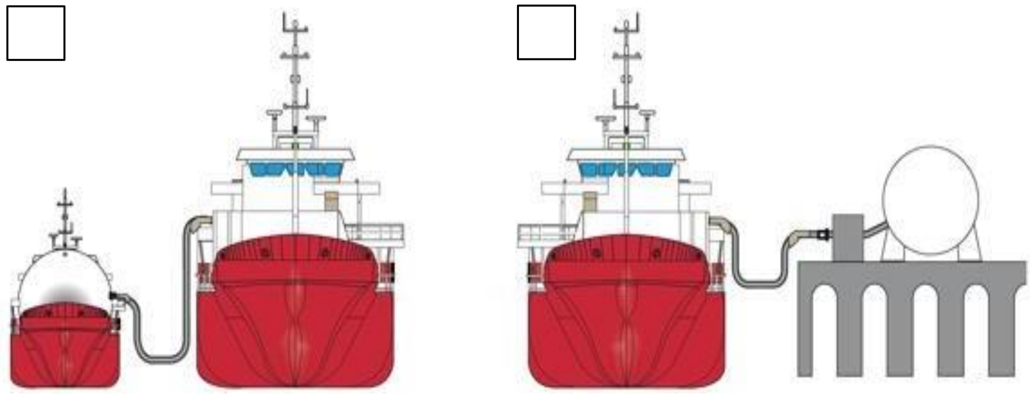
ENEVA's projects also include the NG supply of two more thermoelectric plants close to the wells, Azulão I and Azulão II.

Infrastructure for transport and supply

Delivery of LNG will normally take place by trucks, but for the use of natural gas as fuel on vessels, there are three alternatives, highlighted in red in the figure per be the one the focus of gift study.

The first alternative is the Terminal I'm ship per pipeline (*Terminal I'm ship via pipeline* , TPS): in this case, a structure on land must be built to moor the ship to be stocked. This terminal must have tanks for storage and conditions of adequate access to the vessels to be supplied, as shown in figure 10; Truck to ship (*Truck I'm ship* , TTS): usually use the terminal itself of operations of the vessels to be supplied, instead of the need to use in The terminal dedicated. trucks connect The vessel and transfer the LNG for their tanks of storage, as shown in figure 10.

Figure 10: Operations STS (A) and TPS (B)



Source: KLAW LNG (2017)

Alternative number two is Ship to *Ship. I'm ship* , STS): a vessel, which can be a ship or tank raft (*bunkering) ship* or *bunkering barge*) is employed to supply the other vessels. This supply vessel shall be loaded at an LNG terminal, which could be the liquefaction terminal itself or just the storage plant. With this, this vessel will be free to go to where the ships to be supplied are, either a few kilometers or up to the hundreds in kilometer, as shown in Figure 11.

Figure 11: Operation TTS

Source: THE MARITIME EXECUTIVE (20 **13)**

A variation of the mentioned methods is the modular supply, which can be used in all of them. Instead of the LNG being transferred by flexible pipeline directly to the ships' tanks, it can be stored in containers or in tanks on *skids* , beingthen positioned on the deck. Finally, the LNG module is then connected to the ship's fuel network. An example is LNGTainer , as shown in figure 12.

Figure 12: LNGTainer : example in system in supply modular

Source: LNGTainer (2021).

As LNG fueling systems become more widespread, studies and procedure guides begin to appear. Classification societies, for their part, knowledge technician, has if highlighted with contributions important (AMERICAN BUREAU OF SHIPPING, 2014; DNV GL, 2014).

types in vessels in supply

With the gradual maturation of supply systems over the past 20 years, several vessels were conceived, and some of them are already in operation. Examples relevant follow below, with considerations about your applicability in this study:

Converted from a *ferryboat* in Sweden, Seagas was, in March 2013, the first vessel to supply LNG STS in history, as shown in figure 13. THE conversion he was made possible thanks I'm Support of program TEN-T (*Trans-European Transport Networks*), what finance and subsidies infrastructure in transport at Europe. Operated for the Nauticor , he supplies daily O *ferry boat* in great carry Viking grace with 60-70 tones in LNG (MARITIME CYPRUS, 2015).

Figure 13: Raft in *seagas* supply

Source: Maritime Cyprus (2015).

To supply TOTE's aforementioned container ships, the shipowner Clean Marine Energy has ordered the first LNG fueling ferry built in North America (LNG WORLD NEWS, 2015). This ferry, whose name will be *Clean Jacksonville* , has the capacity to 2,200 m ^{3} of LNG (PIELLISCH, 2017) and should be delivered in 2018, as shown in figure 14

Figure 14: *Clean Jacksonville* supply ferry

Source: LNG world News (2015).

The articulated pusher and raft assembly (*Articulated tug and Barge* , ATB)from the US company Q-LNG, to be chartered to Royal Dutch Shell. THE ferry, currently in construction, will have The capacity in carry and supply 4,000 m ^{3} of LNG (GCAPTAIN, 2017-a), which is equivalent to 2.4 million m ^{3} of natural gas or approximately 17% of Urucu's daily production. your project original is to serve the supply of large cruise ships in Florida. For the north arc, the capacity of each vessel will need to be smaller, but the ATB concept is quite interesting, as the decoupling between ferry and pusher allows greater flexibility operational, as shown in figure 15.

Figure 15: ATB gives *Q-LNG Transport*

Source: gCaptain , (2017-a).

There is also a relevant set of ships for supplying natural gas in the range from 5,000 m ^{3} to 8,000 m ^{3} , for service in port regions with a projection of large demand for gas as fuel for vessels (THOMAS, 2017). Are they: *Engie Zeebrugge* (5,100 m ^{3} , from Gas4Sea), *Coralius* (5,800 m ^{3} , owned by shipowner Anthony Veder ,chartered The Skangas), *cardissa* (6,500 m ^{3} , of shipowner Shell). There is also two ships in 7,500 m ^{3} currently under construction, one for use in Europe (from the shipowner Babcock Schulte Energy, chartered to Nauticor) and another for use in South Korea (ship owner Korea Gas). Another very relevant and innovative vessel is the *Hummel* ferry, the first hybrid LNG in the world, operated fur shipowner Becker marine Systems. that ferry generates energy for The power supply to cruise ships in the port of Hamburg, Germany, reducing thus the consumption and pollution of these vessels when moored (BECKER MARINE SYSTEMS, 2017).

In addition to the already mentioned existing or under construction vessels, there are also projects noteworthy concepts. To target what it considers to be a growth market (DAMEN, 2017), the Dutch shipbuilding and design conglomerate Damen Shipyards Group has designed a very complete line of vessels for LNG supply, with capabilities in 500, 1,500, 3,000, 5,000, 6,500 and 7,500 m ^{3} . THE figure 16 illustrations O ship of 6,500 m3. Others offices in project also developed news proposals in supply vessels in recent years, with emphasis on Sener (Spain) and Jensen Maritime (USA).

Figure 16: Ship in supply in Damen LNG 6,500 m ³

Source: Damen (2017).

One last reference conceptual even relevant for possible applications at Amazônia is the shallow draft multimodal ferry cited by Regan, 2017. This ferry would not be propelled, therefore it would be cheaper, but it would be dependent on pushers for its movement. It would be capable of supplying ships with three tanks of 2,270 m^3 each and, thanks to the cranes articulated installed about O deck, could also i do O transhipment in LNG per containers *iso tank* , ensuring greater modularity I'm system, as shown in figure 17.

Figure 17: ferry in shut up shallow for supply in LNG

Source: Regan (2017).

METHODOLOGY

Search Classification

how much to the goals, it's about in *search exploratory* , then looking for one larger familiarization with O problem, using withdrawals bibliographical, application in information in nature practice and elaboration of a case study.

As for the technical procedures, this is a *bibliographical research* , as there are many already published information about the theme that can be applied in the case studied and *research by case study* , as the methods will be applied in a reasonably limited system, but with limits not so clearly defined. There was practically no *documentary research* , with its use being done only in the extraction of ANP data on natural gas production in Urucu and ENEVA (ANP, 2021) and , and the method of *experimental research* has not been applied.

how much The nature, it's about in one *search applied* , one turn what treat in The practical problem existing in a given sector. The proposed solutions for the problem start from knowledge previously developed in others researches, what will be articulated and modified within the limits of their practical application in interests locations.

how much to the approach of the problem, it is about *research mixed approach* . Next, the attraction by demand model, therefore trend, to define optimal supply points.

Data Identification

The data to be collected, in addition to those already articulated in the bibliographic review, will be the gravitational axis of charge flow, which will be further discussed in the next chapter.

DEVELOPMENT OF THE THEME

Navigation routes and LNG availability

Although natural gas as fuel for vessels in the Amazon has potential for several applications, in this work we will focus only on the growing transport market of grains by the Madeira, Tapajós and Amazon rivers. The area of interest is illustrated in figure 18.

Figure 18: Area in interest of study

Source: adapted sheet in S. Paul (2016).

Inside the highlighted polygon are: almost the entire course of the Madeira River, the lower course of the Tapajós River and the middle and lower courses of the Amazon River. The Amazon River is navigable in all your extension, since your formation in Manaus (AM) The leave From riversNegro and Solimões to its mouth. The mouth of the Amazon is quite complex, dividing into two outfalls that are known as “Barra Norte” and “Barra Sul”, separated by Ilha in Marajó.

you rivers wood and Tapajós, per be taxation gives margin right of Amazonas, provide a natural route of communication with the center-west of Brazil, the region with the largest grain production in the country.

Through intermodal terminals, connected to a road network, they allow the flow of millions of tons of grain by large push trains. Due to favorable climatic conditions in this region of the country, which allow for two to three harvests per year, in addition to the fact that the rivers remain navigable throughout the year, with very rare exceptions, an almost continuous flow of corn and soybeans is maintained.

There are also studies for the expansion of the road network and the construction of railway branches in the coming years, a condition that will encourage the attraction of agricultural cargo to the region, increasing the number of trains and the demand for fuel.

The fleet of pushers working in the system exceeds 100, with powers between 1200 HP and 7,200 HP and the BERTOLINI fleet, object of the case study for this work, has 26 pushers and due to the precocity of the logistic corridor, all pushers are less than 20 years old, most of them less than 10 years old .

This is yet another difficulty factor in consolidating LNG as a fuel, given that all this equipment was built to use conventional fuels and its conversion is not a viable option, mainly due to the space required and not contemplated in the project for the installation of cryogenic tanks capable of providing necessary autonomy to these vessels on the routes in question.

Another crucial point for building a supply solution is the availability of LNG. As we have seen, there are large deposits of gas in the Amazon, but these are distributed in areas where there is no consumption and far from commercial navigation routes, in addition to the fact that there are no liquefaction plants, other than that of the company ENEVA in the Azulão field. Also with the current global geopolitical instabilities, today, the import of LNG is not an option and there are doubts about how this world market will stabilize in the medium term.

In this way, the only available source of LNG existing in the medium term, which is close to the main route of TBL trains and which presents real supply conditions for these trains, are the Azulão fields through the ENAVA liquefaction plant.

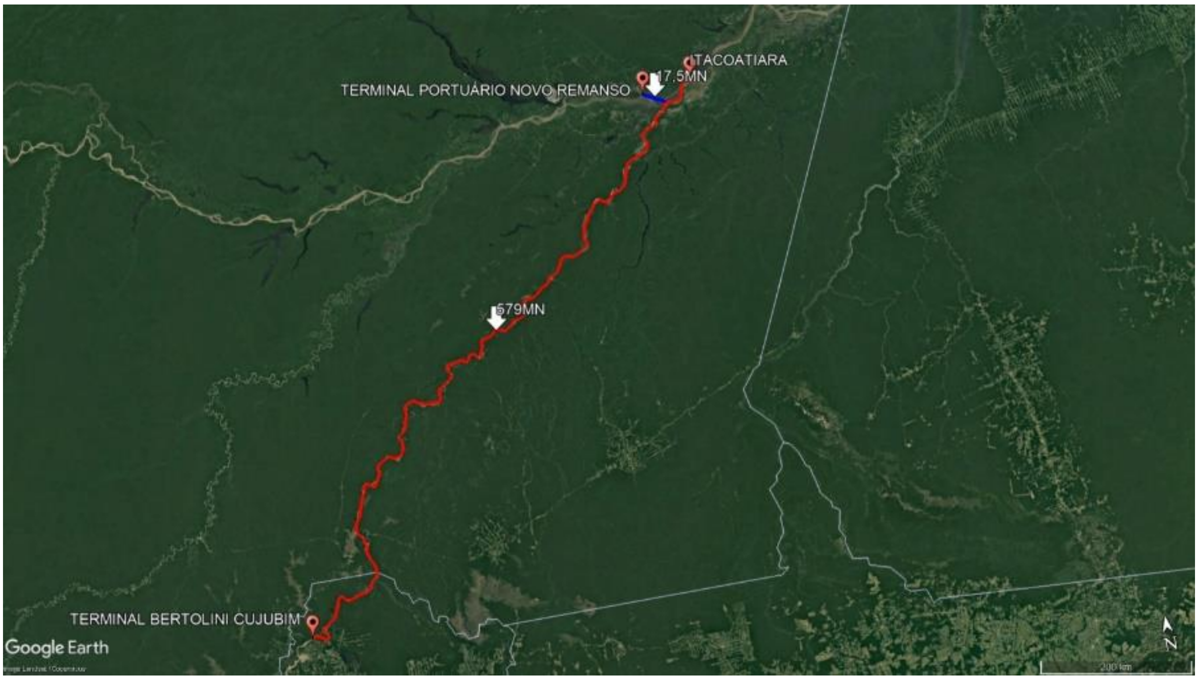
As the LNG liquefaction plant is located approximately 70 kilometers from Itacoatiara, the point where the Madeira River and the Amazon River meet and also because this location is already the current fueling point for TBL trains with diesel, the operating with LNG at this point would not generate impacts on the fleet's current supply chain.

The existence of only one supply point poses a major problem, as the vessels should have great autonomy and the deployment of a fleet of supply vessels to create LNG capillarity would greatly increase the cost of a low-scale operation. This would be a point that would practically make this operation unfeasible, but a new possibility arises in this complicated matrix.

Now, in October 2022, at the Bertolini shipyard in Manaus, the Floating Grain Transshipment station was built that will make up the port facilities in Novo Remanso, a location 6 miles from the mouth of the Madeira River. This new port should receive Oceanic ships that will carry cargo from the Madeira River and for the first year of operation, 500 million tons are expected and the expectation is to reach 5 million in 2027.

Bertolini convoys should start their trips in Itacoatiara to Porto Velho, where they will carry the cargo to Novo Remanso and finish the girder again in Itacoatiara, as shown in figure 19.

Figure 19: Bertolini train route proposal



Source: the author.

As for this stretch the fuel autonomy of the pushers will be significantly lower and they may still be captive on this route, this presents itself as an ideal pilot plan to start the LNG operation in the Amazon.

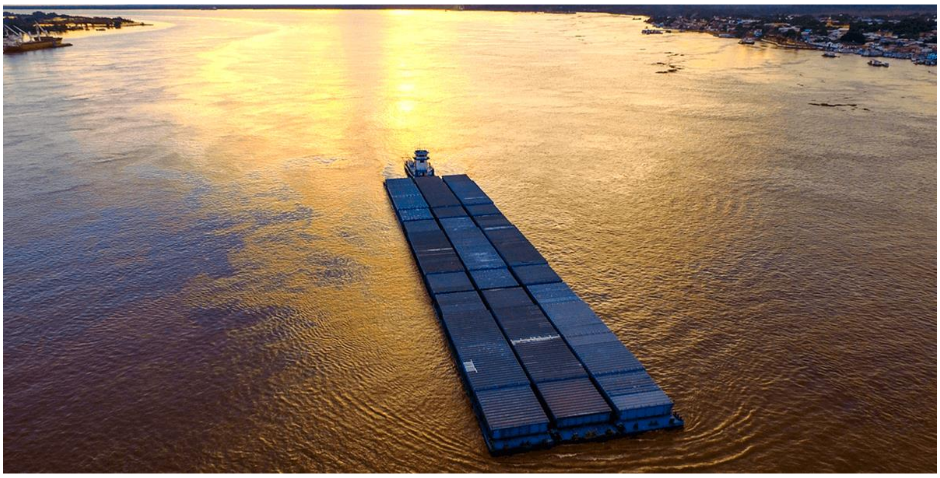
The consumption of the round trip would be 65 thousand liters of diesel, equivalent to 150 m3 of LNG and these volumes could be supplied by Itacoatiara trucks with LNG from the field of the ENEVA Plant in Azulão, eliminating the costs of terminals or a network of supply vessels , as shown in figure 20.

Figure 20: Route proposal

Source: the author

As in the first year of operation, around 500 thousand tons of grain are expected, the intention is to work with 02 convoys composed of 9 barges and with a load capacity of 22,500 tons of cargo. These convoys will be propelled by similar pushers and with the same power as the current Bertolini “C” Class, which have 1800 hp of propulsive power, as shown in figure 21.

Figure 21: Bertolini company train



Source: the author.

The flow of convoys for supply should be 2 per week per week and we intend to use the 50 m3 LNG trucks already operated by ENEVA to carry out this supply. To cover the 75-kilometer stretch between the liquefaction plant and the port, plus the supply times at the plant and transshipment to the tug, and knowing that 150 m3 must be supplied per tug, we estimate a total of 3 trailers for the operation.

CONCLUSION

It is therefore concluded that LNG is indeed an option as a naval fuel to be used in the Amazon, and that in the medium term its use will be restricted to routes that will originate from Itacoatiara, given its proximity to the Azulão field and the only source of LNG of the Amazon region.

It is also understood that with the advent of the first vessels there will be a natural search for this fuel, generating an increase in the fleet of LNG vessels. This situation should increase the demand, generating scale of the operation and thus the system will need the capillarity of the fuel through the Amazon, generating needs of solution for transport probably for a fleet of supply vessels and storage tanks, already presented in this work.

Still due to the large deposits of Natural Gas in the Amazon, the constant world demand for fuels with low carbon emissions and other polluting gases, it is believed that in a slightly longer period there will be the installation of more liquefaction units that will be able to supply LNG to both vessels that operate in the Amazon in terms of providing energy solutions to isolated systems and also opening up the possibility of exporting LNG via tankers.

Thus, it would need to be done, including environmental impacts on the Amazonian environment, amount of generation of jobs, potential for generating value and technological development, among others. However, one of the biggest gaps remains the provision of infrastructure. At the only supply ferries would need to be built and operated, but also terminalsstorage and liquefaction, compression terminals for making CNG available to applications in smaller port, terminals in transshipment, systems in receipt in regasification , in between others.

With the involvement of different participants in the natural gas value chain and the resolution of the different barriers that still remain, the energy transition of the future can if approach the present.

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