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STUDY ON LNG SUPPLY LOGISTIC CHAIN

WP1. LNG BUNKERING SOLUTIONS CHARACTERIZATION

Activity 2 – WP2.1 – ET3 – WP1

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Customer ENAGÁS, S.A.
Paseo de los Olmos 19
28005 Madrid, Spain

Project led by:

Shipping Business Consultants
Basauri 17, 28023 Madrid, Spain
Tel. +34 91 372 96 77
www.sbc-spain.com
Contact: Jesús Nieto García
jesus.nieto@sbc-spain.com

Colaborators:

Cringás LNG

I.C.C. Ingenieros, S.A.

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1 INTRODUCTION

This document LNG BUNKERING SOLUTIONS CHARACTERIZATION, is the first deliverable (D1) of the STUDY ON LNG SUPPLY LOGISTIC CHAIN, part of the LNG GAS HIVE, a project aiming to develop a safe and efficient, integrated logistics and supply chain for LNG in the transport industry (small scale and bunkering), particularly for maritime transport of the Iberian Peninsula, Spanish and Portuguese islands and territories.

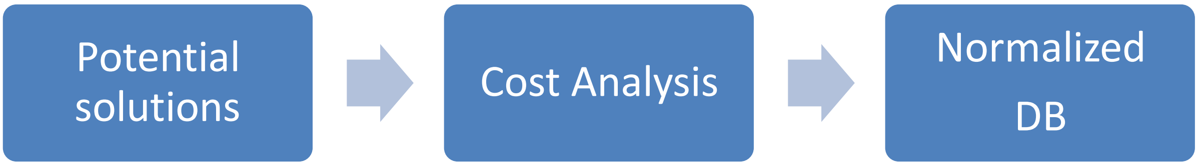
The main objective of this work is to study the optimal logistic chains to attend the potential LNG demand, identifying the infrastructure to be deployed in the Iberian Peninsula and islands. This is a planning exercise that will match supply and demand. LNG bunkering technologies is a new and unmatured market, and most of the system references are at prototype or even conceptual engineering state. On the other hand, demand projections today still carry a high level of uncertainty. In this context, this project aims to provide the tools to facilitate a continuous update of both bunkering supply technologies and demand forecast.

This work package (WP1) focus is placed on the cost components of all the potential elements of the LNG bunkering supply chain. The output of this activity will feed further analysis when supply chains will be designed, simulated against the expected demand and economically and financially validated.

Besides this report a database is delivered normalized to feed the mathematical tool that will support the design job.

2 METHODOLOGY

The methodology applied had three phases



- **First** a thorough review of potential solutions based on existing literature and previous studies at international level. LNG bunkering is a new activity and technologies are not yet mature. The research therefore will be oriented to the identification of the most probable technologies that will support the development of this new bunkering sector. These technologies will be grouped in chain link with the same function (product source, transport or bunkering means).
- **Second**: Those solutions that can be considered market ready, counting with adequate regulatory support will be studied in detail obtaining both fixed and variable cost components. Contact will be established with vendors to collect both technical and economic information for each equipment category. Often the consultant team will contribute with their background experience both in small scale land based LNG supply chains and conventional bunkering process and equipment technologies in the cost element analysis. The components will be grouped chain links already to facilitate the future usage, for each chain link, several variations will be calculated providing a range of components with certain capacity levels.
- **Third**: The resulting technologies will finally be normalized to provide input to future modules, WP2 and WP3 where along with demand forecast supply chains will be designed. Those aspects that cannot be normalized, imposing operational limitations to its usage, will be identified to become rules. The results, will be provided in a database that can be dynamically adjusted should future information become available.

The three components categories to be analysed are:

1) Sources of supply
2) Transport means
3) Bunkering means

The analysis of each system category under this work package has placed the focus on modelling each component category to facilitate further design of supply chains. For each category, a set of specific elements have been calculated, but as market matures, costing data will become more accurate, and new elements could be added to WP1 database. Due to the functional grouping of the elements, transport and bunkering means will be jointly modelled into a category to facilitate the construction of complex supply chains.

2.1 *Financial considerations*

The assessment of investment costs in this study not only addresses the capital investment associated with the asset acquisition, but also makes a proper distribution of the assets costs over time, resulting in the yearly capital cost of it. This **capital costs considers the equipment depreciation and the financial costs.**

In this planning exercise, certain common assumptions have been made in terms of the capital cost calculation for every component (equipment or infrastructure) analyzed, as follows:

- Conservative depreciation approach. An annual linear early linear depreciation over a period close to total equipment lifespan.
- 100 % external financing
- 4.5 % annual interest rate
- 15 % of residual value
- Operational fixed cost will remain constant from first year. A decrease in financial costs is balanced with an increase in staff and maintenance costs

A general surcharge has been applied incorporating both: corporate overheads and industrial profit. This additional cost, labeled under "Margin & Structure" has been fixed in 15% for all equipment and infrastructure operations.

Finally, Annex 1 contains a table of constants values shared across all calculations. Therefore, all costs models could be recalculated after the update of the Annex 1 table.

3 SOURCE OF SUPPLY

The logistic supply chain will always start in source of LNG product that will be transported and served to the customer's vessels at their operating ports.

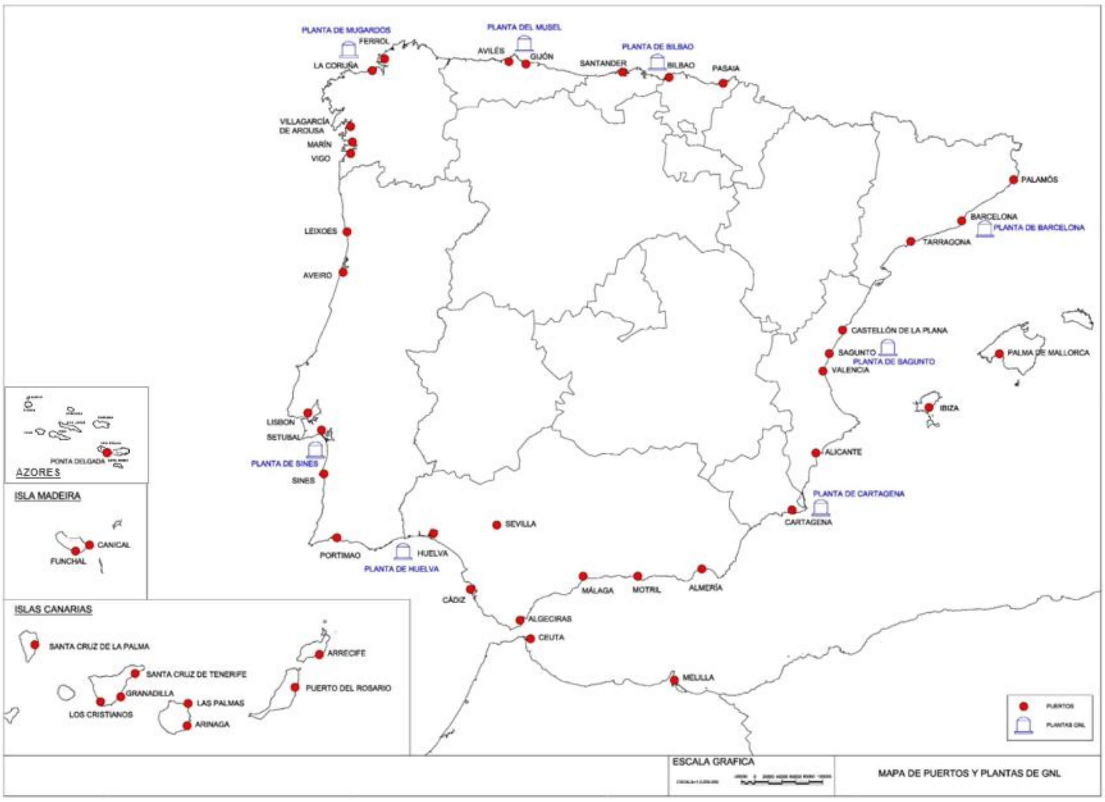
There are three potential supply sources analysed in this chapter:

1) Import Terminals
2) Auxiliary Terminals
3) Small Liquefaction Plants

Import Terminals will be the preferred source as they will reuse existing infrastructure reducing additional CAPEX and OPEX. When designing the logistics supply chains to meet the expected demand, alternative sources of supply could be needed to reduce the logistic cost and guarantee the minimum service level in certain ports. Auxiliary Terminals or Small Liquefaction Plants will be considered, compared and validated as alternatives during WP2 and WP3.

3.1 IMPORT TERMINALS

In this section LNG import terminals will be characterized. Location of the terminals around the Iberian Peninsula coast are shown in the next figure:



3-1. Existing Import Terminals

Existing import terminals in the Iberian Peninsula are the following:

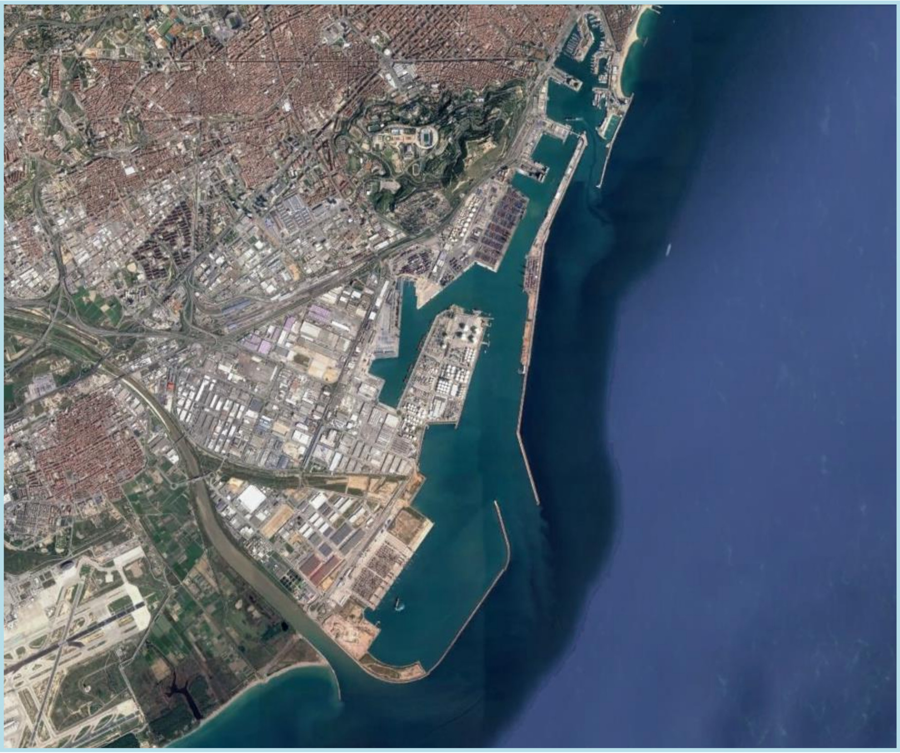
- Import Terminal of Barcelona
- Import Terminal of Sagunto
- Import Terminal of Cartagena
- Import Terminal of Huelva
- Import Terminal of Sines
- Import Terminal of Mugardos
- Import Terminal of Bahía de Bizkaia Gas (BBG)
- Import Terminal of El Musel
- Import Terminal of Granadilla (in Project phase)

When the logistic chain of supply is evaluated, potential auxiliary terminals could be defined attending to the demand and distance from import terminals.

The main characteristics of the Import Terminals, will be showed in the following chapters.

3.1.1 Import Terminal of Barcelona

Located on the Dock of the Energy in the Port of Barcelona.



3-2. Barcelona Port. Source: Google Earth

The main characteristics of the terminal are:

TERMINAL OF BARCELONA		
Number of Tanks	6	
Storage capacity	760,000 m^3 LNG	
Emission capacity	1,950,000 $m^3(n)/h$	
Docking capacity:	**Minimum**	**Maximum**
Dock 1	500 m^3 LNG	87,600 m^3 LNG
Dock 2	69,000 m^3 LNG	266,000 m^3 LNG
LNG Ship Unloading	12,000 m^3 LNG/h	
LNG Trucks Loading	15 GWh/day (3 bays, 50 trucks/day)	
LNG Ship Loading	Maximum 4,000 m3/h	
Transshipment	Available	
Bunkering services	Available	

Main characteristics of the port and tanker:

- Docks:
  - Dock 1: For methane LNG tankers of up to 87,600 m^3 LNG.
  - Dock 2: For methane LNG tankers of up to 266,000 m3 LNG.
- Typology:
  - Structure of the dock and loading platform: vertical quay with reinforced concrete drawers.
  - Mooring structure: dolphins made of reinforced concrete drawers.
- Maximum draught: 14 m attending to the minimum water level.
- Dock coping:
  - Offloading platform: +4.00 attending to port zero.
- Mooring dolphins: +4.00 and +4.50.
- Maximum height allowed for the tanker's superstructure: Not limited.

3.1.2 *Import Terminal of Sagunto*

Located at the end of the southern inner breakwater of the Port of Sagunto.

3-3. Sagunto Port. Source: Google Earth

The main characteristics of the terminal are:

TERMINAL OF SAGUNTO		
Number of Tanks		4
Storage capacity		600,000 m^3 LNG
Emission capacity		1,000,000 m^3(n)/h
Docking capacity: **Dock 1**	**Minimum** TBA	**Maximum** 266,000 m^3 LNG
LNG Ship Unloading		12,000 m^3 LNG/h
LNG Trucks Loading		2 bays, 35 trucks/day
LNG Ship Loading		Max. 3,000 m^3/h
Transhipment		Available
Bunkering services		Available

3.1.3 *Import Terminal of Cartagena*

Located into Escombreras dock.

3-4. Cartagena terminal. Source: Google Earth

The main characteristics of the terminal are:

TERMINAL OF CARTAGENA		
Number of Tanks		5
Storage capacity		587,000 m^3 LNG 4,021 GWh
Emission capacity		1,350,000 $m^3(n)/h$ 376.8 GWh/day
Docking capacity:	**Minimum**	**Maximum**
Dock 1	500 m^3 LNG	40,000 m^3 LNG
Dock 2	69,000 m^3 LNG	266,000 m^3 LNG
LNG Ship Unloading		12,000 m^3 LNG/h
LNG Trucks Loading		15 GWh/day (3 bays, 50 trucks/day)
LNG Ship Loading		Maximum 7,200 m^3/h
Transhipment		Available
Bunkering services		Available

Main characteristics of the port and tanker:

- Docks:
  - Dock 1: For methane tankers of up to 40,000 m^3 LNG.
  - Dock 2: For methane tankers of up to 266,000 m^3 LNG.
- Typology:
- Loading platform: reinforced concrete structure built on dolphins made of armoured concrete drawers.
  - Structure of dockage and mooring: dolphins made of reinforced concrete drawers.
- Maximum draught: 15 m referred to LLW.
- Static maximum draught to access the twist and dock area: 13 m.
- Dock coping:
  - Offloading platform, docking and mooring dolphins: + 10.00.
- Maximum height allowed for the vessel's superstructure: Unlimited.

3.1.4 Import Terminal of Huelva

Located at the mouth of the rivers Tinto and Odiel.

3-5. Huelva Terminal. Source: Google Earth

The main characteristics of the terminal are:

TERMINAL OF HUELVA		
Number of Tanks		5
Storage capacity		619,500 m^3 LNG 4,244 GWh
Emission capacity		1,350,000 $m^3(n)/h$ 376.8 GWh/day
Docking capacity: **Dock 1**	**Minimum** 500 m^3 LNG	**Maximum** 180,000 m^3 LNG
LNG Ship Unloading		12,000 m^3 LNG/h
LNG Trucks Loading		15 GWh/day (3 bays, 50 trucks/day)
LNG Ship Loading		Maximum 3,700 m^3/h
Transhipment		Available
Bunkering services		Available

Main characteristics of the port and tanker:

- Name: Enagás dock.
- Typology:
  - Loading platform: reinforced concrete structure, secured on foundation piles.
  - Structure of dockage and mooring: reinforced concrete mooring dolphins secured on piles.
- Maximum draught spaces: 13 m referred to LLW.
- Turning area in front of the dock: 13 attending to LLW.
- Minimum draught in the interior canal: 11.3 attending to LLW.
- Under keel clearance: 2.27 m above LLW.
- Maximum draught is the maximum deep less 1.5 m of UKC.
- Vessels will start their entry in the estuary 2-2.5 hours (from the approach buoy) before high tide. Minimum tide coefficient: C>=46.
- Minimum speed allows: never up to 7 knots.
- Dock coping:
  - Offloading platform: +12.47
  - Docking dolphins: between +6.30 y +6.33
  - Mooring dolphins: between +6.32 and +6.36 (Docking 1st at +7.37).

3.1.5 *Import Terminal of Sines*

Located on the Port of Sines.

3-6. Sines port. Source: Google Earth

The main characteristics of the terminal are:

TERMINAL OF SINES		
Number of Tanks	3	
Storage capacity	390,000 m^3 LNG	
Emission capacity	1,350,000 m^3(n)/h	
Docking capacity: Dock 1	**Minimum** 500 m^3 LNG	**Maximum** 216,000 m^3 LNG
LNG Ship Unloading	12,000 m^3 LNG/h	
LNG Trucks Loading	3 bays, 50 trucks/day	
LNG Ship Loading	Maximum 2,000 m^3/h	
Transhipment	Available	
Bunkering services	Available	

3.1.6 *Import Terminal of Mugardos*

Located on the Port of Ferrol.

3-7. Mugardos terminal. Source: Google Earth

The main characteristics of the terminal are:

<table>
<tr><th colspan="3">TERMINAL OF MUGARDOS</th></tr>
<tr><td>Number of Tanks</td><td colspan="2">2</td></tr>
<tr><td>Storage capacity</td><td colspan="2">300,000 m^3 LNG</td></tr>
<tr><td>Emission capacity</td><td colspan="2">420,000 m^3(n)/h</td></tr>
<tr><td>Docking capacity:
Dock 1</td><td>Minimum
500 m^3 LNG</td><td>Maximum
266,000 m^3 LNG</td></tr>
<tr><td>LNG Ship Unloading</td><td colspan="2">12,000 m^3 LNG/h</td></tr>
<tr><td>LNG Trucks Loading</td><td colspan="2">35 trucks/day</td></tr>
<tr><td>LNG Ship Loading</td><td colspan="2">Maximum 2,000 m^3/h</td></tr>
<tr><td>Transhipment</td><td colspan="2"></td></tr>
<tr><td>Bunkering services</td><td colspan="2">Available</td></tr>
</table>

3.1.7 *Import Terminal of Bahía de Bizkaia Gas (BBG)*

Located in the municipality of Ziérbana (province of Biscay), in the grounds of the outer port of Bilbao and in its industrial zone.

3-8. Bilbao Port. Source: Google Earth

The main characteristics of the terminal are:

TERMINAL OF BBG		
Number of Tanks	3	
Storage capacity	450,000 m^3 LNG	
Emission capacity	800,000 m^3(n)/h	
Docking capacity: **Dock 1**	**Minimum** 500 m^3 LNG	**Maximum** 266,000 m^3 LNG
LNG Ship Unloading	12,000 m^3 LNG/h	
LNG Trucks Loading	1 bay (15 trucks/day)	
LNG Ship Loading	Maximum 3,500 m^3/h	
Transhipment		
Bunkering services	Available	

3.1.8 Import Terminal of El Musel

Located on the extension of the El Musel port, between the Torres dry dock and the north quay.

3-9. El Musel Port. Source: Google Earth

The main characteristics of the terminal are:

TERMINAL OF EL MUSEL		
Number of Tanks		2
Storage capacity		300,000 m^3 LNG
Emission capacity		800,000 m^3(n)/h
Docking capacity: **Dock 1**	**Minimum** TBA	**Maximum** 266,000 m^3 LNG
LNG Ship Unloading		18,000 m^3 LNG/h
LNG Trucks Loading		2 bays (30 trucks/day)
LNG Ship Loading		Maximum 6,000 m^3/h
Transhipment		Available
Bunkering services		Available

3.1.9 *Import Terminal of Granadilla*

Located on the grounds of the industrial port of Granadilla (Tenerife), in project phase.

3-10. Granadilla Port. Source: Google Earth

The main characteristics of the terminal are:

TERMINAL OF GRANADILLA		
Number of Tanks		1
Storage capacity		150,000 m^3 LNG
Emission capacity		150,000 m^3(n)/h
Docking capacity: **Dock 1**	**Minimum** TBA	**Maximum** 145,000 m^3 LNG
LNG Ship Unloading		12,000 m^3 LNG/h
LNG Trucks Loading		Projected
LNG Ship Loading		Projected
Transhipment		
Bunkering services		Available

3.1.10 *Summary of import terminals*

3-1. Summary import terminals

Import Terminal	Barcelona	Sagunto	Cartagena	Huelva	Sines	Mugardos	BBG	El Musel	Granadilla
Number of tanks	6	4	5	5	3	2	3	2	1
Storage Capacity (m^3)	760,000	600,000	587,000	619,500	390,000	300,000	450,000	300,000	150,000
Emission Capacity (m^3(n)/h)	1,950,000	1,000,000	1,350,000	1,350,000	1,350,000	800,000	800,000	800,000	150,000
Dock Capacity (m^3)	Max. 266,000 Min. 500	Max. 266,000 Min. TBA	Max. 266,000 Min. 500	Max. 180,000 Min. 500	Max. 216,000 Min. 500	Max. 266,000 Min. 500	Max. 270,000 Min. 500	Max. 266,000 Min. TBA	Max. 145,000 Min. TBA
LNG Trucks loading	3 bays 50 trucks/day	2 bays 35 trucks/day	3 bays 50 trucks/day	3 bays 50 trucks/day	3 bays 50 trucks/day	35 trucks/day	1 bay 15 trucks/day	2 bays 30 trucks/day	
Ship unloading (m^3/h)	12,000	12,000	12,000	12,000	12,000	12,000	12,000	18,000	10,000
Ship loading (m^3/h)	Max. 4,000	Max. 3,000	Max. 7,200	Max. 3,700	Max. 2,000	Max. 2,000	Max. 3,500	Max. 6,000	
Small scale ready to ship loading	Available	Considered available in 2020	Available	Available	Considered available in 2020	Available	Available	Considered available in 2020	Considered available in 2020

3.2 AUXILIARY TERMINALS

In all ports that do not have LNG terminal or its distance from an existing terminal is very far, it may raise the possibility of an alternative storage system through pressure tanks or by flat bottom vessels of different storage capacities.

3.2.1 Tanks and auxiliary equipment for LNG

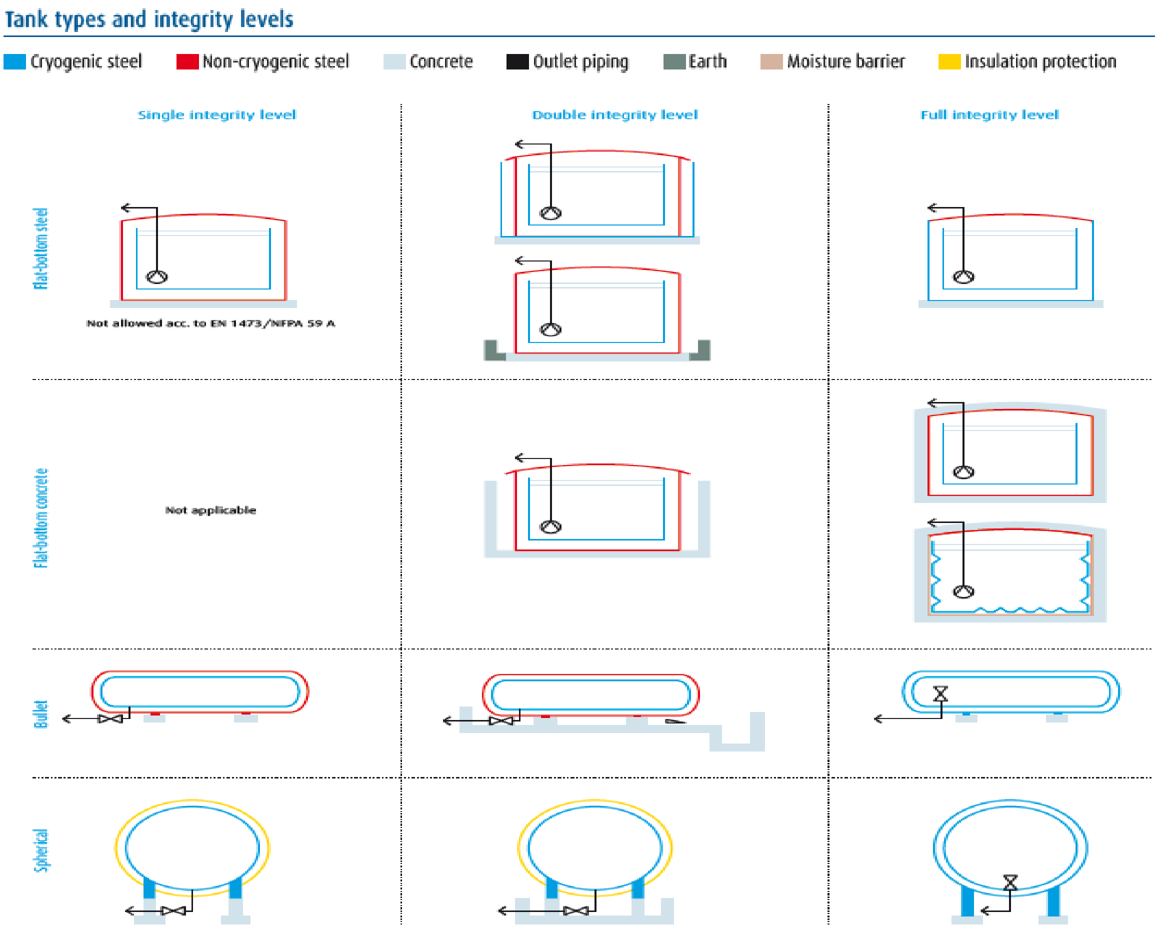
Usually LNG storage is classified in three big groups:

- **Cylindrical pressurized vessels:** Used to storage small and medium volumes. Capacity usually ranges from 40 m³ to 320 m³ for standard fabrication vessels. Beyond this capacity and up to 1,500 m³ must be assembled on site or transported by sea,
- **Spherical storage:** Not very popular, usual capacities ranges from 1,000 m³ to 8,000 m³
- **Flat bottom or atmospheric storage tanks:** Used to medium and big capacities. This type of tanks are built on site and customised to every particular project. Capacities ranges from 1,000 m³ to 200,000 m³

LNG tanks are comprised of two recipients that can be built in different materials depending on safety and BOG requirements.

Main type of construction and its materials for the different types of storage are summarized in the picture below and explained further in the next pages.

3-11 Tank types and integrity levels



3.2.1.1 Horizontal and Vertical Cryogenic pressurized vessels

As it was showed in the figure 3.11 pressure vessels are built always with a inner tank of stainless steel, but depend on the grade of security required, the outer tank can be built in carbon steel, that required additional security measures as bund walls, or can be built in inox steel also, assuring full integrity.

Regarding to insulation material between tanks, there are two main options:

- **Perlite and vacuum insulation**: Raise the cost of the equipment, but provides stable and high quality insulation of the product
- **Solid insulation**: There are many options available, although any of them are really popular in this equipment. Some options are PIR, Aerogels, fiber glass, foam glass, etc…

Horizontal and Vertical stationary pressure vessels normally uses vacuum and perlite insulation for long term storage of cryogenic liquefied gas under pressure. Besides, the vessel should be provided with a hydroscopic material to capture moisture between cylinders (It required for high vacuum equipment).

Describe below are typical characteristics of deposits provided by one of the main manufacturers available on the market and considered for further calculations within this project.

General characteristics of the studied tanks:

- Design temperature: -196°C. (As the tank can handle liquid N2 pre-cool)
- European Directive 2014/68/CE Real decreto 709/2015 *Laws relating to the commercialization of pressure equipment*
- CE marking.
- Inner tank in austenitic stainless steel (304-L) and outer tank in carbon steel (A-106 B).
- Intermediate chamber with perlite insulating and vacuum. Hidroscopic material

Features of the storage tank (inner tank):

- Built in austenitic stainless steel (304-L).
- Working pressures according to the characteristics of the installation of supply ypically from 5 bar and up to 44 bar, even higher for other uses apart from storage).
- Capacities from 5 to 1,200-1,500 m^3.

Characteristics of the envelope regarding to vacuum insulated tank (external tank and camera surround):

- Built in carbon steel (areas of austenitic stainless-steel pipes).
- Protection against overpressure in the chamber with safety valves
- With connection for vacuum measurement.
- Absolute Vacuum admissible in camera.
- Vacuum provided: 0.05 mbarg

Tank equipment included regarding to the vacuum insulated tank:

- Cryogenic valves.
- Equipment to increase the tank pressure (PPR).
- Pressure gauge and level gauges.
- Safety valves.
- Vacuum connector.

The volume of the LNG storage tanks has been conditioned by the safety distances set out in the regulatory standards (Standard UNE 60210:2015). In this Standard, groups or ranges of storage volumes are established and a safe distance for each range to different items. The different manufacturers choose to manufacture tanks in such a way the storage volume gets the maximum level of each range.

In addition to the risks indicated in this Norm, the ports will impose their own safety rules and regulations for the storage of combustible such as LNG.

Risk defined in the Standard UNE 60210:2015:

a) Openings of buildings, basements, sewers or drains.
b) Motors, switches (not explosion proof), deposits of flammable material, ignition points controlled.
c) Projections of power lines.
d) Limits of property, public roads, roads, railways.
e) Openings of public buildings, use administrative, teaching, commercial, hospital.

For storage capacities greater than 320 m^3, pressure vessels cannot be found normally industrialized therefore, additional safety regulations must be considered and depend of the site conditions vessels would have to be transported by sea or preassembled in workplace and finally assembled on site, raising the final price. **In any case, it will always be the port authority who decides on the application of other safety distances and the assembly of other surveillance and safety devices.**

3-12 Safety distances for auxiliary terminals

Volume (m^3)	Type	Occupation surface base (m^2)	Storage Capacity	Risk defined in the Standard UNE 60210:2015				
				a	b	c	d	e
60	Vertical	64.0	E	15	15	15	15	24
80	Vertical	100.0	E	15	15	15	15	24
100	Vertical	100.0	F	20	15	15	25	34
120	Vertical	100.0	F	20	15	15	25	34
150	Vertical	144.0	F	20	15	15	25	34
200	Vertical	196.0	G	20	15	15	30	44
240	Vertical	196.0	G	20	15	15	30	44
300	Vertical	196.0	G	20	15	15	30	44
320	Vertical	196.0	G	20	15	15	30	44
60	Horizontal	126.0	E	15	15	15	15	24
80	Horizontal	128.0	E	15	15	15	15	24
100	Horizontal	136.0	F	20	15	15	25	34
120	Horizontal	144.0	F	20	15	15	25	34
150	Horizontal	176.0	F	20	15	15	25	34
200	Horizontal	184.0	G	20	15	15	30	44
240	Horizontal	243.0	G	20	15	15	30	44
300	Horizontal	264.0	G	20	15	15	30	44
320	Horizontal	272.0	G	20	15	15	30	44
1,000	Horizontal	800.0	H	25	15	15	35	55

In case the storage capacity of the auxiliary terminal exceeds 1,500 m^3, the involvement of all the actors that will participate in the process will be necessary. According to the Regulations, a Safety Report must be made before the construction of the Plant, in which an identification of the accident risks that may occur in the auxiliary plant or terminal, the consequent damages and the distances that they can reach.

Based on the described analysis, on which both design changes and safety measures are established to avoid accidents, as the minimum distances that must be safeguarded not only between the different equipment of the plant but also with respect to other nearby activities and nearest population nuclei. This is a fundamental aspect to observe since the Ports may have centres of activities for the works that are developed in these ports, there may be other storage of combustible products that in turn have to comply with their specific regulations, etc.

Dimensions and volume of different LNG vertical tanks (depending on model) are:

3-2. Vertical tank. Source: Lapesa

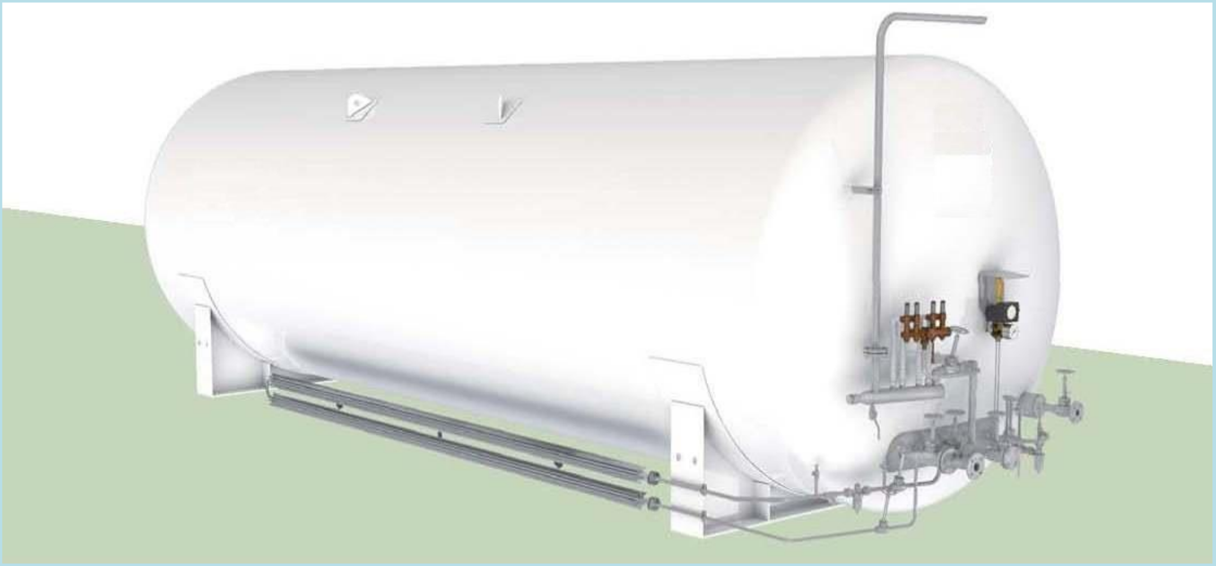
Volume (m3)	Diameter (mm)	Height (mm)
60	3,000	14,300
80	3,800	11,300
100	3,800	14,050
120	3,800	15,300
150	3,800	19,300
200	4,200	19,660
240	4,200	23,660
300	4,200	29,660
320	4,200	30,661

3-13. Vertical tank. Source: Lapesa

Dimensions and volume of different LNG horizontal tanks (depending on model) are:

3-3. Horizontal tank. Source: Lapesa

Volume (m^3)	Diameter (mm)	Length (mm)
60	3,000	13,374
80	3,800	10,292
100	3,800	13,042
120	3,800	14,322
150	3,800	18,332
200	4,200	18,700
240	4,200	22,700
300	4,200	28,700
320	4,200	29,700
1,000	6,000	54,000



3-14. Horizontal tank. Source: Lapesa

3.2.1.2 Spherical tanks

Rarely used for LNG onshore, this kind of storage is commonly used in LNG carriers. Consists of an sphere supported usually by a vertical steel cylinders, both sphere and outer shell may be made in aluminium alloy, stainless steel or 9% nickel steel. Capacities ranges typically from 2,000 m^3 to 8,000 m^3.

The sphere creates a better distribution of the stresses on the sphere's surfaces, providing a strong structure saving important material costs by a reduction in shell thickness, besides the less surface area reduces BOG generated.

3-15Spherical tank. Source: SPG

3.2.1.3 Flat bottom Storage Tanks

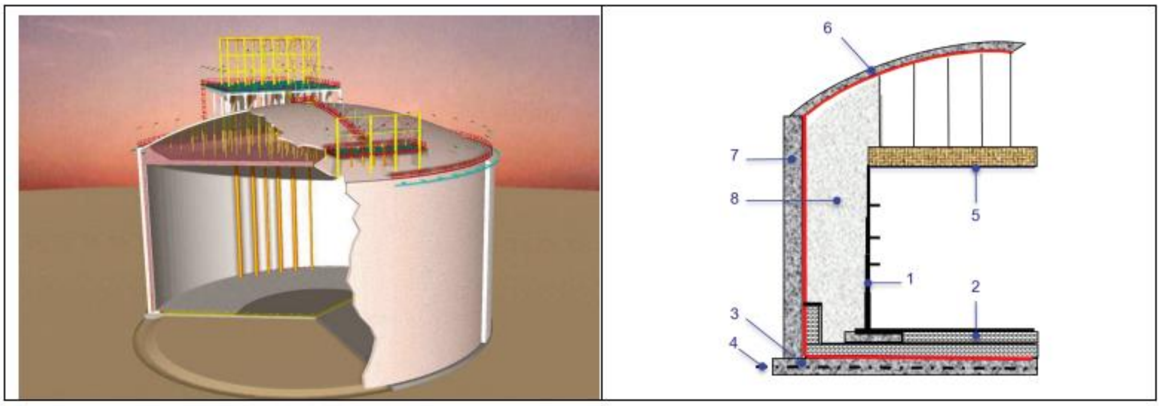
Main characteristics

As it was showed in Fig. 3-11 there are 7 types of flat bottom tanks (including under-ground, in-ground and above-ground configurations) depend of their materials and technology used.

In this study only above-ground full integrity tanks with concrete outer tank are considered. Within this category we can observe two main types:

Full double containment

A non-pressurized stationary flat bottom tank consists on two vessels, one placed inside the other, an inner and an outer vessel. The inner vessel is made of stainless steel or 9% nickel steel, and the outer vessel is made of carbon steel or concrete, depending on the project. The space between the walls is filled with an insulation material: foamed glass on the bottom, expanded perlite on the walls and on the roof. The space is filled with dry nitrogen to ensure efficient and durable insulation, keeping it dry and oxygen-free. The tanks are delivered as a set of components to be erected on site.



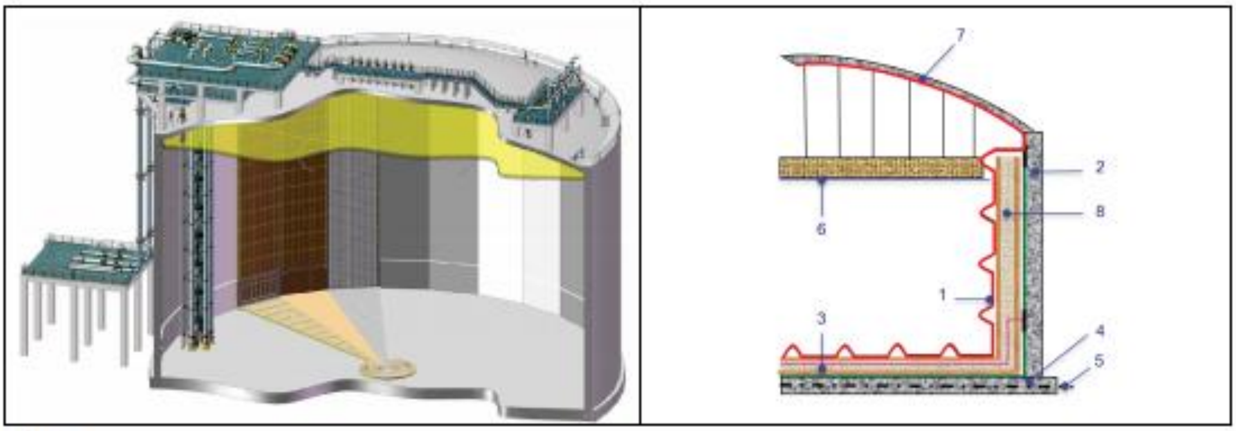
Keys:

1. Primary container (9% Ni steel)
2. Bottom insulation (load bearing rigid cellular glass)
3. Slab (reinforced concrete)
4. Slab heating system
5. Insulated suspended deck (aluminum & fibreglass)
6. Hemispherical dome roof (reinforced concrete)
7. Sidewalls (pre-stressed concrete)
8. Wall insulation (loose fill perlite / 1m thick)

3-16. Flat bottom tank

Membrane containment

The primary container is a thin stainlees steel corrugated membrane not self-suported and the secondary container is a pre-stressed concrete tank that ensures the structural function. Thermal insulation function is ensured by a panel composed of different materials like polyurethane foam and plywood.



Keys:

1. SS corrugated membrane (1.2mm thick)
2. Sidewalls (pre-stressed concrete)
3. Bottom insulation (load bearing PU / 40cm thick)
4. Slab (reinforced concrete)
5. Slab heating system
6. Insulated suspended deck (aluminum & fibreglass)
7. Hemispherical dome roof (reinforced concrete)
8. Wall insulation (load bearing PU / 40cm thick)

3-17. Membrane tank.

The basis of the deposits considered in this study is built in concrete and the main design requirement are:

- NFPA 59A
- EN 1473
- Mechanic: API 620 general + app. Q
- External pressure: API 650 app. V
- Civil works: EC 2 y 3 ACI code
- Seismic: API 650 app. E / API 620 app. In Spain is ruled by NCSE
- Wind/Snow: National Codes
- EN14620
- Alternative Designs: DIN 4119, BS7777, AD B6
- Thermal Calculations
- Flexibility Calculations
- Calculations of load to the battery lines
- Most common volumes:
  - 5,000 m^3 LNG full containment. Diameter 21.3 m. Height 24.3 m H/d = 1.15 m
  - 10,000 m^3 LNG full containment. Diameter 26.3 m. Height 29.6 m H/d = 1.12 m
  - 30,000 m^3 LNG full containment. Diameter 37.4 m. Height 40.5 m H/d = 1.08 m
  - 50,000 m^3 LNG full containment. Diameter 50 m. Height 26.8 m H/d = 0.536 m

Capacity designs can be made with different values for H/d, depending on different building constraints as lifting capacities, dome sizing or others.

Limitations of the application of the Standards:

- Up to 200 Tons of capacity (450 m^3 considering a density of 450 kg/m^3):
  - Exclusion of the obligatory nature of the application of the standard SEVESO III (RD 840/2015).
  - Application of the Standard UNE-EN 60210
- Up to 1,500 m^3 (3,300 m^3) of storage capacity:
  - Application of the Standard SEVESO III (RD 840/2015)
  - Application of the Standard UNE-EN 60210
- Above 1,500 m^3 (3,300 m^3) of storage capacity:
  - Application of the Standard SEVESO III (RD 840/2015)
  - Application of the Standard UNE-EN 60210

3.2.1.4 *Floating storage*

Nowadays off-shore LNG storage technologies are commonly used for providing an alternative to on-shore LNG storage. Operative capacity and reduced initial investment make them a proficient solution to the problem, which also can be installed easily and fast. This shows up the FSU (floating storage units) as a high growing and very interesting solution for solving problems related to adapting complex logistics for fuelling maritime routes already defined with lower initial investments and competitive prices (mainly thanks to the reuse of LNG tankers that are near the end of their life in service or whose propulsion is no longer efficient at competitive costs). As a summary, this are the principal advantages vs onshore infrastructure, that would be explained further:

ADVANTAGES

- No land using
- Delivery between 1 to 2 years
- Posibility of relocation
- Short and long-term leasing contracts possibility
- Low social and visual impact

DISADVANTAGES

- Higher OPEX
- Higher BOG generation
- Tighter operative range for storage and regasification
- Weathers conditions dependence
- No LNG supply or more complex to realize
- Deepsea conexions are necessary

Although this type of technologies are currently oriented to large-scale, it is true that more applications are being developed to small and mid-scale usage. They can be adapted to the needs and particularities of each one of the projects to be addressed, encompassing a wide range of capacities according to the project needs.

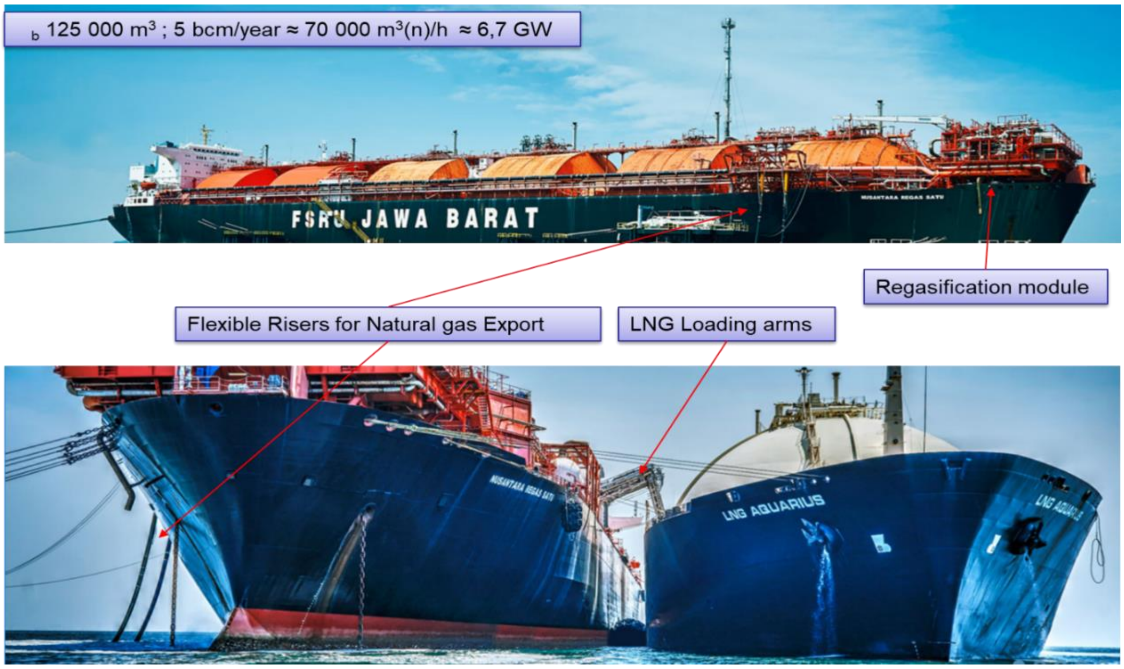
Floating Storage Solutions are divided into two groups, the FSRU vessels (Floating Storage & Regasification Units) and the FSU vessels (Floating Storage Units). The main difference between them is the FSRU capacity to regasify LNG on board.

FSRU´s regasification unit is integrated in the ship itself while normally the FSU alternative consists just in an off-shore storage and a suitable connection either to the jetty or land, where the regasification equipment is located (if any).

Floating Storage facilities are commonly based on old vessel conversions at the end of their life in service. FSUs get normally docked in a jetty, thanks to which other cargoes can easily be loaded, either by the use of hoses in a Ship To Ship operation (STS), or by loading arms situated on both sides of the jetty, in which vessels would lie moored while interconnected between themselves.

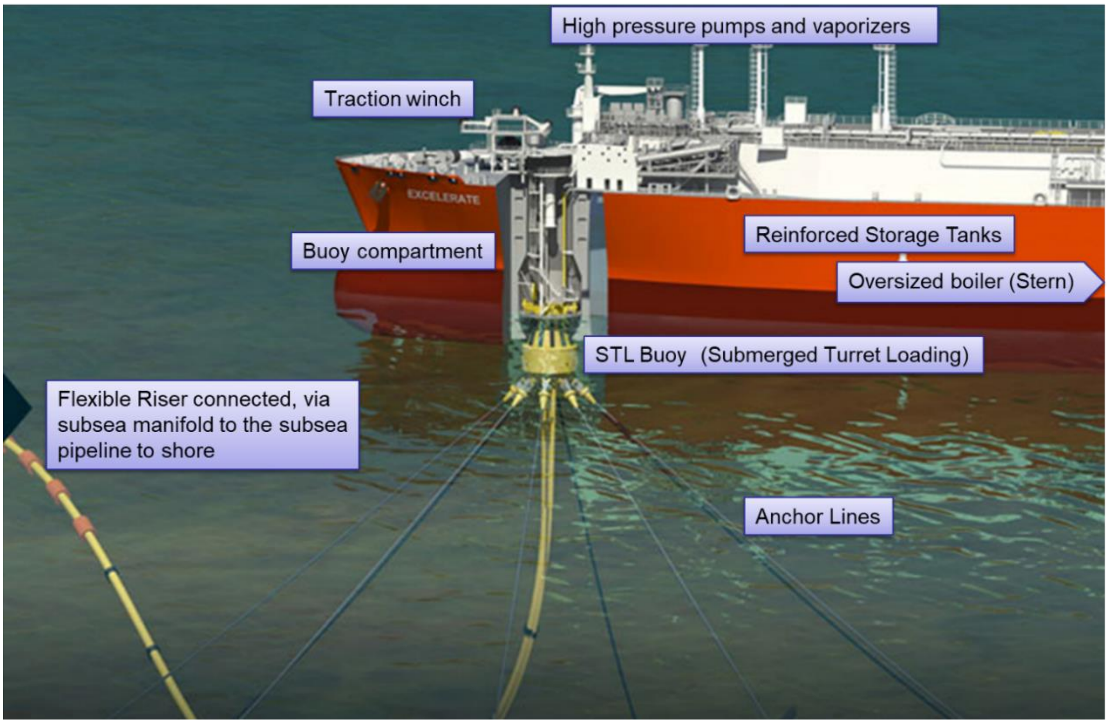
Hoses provide flexibility and a lower initial investment costs but greater operational problems, a lower transfer capacity in general terms, a greater generation of boil-off gas and higher frictional pressure losses.

Loading arms operation is safer and generates less BOG. Nitrogen is used for returning back the LNG excess to the tank (used as a displacing piston for loading arms drainage). High nitrogen consumption is the main drawback of this kind of systems.



3-18. Nusantara Regas Satu. West Java

For large scale needs, the option of using turrets or buoys to connect the FSU with inland facilities should also be considered, especially when the FSRU is not going to be near the coast. For a further understanding a image of a FSRU with buoy conexion is showed in first place and above a turret installation



3-19. Energy bridge regasification unit

3-20. PNG FSRU Lampung. Indonesia

From a commercial point of view, barge solutions are already available in the market with storage capacities between 10,000 and 25,000 m^3 as the showed in the pictures below. An operative solution would be freightage of these barges with suitable capacities (adapted to the demand forecast) in time charter. This allows shipping to offer a fast-track or definitive solution in these facilities and lead their market stand.

3-21. EXMAR FSRU for Bangladesh

Aditionally, small and mid scale LNG vessels can be used also as FSU, an example of that can be found in Bali, Indonesia where a 30,000 m^3 FSU+FRU project has been developed. While the FSU final unit is built, the FRU -already completed- has been connected to a 30,000 m^3 LNG transportation vessel, the "HAI YANG SHI YOU 301". We can see in the pictures below how is working today the installation and how should be in the future.

3-22. Bali FSU+FRU. Actual arrangement

3-23. Bali FSU+FRU+LNG Carrier for refilling. Future arrangement

The type of solutions exposed along this document are usually installed in "Empty and leave" mode or in "permanent seasonal regime" as it will be described in following lines.

Advantages and disadvantages

The capacity to operate on a seasonal basis is one of the most relevant advantages of this type of systems. Although they can be relocated if necessary, is needed to be taken into account that the vast majority of this systems already installed (FSRUs and FSUs mostly in large scale dimensions) have contracts signed for minimum periods of 10 years, in order to be able to amortize the heavy investments carried out in the conditioning of the so-called old ladies (methane tankers at the end of their life in service), or in the construction of systems built on purpose.

Another advantage of this type of systems is the possibility to avoid the sunken costs of an on-shore installation, which requires a large investment in case it needs to be dismantled.

Among the major disadvantages that these system present, is that the large FSUs that are docked in open water suffer the disadvantages of changing weather conditions (very severe sea conditions) that may require the disconnection of the arms and their exit to open water.

In the case of smaller FSUs, it is not foreseeable that this type of situation occurs, since they should be found docked in port.

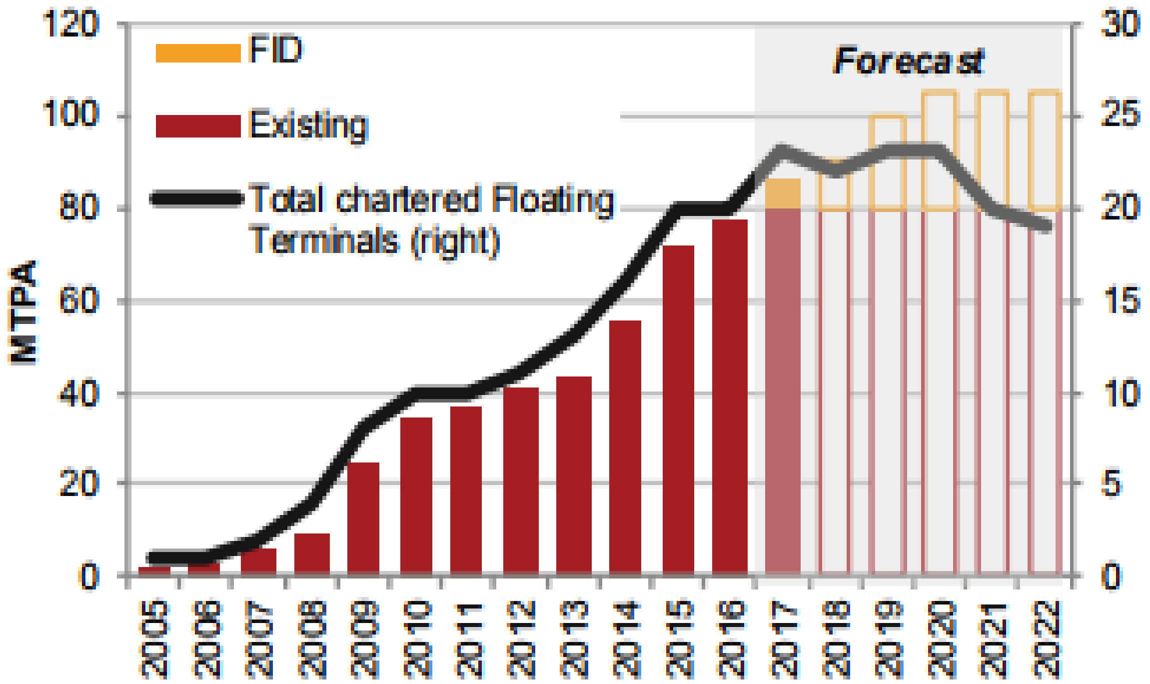
Another of the main disadvantages of FSU systems is that their storage capacity is limited to the size of the vessel itself, and an extension of the storage capacity of the installation makes a new vessel mandatory.

Operating costs significantly higher than on-shore systems penalize this type of systems in the medium and long term, playing a relevant role against the use of this type of solutions compared to the traditional on-shore installations.

The BOG generated in this type of systems will be approximately 0.15% (quite higher than the one of an on-shore tank, but in line with the typical of a methane tanker), so a system to manage it must be foreseen, as well as a security system based either on venting to atmosphere or on controlled combustion in a flare system. In some configurations, the available barges have IMO type C pressure devices, which is a great advantage when handling the boil-off.

Current references

Up to the present, several operational references are available, although all of them operate in the large scale market. These are the Melaka terminals in Malaysia (FSU Tenaga Satu and FSU Tenaga Empat), Montego Bay in Jamaica (FSU Golar Arctic) and the FSU Armada LNG Mediterranean in Marsaxlokk bay, Malta, as well as the construction of a new FSU terminal for Bahrain. A historical and forecast of avalaible installations can be seen in the figure below



3-24. Historical and forecast of Floating storage Installed capacity (2005-2022)

All the installations working today and his main characteristics are:

Ship Name	Shipowner	Shipbuilder	Type	Delivery Year	Capacity (cm)	Propulsion Type	IMO #	Status at end-2015
FSRU TOSCANA	OLT Offshore LNG Toscana	Hyundai	Converted FSRU	2004	137,500	Steam	9253284	Chartered as FSRU
GOLAR FREEZE	Golar LNG Partners	HDW	Converted FSRU	1977	126,000	Steam	7361922	Chartered as FSRU
GOLAR SPIRIT	Golar LNG Partners	Kawasaki Sakaide	Converted FSRU	1981	129,000	Steam	7373327	Chartered as FSRU
GOLAR WINTER	Golar LNG Partners	Daewoo	Converted FSRU	2004	138,000	Steam	9256614	Chartered as FSRU
NUSANTARA REGAS SATU	Golar LNG Partners	Rosenberg Verft	Converted FSRU	1977	125,003	Steam	7382744	Chartered as FSRU
BW INTEGRITY	BW	Samsung	FSRU	2016	170,000	TFDE	9724946	Chartered as FSRU
BW SINGAPORE	BW	Samsung	FSRU	2015	170,000	TFDE	9684495	Chartered as FSRU
EXCELERATE	Exmar, Excelerate	Daewoo	FSRU	2006	135,313	Steam	9322255	Chartered as FSRU
EXCELLENCE	Excelerate Energy	Daewoo	FSRU	2005	138,124	Steam	9252539	Chartered as FSRU
EXEMPLAR	Excelerate Energy	Daewoo	FSRU	2010	151,072	Steam	9444649	Chartered as FSRU
EXPEDIENT	Excelerate Energy	Daewoo	FSRU	2010	147,994	Steam	9389643	Chartered as FSRU
EXPERIENCE	Excelerate Energy	Daewoo	FSRU	2014	173,660	TFDE	9638525	Chartered as FSRU
EXPLORER	Exmar, Excelerate	Daewoo	FSRU	2008	150,900	Steam	9361079	Chartered as FSRU
EXQUISITE	Excelerate Energy	Daewoo	FSRU	2009	151,035	Steam	9381134	Chartered as FSRU
GDF SUEZ CAPE ANN	Hoegh, MOL, TLTC	Samsung	FSRU	2010	145,130	DFDE	9390680	Chartered as FSRU
GOLAR ESKIMO	Golar LNG	Samsung	FSRU	2014	160,000	TFDE	9624940	Chartered as FSRU
GOLAR IGLOO	Golar LNG Partners	Samsung	FSRU	2014	170,000	TFDE	9633991	Chartered as FSRU
GOLAR TUNDRA	Golar LNG	Samsung	FSRU	2015	170,000	TFDE	9655808	Chartered as FSRU
HOEGH GALLANT	Hoegh	Hyundai	FSRU	2014	170,000	TFDE	9653678	Chartered as FSRU
HOEGH GRACE	Hoegh	Hyundai	FSRU	2016	170,000	DFDE	9674907	Chartered as FSRU
INDEPENDENCE	Hoegh	Hyundai	FSRU	2014	170,132	TFDE	9629536	Chartered as FSRU
NEPTUNE	Hoegh, MOL, TLTC	Samsung	FSRU	2009	145,130	Steam	9385673	Chartered as FSRU
PGN FSRU LAMPUNG	Hoegh	Hyundai	FSRU	2014	170,000	TFDE	9629524	Chartered as FSRU
BALTIC ENERGY	Sinokor Merchant Marine	Kawaski	Conventional	1983	125,929	Steam	8013950	Laid-up
ECHIGO MARU	NYK	Mitsubishi	Conventional	1983	125,568	Steam	8110203	Laid-up

Ship Name	Shipowner	Shipbuilder	Type	Delivery Year	Capacity (cm)	Propulsion Type	IMO #	Status at end-2015
FORTUNE FSU	Dalian Inteh	Dunkerque Normandie	Conventional	1981	130,000	Steam	7428471	Laid-up
GAEA	Golar LNG	General Dynamics	Conventional	1980	126,530	Steam	7619575	Laid-up
GOLAR VIKING	Golar LNG	Hyundai	Conventional	2005	140,000	Steam	9256767	Laid-up
GRACE ENERGY	Sinokor Merchant Marine	Mitsubishi	Conventional	1989	127,580	Steam	8702941	Laid-up
LNG CAPRICORN	Nova Shipping & Logistics	General Dynamics	Conventional	1978	126,750	Steam	7390208	Laid-up
LNG GEMINI	General Dynamics	General Dynamics	Conventional	1978	126,750	Steam	7390143	Laid-up
LNG LEO	General Dynamics	General Dynamics	Conventional	1978	126,750	Steam	7390155	Laid-up
LNG TAURUS	Nova Shipping & Logistics	General Dynamics	Conventional	1979	126,750	Steam	7390167	Laid-up
LNG VESTA	Tokyo Gas, MOL, Iino	Mitsubishi	Conventional	1994	127,547	Steam	9020766	Laid-up
LNG VIRGO	General Dynamics	General Dynamics	Conventional	1979	126,750	Steam	7390179	Laid-up
LUCKY FSU	Dalian Inteh	Dunkerque Normandie	Conventional	1981	127,400	Steam	7428469	Laid-up
METHANE KARI ELIN	BG Group	Samsung	Conventional	2004	136,167	Steam	9256793	Laid-up
PACIFIC ENERGY	Sinokor Merchant Marine	Kockums	Conventional	1981	132,588	Steam	7708948	Laid-up
SOUTH ENERGY	Sinokor Merchant Marine	General Dynamics	Conventional	1980	126,750	Steam	7619587	Laid-up
WILENERGY	Awilco	Mitsubishi	Conventional	1983	125,788	Steam	8014409	Laid-up
WILGAS	Awilco	Mitsubishi	Conventional	1984	126,975	Steam	8125832	Laid-up
TENAGA EMPAT	MISC	CNIM	FSU	1981	130,000	Steam	7428433	FSU
TENAGA SATU	MISC	Dunkerque Chantiers	FSU	1982	130,000	Steam	7428457	FSU
ARMADA LNG MEDITERRANA	Bumi Armada Berhad	Mitsui	FSU	2016	127,209	Steam	8125868	FSU
HILLI	Golar LNG	Rosenberg Verft	Converted FLNG	2017	124,890	Steam	7382720	Under conversion
PRELUDE	Shell	Samsung	FLNG	2017	437,000		9648714	Under construction

The main changes that can result in the conversion of an out-of-service carrier into its FSRU version include:

- New LNG pumps with lower capacity (typical capacity for LNG tankers of 12,000 m³ / h)
- Modifications of the discharge pipe manifold, installing pipes of smaller diameters.
- Installation of cryogenic hoses or loading arms.
- Installation of new auxiliary services, suitable for new functions, including power supply (either external, or by using the BOG generated in the FSU itself).
- Modification in the hull and in the propulsion systems according to the requirements of the corresponding port authority.
- Modifications in the mooring system so they can stay sheltered safely even in the most adverse weather conditions that may occur.

In the case of small scale solutions, real references are starting to be available, such as the 25,000 m³ FSRU barge from Exmar, built in the offshore Wison shipyard in Nantong (China), which already has a contract for Bangladesh with the state owned company Petrobangla to be put into operation in that country. Or the Bali installation showed some pages before.

The Exmar barge has two IMO B type aluminum tanks based on the IHI-SPB patent of 12,500 m^3 each. And with a regasification plant in its upper deck designed and built by Black & Veatch.
Other types of companies, such as the Dutch shipyard Damen, are developing solutions based on barges with IMO type C tanks, which represents a great advantage in terms of handling boil-off gas.

3.2.1.5 *Tank selection summary*

The selection of the storage volume dedicated to an auxiliary terminal will be determined by the characteristics of the port and by the demand that is generated.

According to recommendations of the main manufacturers of LNG deposits, the different types can be selected at first depending on the volume of storage.

Thus, for storage volumes of less than 250 m^3, insulated pressurized vessels will be the best option, while for storage volumes greater than 50,000 m^3, flat bottom tanks will be recommended.

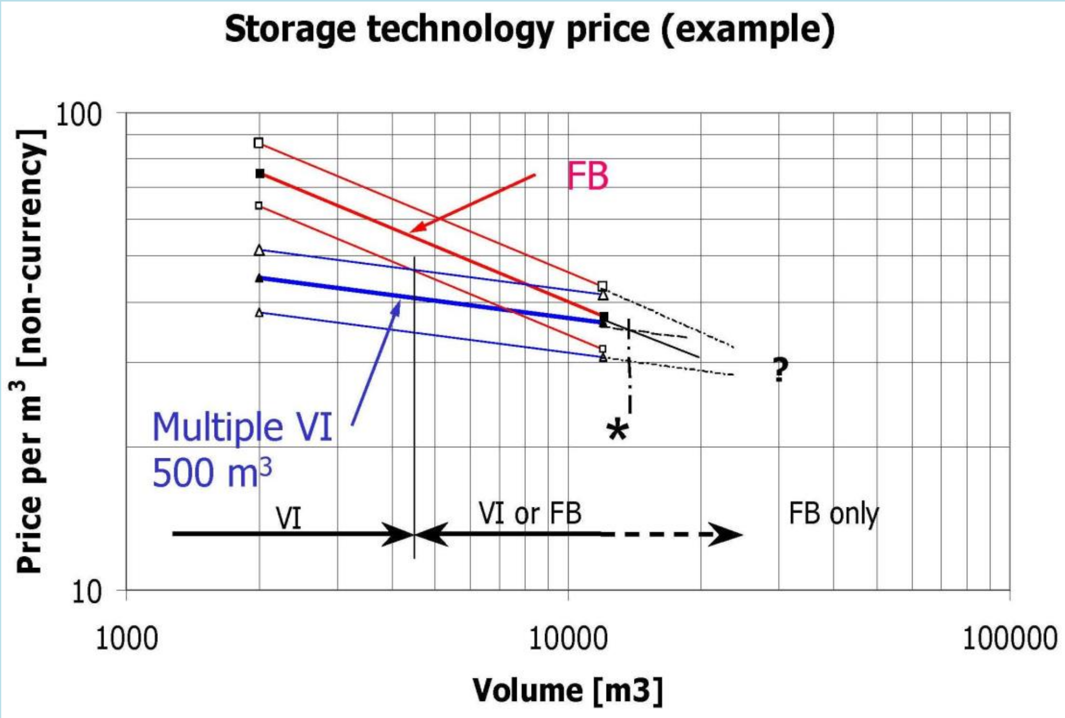
It is very important for a right selection, to consider the storage pressure in the vessels´ tanks. A ship with a low pressure tank may require sub-cooled LNG which could not be provided via pressurized tank. Additional technical solutions, such as vapour flash chamber may be required.

For the economic evaluation, the costs involved in the use of tanks with vacuum insulation or flat bottom deposits will be analysed. In the case of deposits with vacuum insulation, it is considered that auxiliary terminals can be scalable in volume using several tanks

In summary, the following table shows a comparison between the characteristics that can advise the selection of a storage system type or another.

3-4. Main characteristics for the selection of the tank type. Source: Chart-Ferox

Characteristic	Flat bottom	Insulated pressurized vessels
Ground area needed	Small	Vertical: marginally larger Horizontal: much larger
Design of concrete foundations and containment	Expensive	Lower cost
Method of manufacturing	On site with shop preparation	Shop manufactured
Lead time of work shop	Several weeks	Several weeks
Lead time of on site construction	Several months	Several days
Typical max. pressure (barg)	0.3	8
Net daily evaporation rate due to heat leak	0,05% (Spanish installed tanks)	0.06 to 0.08%/day (For vacuum insulated tank)
Need of boil-off compressors (sized to maximum)	Yes	Usually not
Consequent need of temperature and concentration profile continuous control	Yes	No



3-25. Flat bottom tank - Vacuum insulated tank, example of price comparative. Source: Chart-Ferox

As it can be seen in the picture above, it is clear that the best solution for small capacities (up to 4000 m³) is pressurized vessels. Flat bottom tanks are for higher capacities (from 20,000 m³). However, there aremiddle levels, where the best solution should be studied and carefully chosen regarding site location, schedule, modularity, labour costs… etc

As a conclusion and without entering to value the characteristics of each port or the existing or future demand, and as a preliminary step to reduce the multiple options of configuration of plants with alternatives in insulated pressure vessels and flat bottom tanks, as well as tanks with vacuum insulation in scalable plants, the typologies considered in terms of the design of storage capacity in auxiliary terminals will be the showed in the following table.

3-5. Cost per Unit of Auxiliary Terminal (Tanks, equipment and civil works associated)

Volume (m³)	Typology	Price (€)	Occupancy rate (m²)
320 m³	320 m³ Vertical Tank	944,298	2,600
1,000 m³	1,000 m³ Horizontal Tank	3,578,461	2,800
5,000 m³	5 x 1,000 m³ Horizontal Tank	17,892,306	7,000
10,000 m³	10 x 1,000 m³ Horizontal Tank	35,784,613	14,000
5,000 m³	5,000 m³ Flat Bottom Tank	8,344,613	5,625
10,000 m³	10,000 m³ Flat Bottom Tank	12,637,058	7,800
30,000 m³	30,000 m³ Flat Bottom Tank	24,413,529	15,800
50,000 m³	50,000 m³ Flat Bottom Tank	46,000,000	25,000

The occupation surfaces have been established taking as reference the footprint of the tank and the annexed surfaces necessary for the operation of the auxiliary terminal, considering the vials for the circulation of trucks and the surfaces occupied by the operating equipment of each terminal, including the building of control, racks and structures for pipes and cables.

In the case of terminals considered as scalable (with horizontal pressure tanks of 1,000 m^3 of storage capacity) for the calculation of the occupation surface, safety distances between each deposit have been considered. It is these special cases of scalable terminals, the occupancy surfaces are considerably greater than in the auxiliary terminals with flat bottom tanks, because in the case of scalable deposits there is a limitation in the diameter of the tanks, while in the flat bottom deposits the height of the same ones is much greater and safety distance is not required as it happens between scalable tanks

3.2.1.6 Pumping equipment

To ensure LNG transference from across the plant at the required flow-rates, the use of pumping equipment for LNG will be required.

Pumps that work with LNG have to be designed keeping in mind that they will work with a cryogenic fluid, to accomplish this, there are different technologies in the market to assist the different LNG processes.

The two main types of LNG pumps are:

- Submerged pumps
- Non submerged pumps:
    - Alternative pumps
    - Centrifugal pumps

Each type of pump is aimed at a different process function depending on the working conditions that are required , .

It is possible that the process requires the use of pumps that work with small flows of LNG by applying high pressures to the fluid, or it may requires the transfer of high flows of LNG at low differential pressure.

Alternative pumps and centrifugal pumps are considered as "non-submerged" pumps. The difference between submerged pumps and non-submerged pumps is that although both types of pumps need a previous cooling of the pumping system to work properly, gasifying part of the LNG during the process of pumping -avoiding cavitation during the pumping process-. The submerged pumps work inside a container full of LNG while, the non-submerged pumps need a cooling before starting to pump. This cooling is provided through a recirculation of LNG in tanks with the downstream valve closed in a first moment and retuning the BOG generated to the tank. Once the pump is cold enough to run it safely, it is started and the downstream valve is then opened, closing the recirculation.

3-26. Different Pumps system. Alternative pump, centrifugal pump and submerged pump. Source: Vanzetti

Each manufacturer has a family of pumps that groups within the types that have been defined previously and each type has different models that work in different ranges depending on each process or demand. For this study we have taken into account the data provided by one of the main manufacturers of cryogenic pumps for LNG, although the data provided can be extended to other manufacturers that produce pumps of similar characteristics.

Working points for alternative pumps:

Flow rate (lpm) max/min - (m^3/h) max/min	Maximum working pressure (barg)	Power installed (kW)
60/10 - 4/1	420	110
120/20 - 8/2	420	160
180/30 - 11/3	420	250
300/50 - 18/5	420	400

Working points for centrifugal pumps:

Flow rate (lpm) max/min - (m^3/h) max/min	Maximum working pressure (bar)g	Power installed (kW)
200/20 - 12/2	10	4
500/40 - 30/4	10	20
900/80 - 54/8	10	20
1000/80 - 60/8	10	40

Working points for submerged pumps:

Flow rate (lpm) max/min - (m^3/h) max/min	Design pressure (bar)	Power installed (kW)
300/20 - 20/2	10	10
3200/300 - 190/30	10	30
4000/500 - 240/50	10	100
7300/1000 - 440/100	10	140

From the data shown, it can be seen that for small-scale bunkering, the technology that fits better the requirements considered here are submerged pumps or non-submersible pumps of the centrifugal type. The non-submerged alternative pumps work with small flows of LNG and very large pressures, so they are recommended when final users require high pressure product and will not be considered further in this study

In addition to the working ranges of the different types of pumps, the conditions in which these pumps work also advise the type of technology that suits each bunkering process. In situations of plants that are going to carry out few operations (in the order of 1 operation per day), the cheaper cost of centrifugal pump trade-off the BOG generated during the pre-cooling process needed to start the operation. If the pump has frequent use, then it is advisable to install a submerged pump, that is always cold.

As bunkering plants will have a pattern of frequent use and should provide high flow rates for ship loading, submerged pumps are the most recommend kind of pumps. A non-submerged pump also has been included as it could be used for road tank discharging or fit with the smallest auxiliary terminal considered - 320 m^3-

Four flow rates (20, 60, 190, 440 m3 / h) have been selected for terminals considered in this study. These three models will accomplish any transfer flow required for the bunkering process.

For the valuation of costs, two kinds of pumps have been considered (centrifugal non submersible and submersible). It is very important to define the operation frequency of the pump. As discussed above, for continuous use of the equipment, submerged pumps will always be installed.

On the other hand, larger LNG tank inventories will require tighter safety rules which may include tank top connections and consequently the mandatory use of submersible pumps.

3-6. Cost per Unit of Pumping equipment

Flow (m^3/h)	Typology	Price (€)
60 m^3/h	Non submersible (Centrifugal)	77,000
20 m^3/h	Submersible	86,625
190 m^3/h	Submersible	365,750
440 m^3/h	Submersible	481,250

As an indication, the main manufacturers of pumping equipment for small-scale bunkering are named below.

- Submerged pumps: Nikkiso, Ebara, Vanzetti, Cryostar
- Non submerged Vanzetti, Cryostar

3.2.1.7 Line for transfer of LNG

To avoid heating and phase change during the LNG transfer operation between the auxiliary terminal and the ship, especially when the distance between both is large, conduction systems formed by pipes with thermal insulation are used.

There are currently several systems to ensure thermal insulation of pipes that carry cryogenic liquids at very low temperatures.

The main thermal insulation systems in LNG pipes are the following:

- Standard coating of the pipe with rigid polyisocyanurate (PIR) foamPolyurethane (PUR), Aerogels, foam glass, rock wool, etc… with coating on both sides with a metallic foil to prevent from humidity entrance. The termination will be by aluminium sheet, inox or Fibaroll or similar (Fiber reinforced polymers). The insulation of this type is removable by sections for its replacement.
- Concentric double pipe, prefabricated in workshop for assembly on site, with vacuum formation between the two pipes and with super insulating internal material.

The manufacturing and assembly systems are completely different and therefore there is also a great disparity in the cost of implementing one or the other system.

Considering that a minimum temperature transmission from the outside (normal environmental conditions) to the inner fluid (LNG) must be guaranteed, the type of insulation selection used in the pipes that conduct the LNG between the tank and the arm of loading or between the point of discharge and the tank is of maximum importance. It must also be considered the distances between the tank and the point of loading of the ship can be important.

The physical properties and therefore their effectiveness as thermal insulators will also be completely different.

3-7. Physical properties for thermal insulation

Physical properties	Air	PIR or Polyurethane	Vacuum
Thermal conductivity coefficient W/(m.K)	0,024 (*)	0,021 (**)	$5{,}48 \times 10^{-4}$ (***)

- ✓ (*) Value for natural convection.
- ✓ (**) Value for PIR or Polyurethane of 38 kg/m^3 of nominal density.
- ✓ (***) Value for High Vacuum (10^{-3} -- 10^{-7} mbar).

As can be seen in the values relative to the thermal conductivity of the systems that can be used to guarantee the maximum possible isolation in the conduction of the LNG through pipes, the efficiency of the system formed with vacuum insulated pipe is much greater than the efficiency of the system formed with insulated pipe with polyurethane foam or PIR, but cost is between 3 and 5 times greater

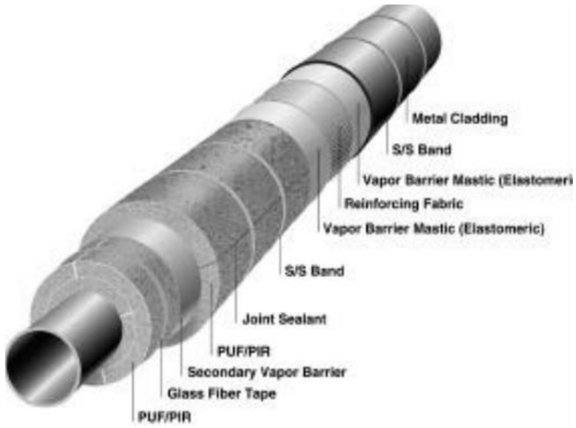
BOG handling (With compressors) is not a normal capability of terminals with pressurized vessels therefore, vacuum lines are more recommended to guarantee the optimal conditions and to avoid considerable BOG generation

Main characteristics of vacuum lines:

- Construction Code:
  - Directive 2014/68/UE.
  - Design Code: ASME B31.3 Process Piping / ASME BPV Section VIII DIV 1 /EN 13480.
  - Welding Code: ASME IX / En 287 & En 15614.
  - NDE: ASME V.
- Most common materials:
  - Pipe: ASTM A-312 Tp 304/304L / 1.4306/ISO1127.
  - Compensators: AISI 321 1.4301.
  - Insulation: Mylar aluminium + Polyester (30 layer)
  - Separator of inside and outer pipe: Epoxy + Fibreglass / PTFE.
  - Absorbents: Molecular sieve.
- Standardized for different flow rates of supply [1]:
  - 60 m^3/h - 2”
  - 130 m^3/h - 3”
  - 230 m^3/h - 4”
  - 500 m^3/h - 6”
  - 1000 m^3/h - 8”
  - 1500 m^3/h - 10”
  - 2,100 m^3/h - 12”

[1] Speed of 8 m/s (Remarkable high, but it’ is a economical consideration, as reduced diameters are needed to economize the expensive materials)

3-27. Vacuum line



3-28. PIR line

3-8. Cost per Unit of Vacuum Line

Maximum Flow (m^3/h)	Diameter (")	Price (€/m) Vacuum Line	Price (€/m) PIR + Aluminum Sheet
60 m^3/h	2"	442	156
130 m^3/h	3"	577	180
230 m^3/h	4"	1,155	212
800 m^3/h	6"	1,540	276
2,100 m^3/h	12"	2,502	476

3.2.2 *Marine LNG loading arm*

A marine loading arm allows the transfer of LNG from the storage tank to the ship.

For the loading of ships from a storage tank, it is necessary to use a hose or a marine loading arm to absorb the movements of the boat, the changes of tides, currents, wind, and many other factors. A marine loading arm provides a great improvement compared to a hose, when transferring fluids between the vessel and the dock. This loading arm provides an easier and more rangeable operation, offering a longer service life and allowing emergency disconnections without loss of product and contamination.

The marine loading arm is a system composed of rigid pipes and rotary joints for a perfect flexibility. The rotary joints are used in a variety of industrial sectors.

3-29. Loading arms. Source: Enagás

The marine loading arm is a hydraulically powered arm specially designed for loading LNG. The loading arm for LNG has a separate support structure and is designed for being used in large areas of operation with low temperatures. The main characteristics are the following:

- Nominal bores from 4" to 20". Depending on the size of the ships that will be charged.
- Operable in temperatures up to –196°C.
- Delivery pressures of up to 45 bar
- Separate counterweights for inner and outer arms.
- Special, flanged cryogenic swivel joints that do not require a special cooling rate.
- Highest level of safety with Emergency Release Couplers (ERC) and Quick Connect/Disconnect Couplers (QCDC).

Major codes and regulations for Marine LNG loading arm:

- OCIMF - Design & Construction Specification for marine loading arms, Edition 1999
- ANSI B 31.3 Petroleum Refinery Piping
- ASME VIII Pressure Vessels Div. I
- ASME IX Welding Qualifications
- PED Pressure Equipment Directive
- EN1474 Installation of equipment for liquefied natural gas Design and testing of marine transfer systems (for parts, which are applicable for a manual bunkering arm design)

The loading arm considered in this chapter is an equipment used to load LNG to the ship from the storage tank. This loading arm does not allow the transfer of LNG from the ship to the storage tank. The loading arm has been designed for correct operation when working in the direction of the impulsion of the pump located in the auxiliary terminal.

For the filling operation of the auxiliary terminal tank from the tanker-ship, it is necessary that the ship itself carries a group of pumps for the transfer of the LNG and its own coupling hoses to the load lines from the berth to the LNG tank of the terminal.

3-9. Cost per Unit of Loading Arm

Maximum Flow (m3/h)	Diameter (")	Price (€/m)
250 m^3/h	4"	-
500 m^3/h	6"	948,200
1,000 m^3/h	8"	1,203,788
1,500 m^3/h	10"	-

The prices of two loading arms operating at present and current supply have been taken as reference. With these two models and with the combination of several of them in the same terminal, it is possible to undertake the bunkering process in any ship.

It is possible to build loading arms with different capacities. In any case to consider other capacities or types of loading arms, it would be necessary to make a study and an in-depth analysis of the characteristics and conditions of the port where it is to be installed. The values included in the study, are therefore real costs of loading arms that are being used in ports at present and that have been designed for those specific ports.

Each auxiliary terminal requires the installation of a loading arm for the LNG filling in the ship and a different loading arm for the return of BOG to the tank from the ship.

3.2.3 Deployable Manifold System with ERS (Emergency Release System) for LNG load

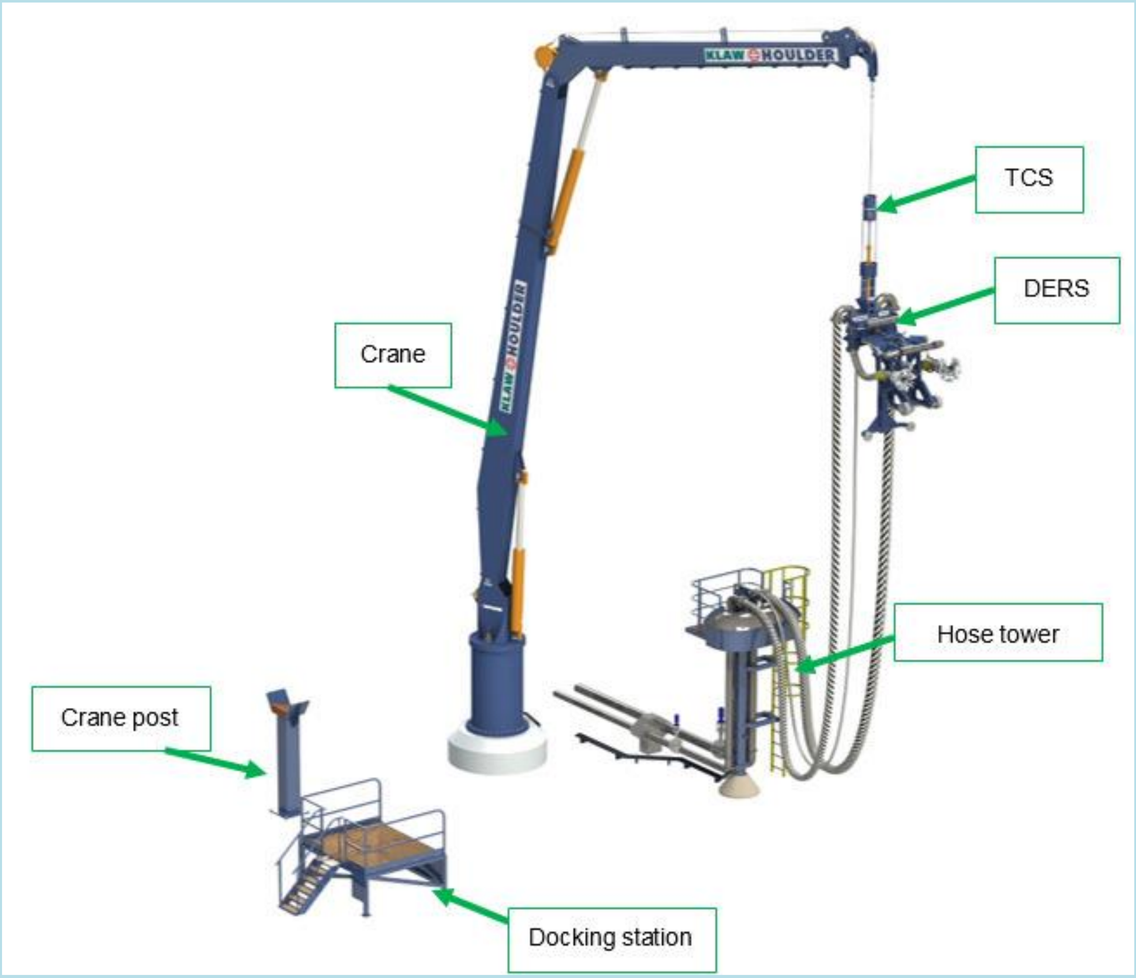
As a possibility of future implementation, it will be considered the implantation of hybrid cranes with LNG loading hoses with break-away safety devices.

The Hybrid Crane for LNG bunkering, Quayside-to-Ship (QTS) solution is designed to satisfy the requirements of the emerging LNG bunkering market for Shore-to-Ship configurations. It employs standard safe, reliable and proven cryogenic components in line with regulations and current industry best practice to deliver a valuable LNG transfer system.

The Hybrid Crane QTS solution consists of:

- A flexible hose base bunker system
- An efficient deployment, connection & disconnection system
- A safe, monitored and controlled SIL 2 Emergency Shutdown System

This results in a cost-effective design with multiple capabilities.



3-30. Hybrid crane with hoses for LNG. Source: HOULDER KLAW LNG

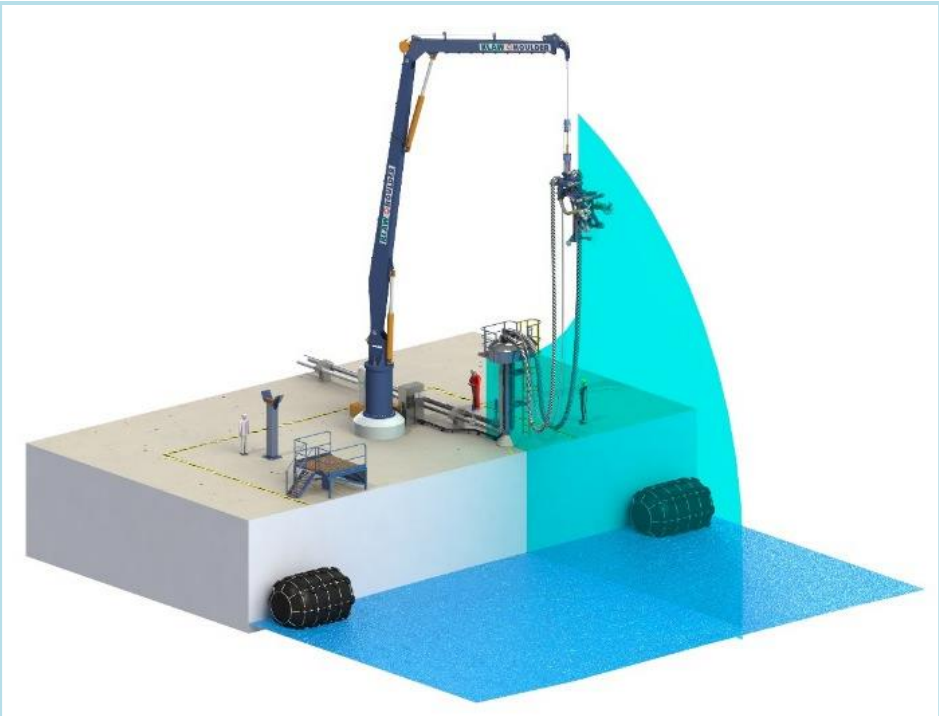
Note:

TCS Tensioner and Compensating System

DERS Emergency Release System

The Hybrid Crane QTS is designed with the aim of improving the shore side transfer team experience in handling hoses and cryogenic equipment while at the same time to reduce the requirements on the Receiving Vessel (LNG Fuelled Vessel). The key features are:

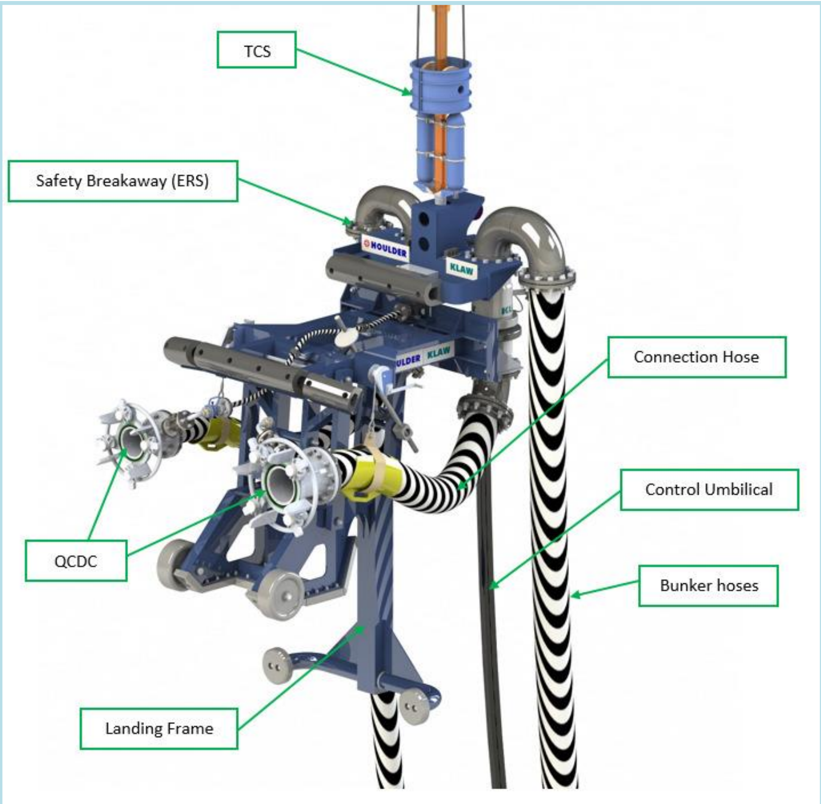
- *Flexibility:* The system is compatible with a range of manifold configurations and positions on receiving vessels. This allows for transfer or bunkering to a wide range of vessels in the future.
- *Hydraulic Powered ERS (Emergency Release System):* Incorporates a hydraulically powered "active"
- Emergency Release System (ERS). This ensures the highest level of operational safety.
- *Dry-Coupler Connection:* Incorporates cryogenic Auto-sealing Dry-coupler for quick connection and disconnection.
- *ESD (Emergency Shutdown) functionality:* Fully supports the standard SIL2 ESD1 (Emergency Shutdown Stage 1 - shuts down the LNG supply operation in a quick controlled manner by closing the shutdown valves, and stopping the transfer pumps and other relevant equipment in ship and shore systems) and ESD2 (Emergency Shutdown Stage 2 - shuts down the transfer operation ESD 1 and uncouples the transfer system after closure of ERS isolation valve/s) functionality. Once the ESD2 signal is triggered, the system performs an emergency disconnection.
- *Controlled Manifold Loads:* The system eliminates the loads being transmitted to the Receiving Vessel manifolds and Dry-coupler, removing risk of spillage at the Receiving Vessel manifold connection.
- *Self-Contained:* The system does not require any additional rigging of hoses to conduct transfer operations, thus reducing time between transfers.
- *Two Lines:* The system is supplied with two transfer lines, maximizing the system's potential transfer rate or allowing for concurrent handling of liquid and vapor.
- *Ease of Operation:* Being based on a standard ship's crane, the KHobra is easy to deploy, connect and recover reducing the amount of operator training required.
- *Ease of Maintenance:* There are no cryogenic swivel joints making the system easily maintainable and allowing quick replacement of bunkering hoses.



3-31. Hybrid Crane KHobra QTS Typical Quay Installation. Source: HOULDER KLAW LNG

The main components of the system are the followings:

1.- DERS Manifold Assembly



3-32. Hybrid Crane KHobra QTS Coupling system components. Source: HOULDER KLAW LNG

- Gas System. With composite flexible cryogenic transfer hose; safety breakaway couplers (Klaw active ERS valve).
- Electrical System. All equipment and materials for operation in the marine environment; intrinsically safe circuit cables are used; electrical equipment in accordance with ATEX directive.
- Tensioning and Compensating System. Developed specifically for bunkering applications.

2.- Control and Safety System

3.- Handling Crane

4.- Additional System Options

The system considered is an equipment used to load LNG to the ship from the storage tank and it can be used in operations Ship to Ship if it is installed over the vessel ship.

3-10. Cost per Unit of Hybrid Crane KHobra QTS

Maximum Flow (m3/h)	Diameter (")	Price (€/m)
500 m^3/h	6"	1,185,641
1,000 m^3/h	8"	1,391,794

Capacity available ranges from 6” to 20”

These are two examples of different Hybrid Crane (loading capacities are similar to those considered in the loading arms section).

3.2.4 Truck Station

The loading procedure for LNG road tanks are regulated by the RD 91/2014 of February 14 th and to be performed in a Spanish import terminal, the GNL supplier must be complied with the “Protocolo de detalle PD-12 Logistica de cisternas de GNL”, belonging to the normative protocole to third party access in Spanish LNG import terminals.

To a deeply understanding of how this procedure is performed properly it should be readed:

- “Especificaciones técnicas de SEDIGAS para conductores de cisternas que realizan descargas de GNL. Unidad 07. Sedigas Julio/2017”
- “Protocolo de detalle PD-12 Logistica de cisternas de GNL”

As complementary equipment in the auxiliary storage modules for those ports that do not have an import terminal, these stores will be provided, where appropriate, from an island or Truck Station for LNG tanker trucks. The truck Station is the same as exists in the Import Terminals, considering in this case that it can only service a tanker at the same time.

The charging method will be that of connection by cryogenic hose.

The charge rate of LNG tanks shall be approximately one tank per hour.

The Truck Station for trucks will have a loading capacity of 15 trucks per day in only one bay.

3-33. Loading Station

For the loading of tanker trucks or containers, there will be an entrance of the cistern delimited by a structure with the necessary safety measures (fire equipment, cryogenic loading hoses with break-away devices...).

3-11. Cost per Unit of Loading Bay for 1 truck

Loading Bay for 1 Truck	Price (€)
Materials for loading	2,064,667
Rest equipments and materials	785,333
Supervision and inspection	106,666
Engineering and Legalization	285,000
TOTAL PRICE	**3,241,666**

3.2.5 *Land-Sea Interface*

The land sea-interface will allow the connection and safe transfer from the terminal to sea (PTS) and the reverse: reloading the terminal from a feeder vessel. Modeling cost for such interface is rather difficult as it highly depends on the existing infrastructure, depth, sea conditions, soil type, etc.

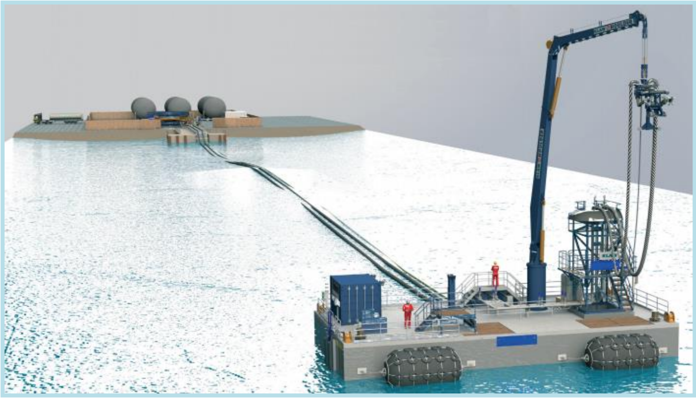
There will be cases where an auxiliary terminal could reuse existing berth infrastructure, required a new development and there are new alternatives to use floating interfaces to reach anchored vessels.

For the berthing of the boats to be used in the LNG loading procedure, it can be done using three types of facilities:

1- **Berth:**
The ships will dock in an existing berth near the auxiliary terminal. This option could be the best choice to integrate a cargo or passenger terminal with its own dedicated LNG auxiliary terminal. The land spaced across the quay could be shared with other port activities, in those cases the piping, safety perimeter and loading arm should be movable to liberate the space for other operations. An option is to bury piping for faster and safer connection. Alternative the berth could become dedicated under a permanent concession allowing for a fixed superstructure setting.

2- **Jetty:**
The ships will dock in a jetty existing (onshore or offshore) which should be adapted to develop the LNG cargo, these new facilities should allow the development of the usual operations of the port, for this reason all the facilities should be installed in recordable manhole that will allow the connection of the ships.
On the other hand, the construction of new jetty intended for LNG cargo should be evaluated, these should be installed in an area that allows easy access to the ships, in addition to having all the facilities for the proper development of operations (loading arm, mooring load monitoring system, a berthing aid system and an environmental monitoring system., ESD, etc).

3- **Jettyless:**
This installation has been developed to enable the transfer of LNG from small- to mid-scale carriers to onshore or floating storage terminals where it is not feasible to construct a jetty for mooring the vessel. This may be because the water is either too shallow for the ship, or too deep for a jetty to be built. The transfer of LNG takes place using floating hoses. When not in use, the hoses are stored onshore with a reel system. The jettyless represents a low investment and quick installation solution in situations where the cost of building a jetty is prohibitive.



3-34. Jettyless LNG. Source: Wärtsilä

As for the costs associated with the adequacy or construction of the facilities described, these should be analyzed for the particularities of the ports where the installation is planned, because the characteristics of these and the ships that will develop the operations cause the related costs vary a large degree.

In the Excel spreadsheet, accompanying this document a suggested cost will be provided as a reference to compare the alternative solutions. The common superstructure cost (piping and loading arm) was allocated to the auxiliary terminal, leaving this way the land-sea interface costs related only to infrastructure.

Bear in mind that not all alternatives would be available to all ports, and not all alternatives would be viable based on the expected demand.

3.2.6 Calculation of costs for Auxiliary Terminals

To proceed with the assessment of the most appropriate supply chain model for each scenario, the costs of implementation of the auxiliary terminals as an alternative system for the storage of LNG, will be explained before used in the calculation tool.

The costs shown include the storage tank and the units of civil, mechanical and electrical equipment costs associated with that storage model.

For further assessment, the area of occupancy and the limit marked by the distance of security according to the regulation (UNE 60210 in the storage up to 1,500 m^3), is included in each of the different capacity scenarios assessed.

The area generated by safety distances required by regulation, will not be considered as a cost of concession or rent. It will be the Port Authority's decision to determine which cases should be considered for security or other distance considerations in accordance with Port security regulations.

Prices used for the valuation of vertical and horizontal flat bottom tanks are as of September 2017 and represent the average price from the largest tank manufacturers. These prices should be reviewed periodically, since changes in the price of the tank's raw materials may influence changes on tanks prices.

Civil works cost for vertical and horizontal pressured tanks, includes the cost of construction of both foundation basis and walls for the containment cube. The height of the wall will depend on the projected volume of each tank.

The pressure design considered for the pressured tanks is 5 bar. Regarding the design of the storage tank, submerged pumps for filling operations will be the selected as the best functional option.

The control box for the plant will be placed in building constructed for this propose. This cost, along with the plant's electrical and control costs, will be included in the total cost of execution.

The storage tanks will include all the LNG inlet and outlet valves, manifold for safety valves, control instrumentation and everything necessary for the perfect functioning and operation of the storage installation.

The study of **CAPEX and OPEX** will be divided into those assigned to the storage tank and auxiliary equipment (pumps and insulated piping), those assigned to the loading arm and those assigned to the tanker loading station.

Five storage capacities have been considered for the auxiliary terminals. The load capacity (m^3/h) of these terminals will be used as the selection criteria for both the pumping equipment and the capacity of isolated pipes needed for LNG transport operations.

Capacity and typology of storage considered:

- 320 m^3 (Vertical Vacuum Insulated Tank)
- 1,000 m^3 (Horizontal Vacuum Insulated Tank)
- 5 x 1,000 m^3 (Horizontal Vacuum Insulated Tank)
- 10 x 1,000 m^3 (Horizontal Vacuum Insulated Tank)
- 5,000 m^3 (Flat bottom tank)
- 10,000 m^3 (Fat bottom tank)
- 30,000 m^3 (Flat bottom tank)

3-12. Reference values for sizing Auxiliary Terminals

Storage Capacity (m^3)	Typology	Pump Capacity (m^3/h) and number of pumps	Diameter vacuum pipe (") and pipe length
320	Vertical Tank	20 x (3)	3" x 200 ml
1,000	Horizontal Tank	20 x (4)	3" x 200 ml
5 x 1,000	5 x Horizontal Tank	190 x (2)	6" x 400 ml
10 x 1,000	10 x Horizontal Tank	190 x (3)	6" x 400 ml
5,000	Flat Bottom Tank	190 x (2)	6" x 400 ml
10,000	Flat Bottom Tank	190 x (3)	6" x 400 ml
30,000	Flat Bottom Tank	440 x (4)	12" x 400 ml

The financial reference terms used to calculate the costs are as shown below:

3-13. Financial Reference Terms

	Term amortization (years)	Type interest (%)	Residual Value (% of Capital)	Useful life (Years)
Storage tank	20	4.50	7.00	35
Pump equipment	10	4.50	0.00	12
Piping	5	4.50	0.00	20
Jetty	20	4.50	7.00	30
Loading arm	10	4.50	0.00	20
KHobra QTS	10	4.50	0.00	20
Truck Station	10	4.50	7.00	20

With these financial terms capital costs and investments necessary for each type of Auxiliary Terminal were calculated. This capital cost will be split in four components: Tank (and associated equipment), Loading arm, Jetty and Truck Station.

For the calculation of operational costs, the cost of personnel depending on the type of terminal and the costs associated to insurance and maintenance of the equipment have been considered.

For the operation of each plant the following personnel has been considered:

- Auxiliary Terminal with 320-1,000 m^3 of storage capacity will count with 6 workers (2 workers in 3 turns). 1 worker will control tank and 1 worker will control the truck station and the loading arm.
- Auxiliary Terminal with 5 x 1,000 m^3 of storage capacity will count with 9 workers (3 workers in 3 turns). 2 workers will control tank and truck station and 1 worker will control the loading arm.
- Auxiliary Terminal with 10 x 1,000 m^3 of storage capacity will count with 12 workers (4 workers in 3 turns). 3 workers will control tank and truck station and 1 worker will control the loading arm.
- Auxiliary Terminal with 5,000-10,000 m^3 of storage capacity will count with 9 workers (3 workers in 3 turns). 2 workers will control tank and truck station and 1 worker will control the loading arm.
- Auxiliary Terminal with 30,000 m^3 of storage capacity will count with 12 workers (4 workers in 3 turns). 3 workers will control tank and truck station and 1 worker will control the jetty.

The cost of personnel will be divided between the loading-unloading operations of the storage tank, as well as the operation of the load arm and the operations within the load station.

As can be seen in the table of economic analysis of the implantation of auxiliary terminals according to different types, the fixed operating costs are very high in small plants (320 m^3 and 1,000 m^3), in plants of scalable type (5 x 1,000m^3 and 10 x 1,000m^3) are adjusted to acceptable ratios of investment/fixed operating cost, while in plants with flat bottom tanks the costs are elevated in those of 5,000m^3 and are adjusted more in the capacity of 10,000m^3 and 30,000m^3.

This is because when considering in all cases three operating shifts in the terminals to guarantee 24h of operation, the operating costs are excessive in the small terminals, while in the terminals of scalable type and in those that have deposits of flat storage of large capacity, these personnel costs are more acceptable considering the investment to be made for the implementation of each terminal.

As it was mentioned in the section "Tank Selection Summary", the occupation surfaces have been established taking as reference the footprint of the tank and the annexed surfaces necessary for the operation of the auxiliary terminal, considering the vials for the circulation of trucks and the surfaces occupied by the operating equipment of each terminal, including the building of control, racks and structures for pipes and cables. In the economic table, also is considered the cost of rental of the surface of the port necessary for the implementation of the auxiliary terminals, the area needed for the loading bay of tankers trucks.

Costs shown in the table below are annualized costs including the financing and amortization terms defined above.

3-14. Breakdown of investment costs by model of Auxiliary Terminal

Tank storage Volume (m3)	1 x 320 m³ Vertical Tank	1 x 1,000 m³ Horizontal Tank	5 x 1,000 m³ Horizontal Tank	10 x 1,000 m³ Horizontal Tank	1 x 5,000 m³ Flat Bottom Tank	1 x 10,000 m³ Flat Bottom Tank	1 x 30,000 m³ Flat Bottom Tank
Occupancy rate for Plant (tank) (m²)	2,600	2,800	14,000	28,000	5,625	7,800	15,800
Price for Storage tank, auxiliary equipment and civil work (€)	**944,298**	**3,578,461**	**17,892,306**	**35,784,613**	**8,334,117**	**12,637,058**	**24,413,529**
Pump equipment (m³/h)	3 x 20	4 x 20	2 x 190	3 x 190	2 x 190	3 x 190	4 x 440
Price pump equipment (€)	**259,875**	**346,500**	**731,500**	**1,097,250**	**731,500**	**1,097,250**	**1.925,000**
Piping pump to ship	100 ml x 3" isolated pipe	100 ml x 3" isolated pipe	200 ml x 6" isolated pipe	200 ml x 6" isolated pipe	200 ml x 6" isolated pipe	200 ml x 6" isolated pipe	200 ml x 12" isolated pipe
Price for Piping (€)	**57,750**	**57,750**	**308,000**	**308,000**	**308,000**	**308,000**	**500,500**
Loading arm (m3/h)	2 x 500	2 x 500	2 x 500	2 x 1,000	2 x 500	2 x 1,000	4 x 1,000
Price for Loading Arm (€)	**1,896,400**	**1,896,400**	**1,896,400**	**2,407,576**	**1,896,400**	**2,407,576**	**4,815,152**
Occupancy rate for Truck Station (m²)	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Price for Truck Station (for 1 truck) (€)	**3,241,666**	**3,241,666**	**3,241,666**	**3,241,666**	**3,241,666**	**3,241,666**	**3,241,666**
INVESTMENT (€)	**6,399,989**	**9,120,777**	**24,069,872**	**42,839,105**	**14,511,683**	**19,691,550**	**34,895,847**

3-15. Costs of Auxiliary Terminal

	VACUUM INSULATED TANKS				FLAT BOTTOM TANKS		
	320 m3	1000 m3	5 x 1000 m3	10 x 1000 m3	5000 m3	10000 m3	30000 m3
OPERATIONAL FIXED COST	**309.039 €**	**340.761 €**	**657.271 €**	**1.063.850 €**	**518.255 €**	**597.713 €**	**876.557 €**
PERSONNEL	**172.800 €**	**172.800 €**	**259.200 €**	**345.600 €**	**259.200 €**	**259.200 €**	**345.600 €**
TANK	86.400 €	86.400 €	86.400 €	172.800 €	86.400 €	86.400 €	172.800 €
LOADING BAY	43.200 €	43.200 €	86.400 €	86.400 €	86.400 €	86.400 €	86.400 €
TRUCK STATION	43.200 €	43.200 €	86.400 €	86.400 €	86.400 €	86.400 €	86.400 €
INSURANCE	**32.230 €**	**48.035 €**	**133.918 €**	**242.508 €**	**76.569 €**	**103.623 €**	**174.284 €**
TANK	5.666 €	21.471 €	107.354 €	214.708 €	50.005 €	75.822 €	146.481 €
LOADING BAY	7.114 €	7.114 €	7.114 €	8.351 €	7.114 €	8.351 €	8.353 €
TRUCK STATION	19.450 €	19.450 €	19.450 €	19.450 €	19.450 €	19.450 €	19.450 €
MAINTENANCE	**27.133 €**	**40.304 €**	**126.873 €**	**242.365 €**	**64.082 €**	**86.628 €**	**98.587 €**
TANK	14.721 €	27.892 €	114.462 €	228.923 €	51.671 €	73.185 €	78.185 €
LOADING BAY	5.928 €	5.928 €	5.928 €	6.959 €	5.928 €	6.959 €	13.918 €
TRUCK STATION	6.483 €	6.483 €	6.483 €	6.483 €	6.483 €	6.483 €	6.483 €
T-C	**64.064 €**	**66.352 €**	**114.400 €**	**194.480 €**	**98.670 €**	**123.552 €**	**215.072 €**
T-A	**12.813 €**	**13.270 €**	**22.880 €**	**38.896 €**	**19.734 €**	**24.710 €**	**43.014 €**
CAPITAL COST	**554.140 €**	**743.935 €**	**1.820.488 €**	**3.150.044 €**	**1.169.825 €**	**1.569.993 €**	**2.743.567 €**
TANK	**99.227 €**	**289.022 €**	**1.338.882 €**	**2.605.347 €**	**688.219 €**	**1.025.296 €**	**1.949.618 €**
STORAGE	**64.956 €**	**245.380 €**	**1.226.901 €**	**2.453.802 €**	**576.237 €**	**873.751 €**	**1.688.000 €**
DEPRECIATION	25.296 €	102.242 €	511.209 €	1.022.418 €	226.212 €	343.006 €	662.653 €
FINANCIAL	39.660 €	143.138 €	715.692 €	1.431.385 €	350.026 €	530.745 €	1.025.347 €
PUMPS	**28.111 €**	**37.482 €**	**79.128 €**	**118.692 €**	**79.128 €**	**118.692 €**	**208.231 €**
DEPRECIATION	18.408 €	24.544 €	51.815 €	77.722 €	51.815 €	77.722 €	136.354 €
FINANCIAL	9.703 €	12.938 €	27.313 €	40.970 €	27.313 €	40.970 €	71.877 €
PIPING	**6.160 €**	**6.160 €**	**32.853 €**	**32.853 €**	**32.853 €**	**32.853 €**	**53.387 €**
DEPRECIATION	3.850 €	3.850 €	20.533 €	20.533 €	20.533 €	20.533 €	33.367 €
FINANCIAL	2.310 €	2.310 €	12.320 €	12.320 €	12.320 €	12.320 €	20.020 €
LOADING BAY	**171.789 €**	**171.789 €**	**198.483 €**	**261.573 €**	**198.483 €**	**261.573 €**	**510.826 €**
LOADING ARM	**165.629 €**	**165.629 €**	**165.629 €**	**228.720 €**	**165.629 €**	**228.720 €**	**457.440 €**
DEPRECIATION	94.820 €	94.820 €	94.820 €	120.379 €	94.820 €	120.379 €	240.758 €
FINANCIAL	70.809 €	70.809 €	70.809 €	108.341 €	70.809 €	108.341 €	216.682 €
PIPING	**6.160 €**	**6.160 €**	**32.853 €**	**32.853 €**	**32.853 €**	**32.853 €**	**53.387 €**
DEPRECIATION	3.850 €	3.850 €	20.533 €	20.533 €	20.533 €	20.533 €	33.367 €
FINANCIAL	2.310 €	2.310 €	12.320 €	12.320 €	12.320 €	12.320 €	20.020 €
TRUCK STATION	**283.123 €**	**283.123 €**	**283.123 €**	**283.123 €**	**283.123 €**	**283.123 €**	**283.123 €**
DEPRECIATION	162.083 €	162.083 €	162.083 €	162.083 €	162.083 €	162.083 €	162.083 €
FINANCIAL	121.040 €	121.040 €	121.040 €	121.040 €	121.040 €	121.040 €	121.040 €
MARGIN (%)	**129.477 €**	**162.704 €**	**371.664 €**	**632.084 €**	**253.212 €**	**325.156 €**	**543.019 €**
TOTAL FIXED COSTS	**992.656 €**	**1.247.400 €**	**2.849.423 €**	**4.845.978 €**	**1.941.291 €**	**2.492.862 €**	**4.163.143 €**
FIXED COSTS (€/day)	**2.720 €**	**3.418 €**	**7.807 €**	**13.277 €**	**5.319 €**	**6.830 €**	**11.406 €**
VARIABLE COST	**15.768 €**	**21.024 €**	**31.536 €**	**47.304 €**	**31.536 €**	**47.304 €**	**105.120 €**
PUMPING COST (€/m^3)	15.768 €	21.024 €	31.536 €	47.304 €	31.536 €	47.304 €	105.120 €

CAPACITY (m3)	**320**	**1.000**	**5 x 1.000**	**10 x 1.000**	**5.000**	**10.000**	**20.000**
INVESTMENT	**6.399.989 €**	**9.120.777 €**	**24.069.872 €**	**42.839.105 €**	**14.511.683 €**	**19.691.550 €**	**34.895.847 €**

REGULATED FEES AND OTHER COSTS		
FEE	**Units**	**Cost**
T-3	tons supplied	0,80 €

3-35 Cost of sea-land interface

LAND SEA INTERFACE COST MODEL					
	Existing not dedicated berth infrastructure	Existing dedicated berth infraestructure	Adaption of jetty	Newbuilding jetty	Jettyless
OPERATIONAL FIXED COST					
INSURANCE	-	18,000 €	18,000 €	90,000 €	?
MAINTENANCE	-	45,000 €	45,000 €	225,000 €	?
T-C	-	80,080 €	114,400 €	114,400 €	?
T-A		16,016 €	22,880 €	22,880 €	
CAPITAL COST	-	181,500 €	181,500 €	948,000 €	?
DEPRECIATION	-	60,000 €	60,000 €	300,000 €	?
FINANCIAL	-	121,500 €	121,500 €	648,000 €	?
TOTAL COSTS	-	340,596 €	381,780 €	1,400,280 €	-
COSTS (€/day)	-	933 €	1,046 €	3,836 €	-
UNLOAD COST JETTY (€/u)					
INVESTMENT	-	3,000,000 €	3,000,000 €	15,000,000 €	-

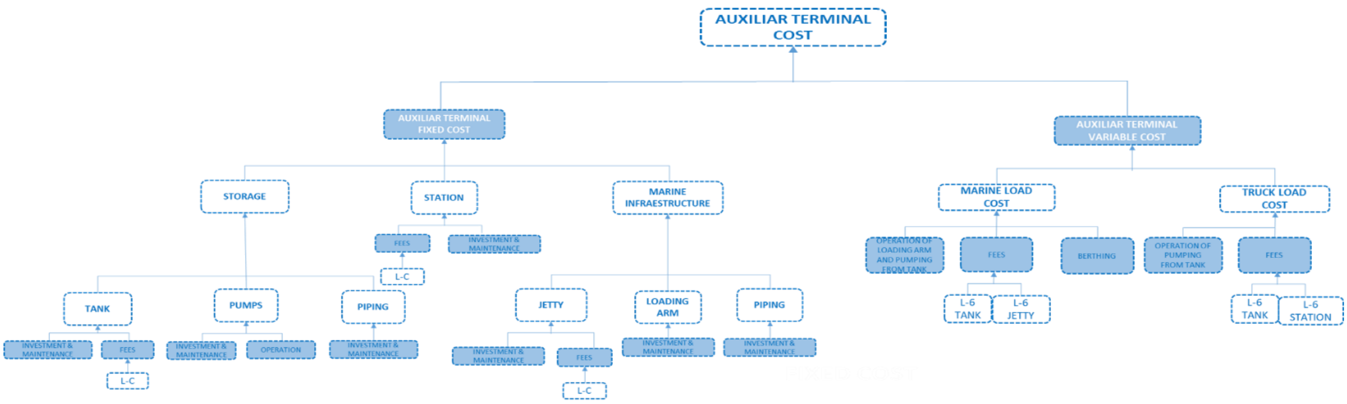
As it was previously mentioned, when implementing Auxiliary Terminals, safety distances to different risks indicated in regulation must be taken in to account. In this case, Norm UNE 60210 for the definition of the safety distances for storage capacity up to 1,500 m^3 was used as the normative reference.

Norm UNE 60210 defines the different risks that must be addressed, and the safety distances involved with these risks, depending on the storage volume. All these safety distances will be met up to a maximum storage volume of 1,500 m^3.

In addition, ports will impose their own safety rules and regulations for the storage of combustible such as LNG. For storage capacities greater than 1,500 m^3, other safety regulations and conditions shall be considered. In any case, it will always be the port authority who decides on the application of other safety distances and the assembly of other surveillance and safety devices.

Considering all the items described above are put together they conform an auxiliary terminal capable of loading/unloading vessels and trucks, store LNG and provide bunkering via port-to-ship just as big-scale terminals. Understanding the costs involved in the auxiliary terminal is essential for a good analysis of the final costs involved in every logistic chain, since the final cost per ton of every means of bunkering is going to be affected by the cost of auxiliary terminal.

3-36 Auxiliary terminal scheme cos



3.3 SMALL SCALE LIQUEFACTION PLANTS

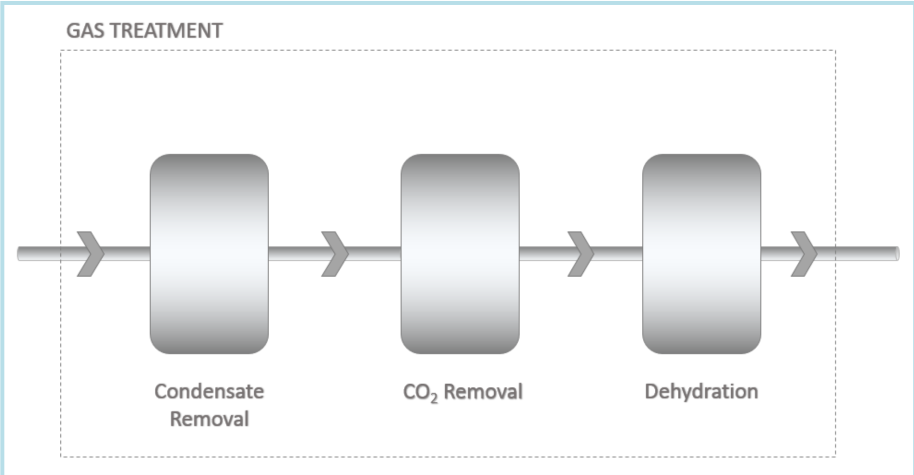
Small scale liquefaction plants are used when natural gas is fed from the local pipeline.

3.3.1 Liquefaction process

The steps of the liquefaction process in small scale liquefaction equipment are:

- Prior to liquefying the gas, processing and cleaning is needed. For the initial processing of the gas, pressure swing adsorption technology is used.

  The main gas conditioning technologies for LNG are:
  Acid gas removal (for H2S, mercaptans and CO2) - to prevent downstream corrosion and freezing and meet product specifications, Dehydration - to prevent downstream freezing



3-37. Gas treatment PFD. Source: ICC Ingenieros

  The cleaning process is critical to avoid dry ice in the system that would otherwise clog up heat exchangers, pumps and others equipment. For this reason, it is necessary to introduce this process before the liquefaction and thus ensure the proper functioning of the equipment.

- The first cooling sequence is carried out in a regular cooling system. This will bring the natural gas to a temperature of approx. -50°C.
- From the pre-cooling system, the natural gas is led to the cold-boxes.
- From the cold-boxes, the now liquefied natural gas (LNG) at a temperature of -150°C is sent to storage tanks on site.
- Expansion to accommodate the gas to storage temperature if its needed
- This storage tank allows the distribution of LNG to off-site clients.

3.3.2 Small-scale liquefaction plants

Small-scale liquefaction plants are an increasingly attractive complement to large scale LNG infrastructure.

Technological advances have made monetization of small and stranded gas reserves possible in new locations. This opens the door for business owners and energy companies to take advantage of the growing LNG market.

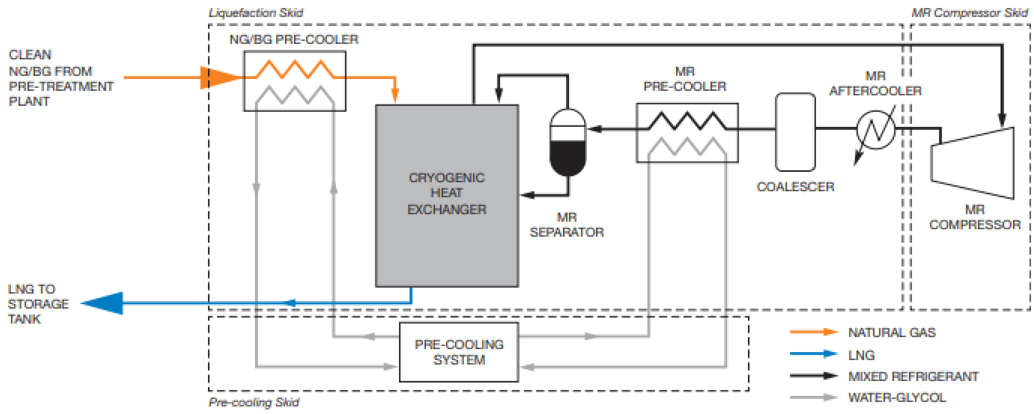
Small-scale liquefaction plants presents 2 uses mainly:

- Production of LNG to be transported or used by a vehicle as a fuel
- Mini liquefaction plants to avoid BOG losses

Like in big-scale liquefaction, there are a few process technologies available, being the key difference between them, which refrigerant is used to chill the natural gas. For small and mid scale applications, the most popular technologies are:

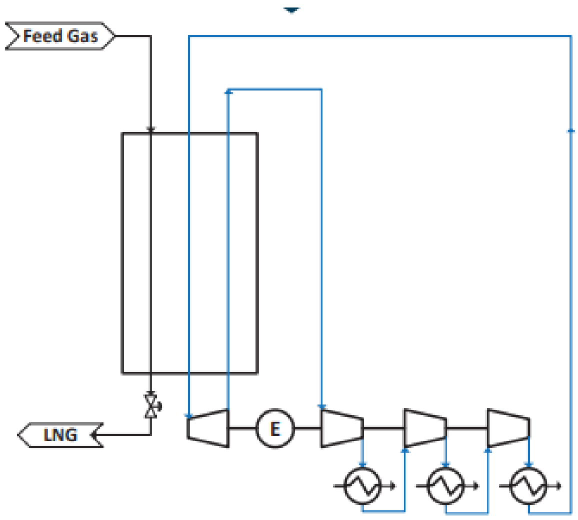
- **Liquefaction with single mixed refrigerant (SMR)**

  The most popular process for small-scale liquefaction. Presents a low energy consumption but could not be suitable for low and/or unstable demands



- **Liquefaction with liquid nitrogen**

  Mainly used to small applications like re-liquefaction of BOG in LNG vessels as consumes more power than the MR cycle with continuous baseload.



With similar capital costs, the key point to choose between this technology would be operative costs. N_2 solutions offers significant startup time reductions, wide partial-load capabilities and no make-up needed On the other hand MR processes offers more efficiency but, narrow partial-load capabilities and large startup times. So, with less operating hours and unstable flow (BOG reliquefaction) , N2 solution is preferable, but if operation is close to the baseload and continuous MR solutions are more efficient.

3.3.3 *Small-scale liquefaction technology selected*

Technical description and main characteristics:

3-16 Technical description and main characteristics of small-scale liquefaction

Capacity	14 – 219 TPD
Operation pressure	Minimal 11 bar
Manufacturing method	Pre-fabricated in factory
Gas source	Pipeline gas
Complete plant, including	Gas pre-treatment (Condensate Removal, CO_2 Removal, Dehydration) Liquefaction process Cooling system Electrical and control systems
Energy consumption	Around 347 kWh/m^3 LNG -and 586.5 kWh/ m^3 LNG
Required surface	Around 167 m^2 and 450 for skid

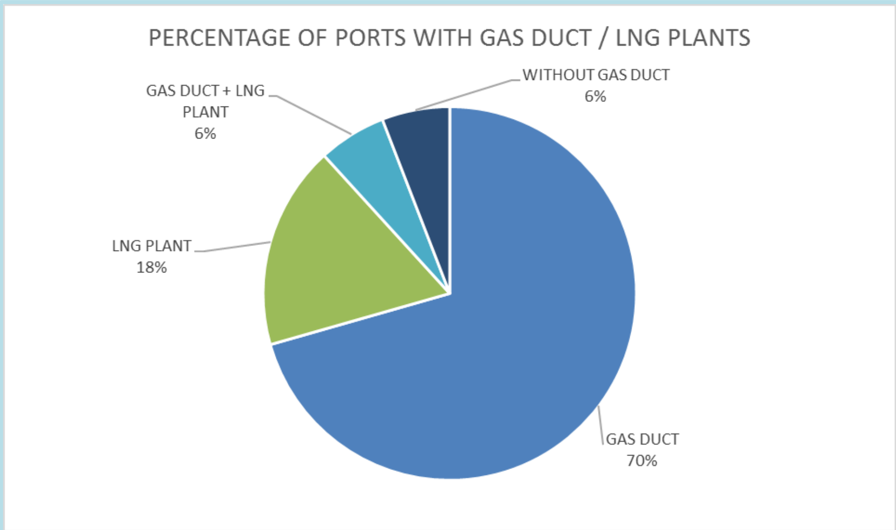
3-38. Small scale liquefaction plant. Source: Galileo/Cryostar

3.3.4 Auxiliary installations for liquefaction plants

For the operation of the liquefaction plants, it will be necessary to install a branch of an existing gas pipeline near the port, which will supply NG to this equipment's to produce LNG.

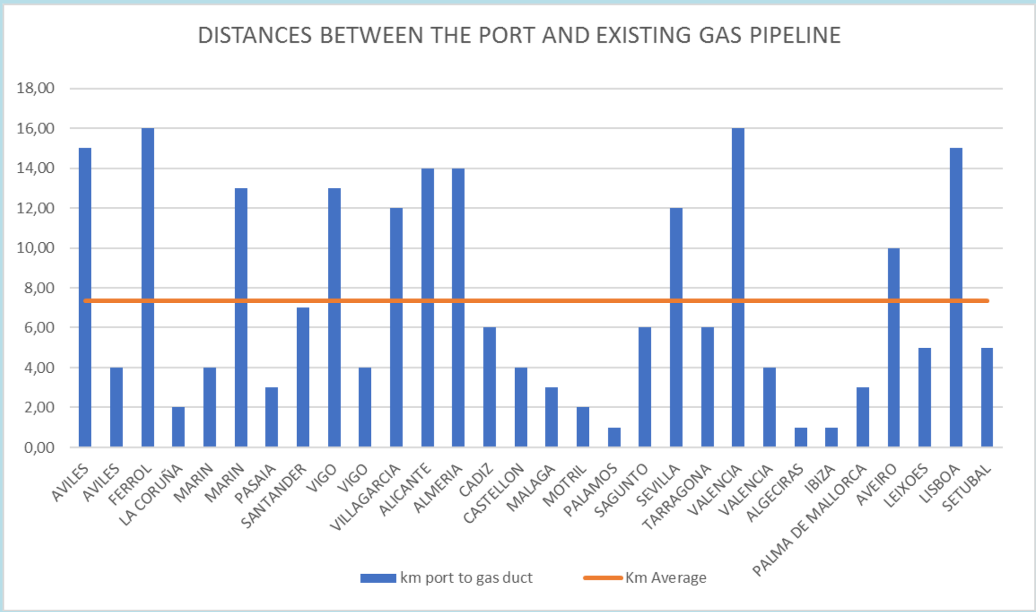
Some ports object of "Core LNGas Hive" count in proximity to sections of the gas pipeline network of the Iberian Peninsula, which makes feasible liquefaction system for the generation ports for ship´s LNG supply.

Of the 46 ports corresponding to the study, 12 of these do not have data on gas pipeline/LNG plants in the zone. However, of the remaining 34 ports, 50% have a near gas pipeline, 18% have a plant LNG, 6% have both supply options and the remaining 6% have no pipeline or plant in the area.



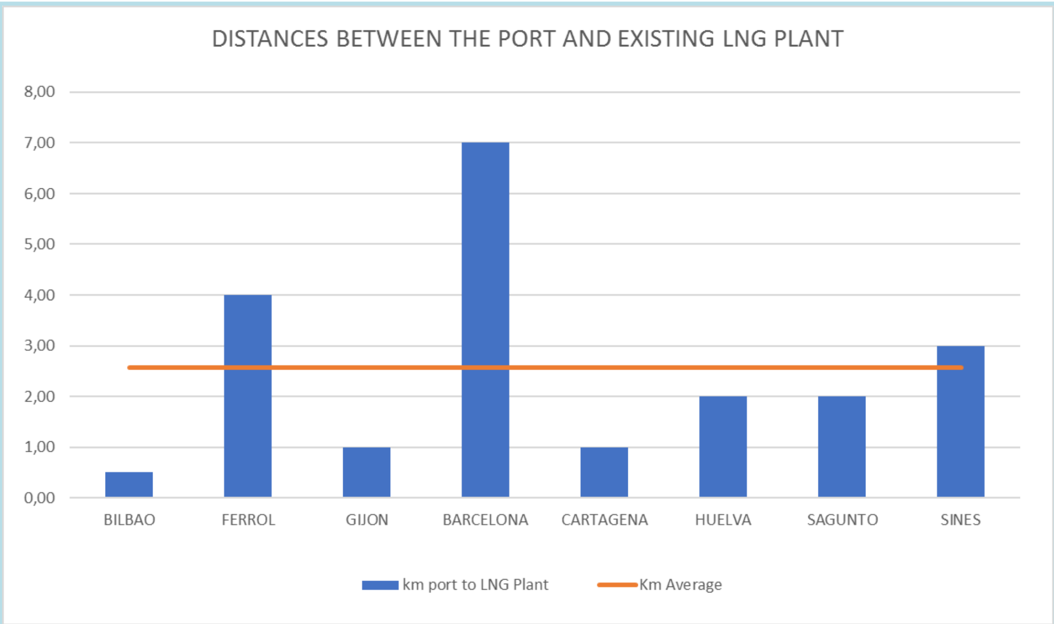
3-39. Percentage of ports with gas pipeline / LNG plants. Source:Wärtsilä

In reference to the distances between the port and the point of connection with the high-pressure pipeline existing, these are between 1-16 km, the average distance being 7.3 km. As shown in Figure 3-39.



3-40. Distances between the port and existing gas pipeline. Source: ICC Ingenieros

In ports that have LNG plants, the distances between ports and plants are around 0.5-7 km, and on average, they are 2.3 km. As shown in the Figure 2-21 Distances between the port and the existing LNG plant.



3-41. Distances between the port and existing LNG plant. Source: ICC Ingenieros

To estimate the pipe diameter that would connect the existing pipelines with the new LNG plants, a series of parameters were established to observe the behaviour of the gas when transported to these new points of consumption under different conditions, these parameters are shown below:

- LNG Consumptions: 2,000-100,000 TPA LNG
- Gas duct length: 1/20 Km
- Operation pressure: 16 Bar / 50 Bar or 16 / 60 Bar

Considering the required LNG flow rates, the necessary calculations were developed to determine the diameter of the pipes required in each typical case of operation and the lengths established for the study. The pipe sizes obtained are presented below in Table 2-22 Characteristics of the pipes.

3-17 Characteristics of the pipes. Source: ICC Ingenieros

Diameter (inch)	Outside diameter (Inch)	Outside Diameter (mm)	Thickness		Inside diameter (Inch)	Steel API 5L
			16 bar	60 bar		
2"	2 3/8	63.5	3.6	3.6	2.21	B
3"	3.5	88.9	3.6	3.6	3.2	B
4	4.5	114.3	3.6	3.6	4.2	B
6	6.62	168.14	4	4	6.3	B
8	8.62	218.95	4	4.8	8.3	B

For constructive reasons pipes with a diameter inferior to 4 inches are discarded.

3.3.5 Cost calculation for liquefaction plant and auxiliary installations

3.3.5.1 Liquefaction plant

Prices obtained from the manufactures has been considered in these calculations. The installation cost shown includes an upgraded plant, liquefaction plant and loading system using data from Criobox 600 equipment manufactured by Galileo with 14 TPD capacity (as a minimum production) and Starlite LNG XL manufactured by Cryostar with 219 TPD capacity (as a minimum production).

3-18 Liquefaction plant cost and surface. Source: ICC Ingenieros

Equipment	Capacity (ton/day)	Capacity (m3/day)	CAPEX	Occupation surface base (m2)
CRYOBOX 600	14.64	34.12	€ 4,950,000	167
STARLITE LNG XL	219	511.01	€ 38,696,000	600

As for OPEX data below are presented for the 2 types of plants studied.

3-19 Liquefaction plant operation cost. Source: ICC Ingenieros

Equipment	Capacity (ton/day)	Capacity (m^3/day)	OPEX (€/m3)		
			Personnel	Manteniance+spares	Electricity
CRYOBOX 600	14.64	34.12	15.74	8.00	28.24
STARLITE LNG XL	219	511.01	3.37	4.36	46.48

For operating costs, the required staff (2 operators for the CRYOBOX / 4 Operator for Starlite LNG XL), supplies, consumables (Spare) and electricity required to produce LNG was considered. All costs will be reflected in the economic model for the evaluation of supply chains.

For the calculation of the electricity costs, the costs of the installed capacity were considered as well as the cost of the energy consumed considering the tariffs for the large industries of the Spanish market.

It was assumed the energy consumption of **a liquefaction skid for the operation of 1 day, which will require a contracted power of 700 KW**, considering the value of contracted power and energy are variable depending on the time, there for a time analysis was developed which allows to know the average annual value of each one of these tariffs, obtaining **the value of the contracted power amounts to 0.040 € / kW/day, while the energy reaches the 0.079 €/kWh.**

3.3.5.2 *Auxiliary installations*

Data used in the calculation of 4" to 8" and 5 to 10 Km pipelines execution costs, which will connect the existing gas pipelines and the liquefaction plant to be installed in the port areas, was obtained from Spanish manufacturers historical market prices from the past 10 years. These prices, combined with the following costs, conform the price of the linear meter of completed gas pipeline:

- Supplies: Pipeline, Pipe coating, fittings, valves, equipment and components.
- Construction and assembly:
  - Pipeline
  - Complementary facilities
  - Communications
- Land:
  - Permanent easement
  - Temporary occupation
- Crops
- Supply and manufacture of measuring station
- Engineering (Project)
- Supervision of the work

Average crop prices have been used for calculating the costs of land management among the different types of crop (rained, irrigated, fruit, vines, bush).

For the calculation of construction costs, prices have been applied for pipes between 4 and 8 inches of diameter, defining the unit price in €/ml.

As for the complementary facilities, corresponding to the new pipeline, the prices have been taken for the design with HOT-TAP load-in connection, main sectionalizing valve, venting by-pass and start-up.

The costs related to the communications system, F.O cable and the F.O tubing were included as well.

The price of pipe transportation refers to tubes of 4"and 8" for lengths between factory and work site up to 500 km.

3-20 Characteristics of the pipes. Source: ICC Ingenieros

Diameter (Inch)	€/ml
4	153
6	180
8	214

3-21 Small-scale liquefaction costs

LIQUEFACTION EQUIPAMENT COST MODEL					
	CRYOBOX 600				STARLITE LNG XL
	14,64 TON/DAY (34,126 M3/DAY)	43,92 TON/DAY (102,39 M3/DAY)	73,20 TON/DAY (170,65 M3/DAY)	102,48 TON/DAY (238,91 M3/DAY)	219 TON/DAY (511 M3/DAY)
OPERATIONAL FIXED COST	**188.299 €**	**564.898 €**	**941.496 €**	**1.318.094 €**	**604.852 €**
PERSONNAL+MANTENIANCE+SPARE	186.389 €	559.166 €	931.944 €	1.304.721 €	597.988 €
Occupancy fee (T-C) €/m2 yearly	1.910 €	5.731 €	9.552 €	13.373 €	6.864 €
CAPITAL COST	**464.006 €**	**1.148.093 €**	**1.832.181 €**	**2.516.268 €**	**2.852.712 €**
LIQUEFACTION	**342.043,73 €**	**1.026.131 €**	**1.710.219 €**	**2.394.306 €**	**2.730.750 €**
LIQUEFACTION EQUIPAMENT	307.881 €	923.642 €	1.539.403 €	2.155.165 €	1.888.061 €
DEPRECIATION	191.250 €	573.750 €	956.250 €	1.338.750 €	1.172.830 €
FINANCIAL	116.631 €	349.892 €	583.153 €	816.415 €	715.231 €
INSTALLATION	**34.163 €**	**102.489 €**	**170.815 €**	**239.141 €**	**842.689 €**
DEPRECIATION	22.500 €	67.500 €	112.500 €	157.500 €	555.000 €
FINANCIAL	11.663 €	34.989 €	58.315 €	81.641 €	287.689 €
GASDUCT (10 KM LENGTH)	**121.962,15 €**	**121.962 €**	**121.962 €**	**121.962 €**	**121.962 €**
GASDUCT PIPELINE	121.962 €	121.962 €	121.962 €	121.962 €	121.962 €
DEPRECIATION	80.325 €	80.325 €	80.325 €	80.325 €	80.325 €
FINANCIAL	41.637 €	41.637 €	41.637 €	41.637 €	41.637 €
TOTAL FIXED COSTS	**652.305 €**	**1.712.991 €**	**2.773.677 €**	**3.834.363 €**	**3.457.564 €**
COSTES FIJOS (€/day)	**1.787 €**	**4.693 €**	**7.599 €**	**10.505 €**	**9.473 €**
VARIABLE COST					
ENERGY COST (€/m^3)	28,24 €	29,88 €	31,53 €	33,18 €	46,43 €
MARGIN (%)	**15%**	**15%**	**15%**	**15%**	**15%**

CAPACITY (m3/year) (1 year= 347 operation days)	**11.841,72**	**35.525,17**	**59.208,61**	**82.892,05**	**177.317,00**
OCCUPANCY AREA	**167,00**	**501**	**835**	**1.169**	**600**

INVESTMENT	**6.556.500,00 €**	**16.456.500,00 €**	**26.356.500,00 €**	**36.256.500,00 €**	**40.302.500,00 €**

REGULATED FEES AND OTHER COSTS		
FEE	**Units**	**Cost**
Occupancy fee (T-C)	€/m2 yearly	11,44 €

Note:

1- the costs presented correspond to upgraded plant, liquefaction plant, loading system and 10 km gas duct, not including storage, to know the costs related to storage see the document section 3.2.5 Calculation of costs for Auxiliary Terminals

2- The CRYOBOX equipment can increase the capacity linearly scalable, however this scalability is no longer economically competitive with a large number of equipment as observed in the cost model and it is recommended to go to equipment such as the Starline LNG.

4 MEANS OF TRANSPORT

4.1 TRANSPORT BY ROAD

4.1.1 Tanker Truck

There are two alternatives for the distribution of LNG by tanker trucks. A fleet of distribution through cisterns with polyurethane insulation or through vacuum insulated tanks.

For each alternative, there are many suppliers with very similar characteristics and methods of manufacturing. In this section, reference will be made to the characteristics of one of these manufacturers for both alternatives.

Although the amount of product transported is similar in both types of tank, the difference between them is that in the vacuum insulation, temperature losses are much lower and therefore the amount of product lost by the boil-off effect is almost negligible.

It has been considered, in the descriptive part both formats of transportation tanker trucks since now the main companies of the sector of the transport use both type in the fleets that maintains operative for the transport of LNG. However, according to European Application Regulations, the manufacture of transport tanks with polyurethane insulation is no longer allowed, and these regulations must be complied with and therefore the manufacture of cisterns with vacuum insulation for the replacement of the current fleets.

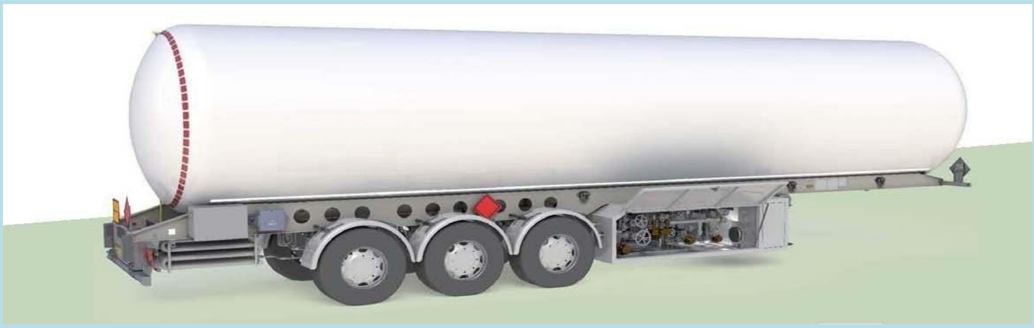
4-1. Polyurethane insulation tanker truck. Source: Lapesa

Product to transport	LNG
Standard	ADR / TPED / DOT / IMO
Nominal total volume	56,500 l
Type	Semitrailer
Dimensions	Inner / Outer diameter: 2,340 / 2,600 mm Total length: 14,040 mm
Weight tare	11,050 ± 100 Kg
Truck considered	7,000 kg
Product capacity	21,000 kg
Maximum pressure service	7 bar
Design temperature	-196°C
Isolation	Polyurethane (130 mm)
Security valves	According to code
Vessel material	Stainless steel
Pumping system	Load / unload by LNG pump
Security systems	Pressure relief system Manual venting circuit Hoses purge system Earthing point Maximum filling Emergency stops
Security system in case of overturned	Depressurization system in case of overturned

4-2. Vacuum insulation tanker truck. Source: Lapesa

Product to transport	LNG
Standard	ADR / TPED / DOT / IMO
Nominal total volume	57,000 l
Type	Semitrailer
Dimensions	Inner / Outer diameter: 2,340 / 2,600 mm Total length: 14,000 mm
Weight tare	15,400 Kg
Truck considered	7,000 kg
Product capacity	21,600 kg
Total weight of the vehicle	44,000 kg
Maximum pressure service	7 bar
Design temperature	-190°C
Isolation	Double wall with intermediate glass beads and vacuum insulation

Security valves	According to code
Vessel material	Inner container Stainless steel 1.4301 Outer carbon steel with reinforcements for vacuum
Pumping system	Load / unload by LNG pump
Security systems	Pressure relief system Manual venting circuit Hoses purge system Earthing point Maximum filling Emergency stops
Security system in case of overturned	Depressurization system in case of overturned



4-1. Truck for LNG. Source: Lapesa

The cost of the supply of LNG through LNG tanker-truck will depend on the distance from the point of charge to the port. It will be analysed in the section of Means of bunkering.

In this section, it will be considered the cost of the tanker truck (CAPEX). These costs will depend on the storage volume. There have been considered only the volume of storage of 57 m^3 (geometric capacity):

4-3. Cost of tanker truck

Type of tanker truck	Cost
Tanker-truck with vacuum isolation	250,000 €
Tanker-truck with polyurethane isolation	Not considered

The storage volume of the tank is 57m^3 (in other manufacturers 56 m^3, or quantities in that environment) because considering the ADR Regulation for the circulation of dangerous goods, a cistern with this geometric capacity can optimize the amount of LNG transported, considering the maximum weight in circulation (including tanker truck and load) must be 40T.

4.1.2 *LNG Container*

As an alternative means to the tanker truck for the supply of LNG via road is the ISO-container (with tractor head).

It is an alternative option for supplying containers with vacuum insulation and similar characteristics to tanks carrying LNG.

This study will cover two possibilities about the supply of LNG Containers:

- 20-feet LNG Container
- 40-feet LNG Container

4-4. Vacuum insulation container 20 feet. Source: Chart

Type	Container ISO 1AA 20 feet
Product to transport	LNG
Total nominal Volume	20,330 l
Empty weight	6,830 kg
Maximum weight full	16,000 kg
Type of insulation	Super insulation + Vacuum
External dimensions	Length 6,058 mm Width 2,438 mm Height 2,591 mm
Pressure	Test pressure: 10.40 Kg/cm^2 Working pressure: 7.00 Kg/cm^2
Working temperature	- 160°C
Inner body	Stainless steel
Outer body	Carbon steel

4-2. 20 feet LNG container. Source Chart

4-5. Vacuum insulation container 40 feet. Source: Chart

Type	Container ISO 1AA 40 feet
Product to transport	LNG
Total nominal Volume	43,435 l
Empty weight	11,450 kg
Maximum weight full	34,000 kg
Type of insulation	Super insulation + Vacuum
External dimensions	Length 12,192 mm Width 2,438 mm Height 2,591 mm
Pressure	Test pressure: 10.40 Kg/cm^2 Working pressure: 7.00 Kg/cm^2
Working temperature	- 160°C
Inner body	Stainless steel
Outer body	Carbon steel

4-3. 40 feet LNG container. Source Chart

The storage capacity of the containers of LNG will depend on the capacity of the storage tank of the ship where the container is destined. Usually and to minimize costs, the containers transported will be 40 feet.

When evaluation the cost of road-transported LNG container supply chain, the cost of the LNG container unit must be considered. As an added cost, it is necessary to consider the rental of the transport truck and the driver. If the destination of the container would be the storage in port, it should be considered the associated costs of the human and auxiliary means for transportation until the final storage.

4-6. Cost of container for LNG

Type of LNG container	Cost
20 feet container	84,600 €
40 feet container	137,600 €

4.2 TRANSPORT BY SEA

Spain and Portugal have a large network of LNG import terminals, storage and regasification plants and, due to the expected demand for LNG as marine fuel, a new network of auxiliary terminals of smaller size will be proposed in some of the ports that are part of the study.

Large LNG vessels cannot be considered for LNG bunkering service for several reasons: size of the vessel would require much larger docking infrastructure and very expensive port services, and large vessels are designed to navigate at full load or laden to avoid sloshing.

Small scale vessels will be required for the supply of these auxiliary terminals. At present, there are some small-scale LNG dedicated transport vessel in operation, but they only do in two specific regions: Japan and Norway. The small scale and shale gas market development is changing this and small-scale LNG carriers are being developed all over the world. Besides, new engineering designs add features to vessels like multi-gas transportation or bunkering capability, improving the range of services provided by the vessel and allowing to pay off the asset should the small-scale LNG business did not grow as expected.

Paying attention to in service and order vessels for small scale LNG transport, it could be clearly identified four main groups of vessels:

- **Small coaster LNG carriers:** Usually, vessels with capacities up to 4,000 m^3 dedicated to distributing LNG to small auxiliary plants out of the grid like ***Shinju Maru No 1,*** in service since 2003 for the coastal area of Japan or ***Pioneer Knutsen*** in Norway in service since 2004.
- **Medium coaster LNG carriers:** Vessels with capacities up to 40,000 m^3 dedicated to distributing LNG to medium scale LNG plants or hubs where LNG is distributed again to small scale plants. The most know vessel off this category is the ***Coral Energy*** *that serves LNG to Swedish terminals from big scale terminals in ARA zone or Spain.*
- **Multi-gas carrier:** Medium scale LNG vessels capable of transport LNG, ethane, shale gas, liquefied petroleum gas and other by-products like **Dragon class ships from Ineos** or **Norgas** 6 vessels chartered to Skaugen[2].
- **Bunkering vessels:** Vessels with capacities from 5,000 m^3 able to provide a wide range of services to small scale LNG business like LNG coastal or deep-sea distribution, bunkering and even as floating storage unit (FSU). This vessel category is in early development and nowadays just have three units in service: *Engie Zeebrugge*, *Cardissa* and *Coralius.* This kind of vessels will be further analysed in chapter 5.2.3.

2 http://www.skaugen.com/our-fleet/

4.2.1 *Small coaster LNG carriers*

Japan and Norway are two countries where an extended gas grid is not possible due to mountainous terrain and remoteness, so Japan has 33 LNG import terminals and roughly 100 satellite plants supplied by road tanks, small LNG carriers and ISO tank containers provide LNG to a wide range of customers. Norway have liquefaction and regasification plants, so the coastal distribution is quite important to allocate the natural gas where demand requires.

Japan has 5 x 2,500 m^3 and 1 x 3,500 m^3 dedicated vessels to this purpose, each of them can deliver up to 200,000 m^3 of LNG a year based on two round trips a week, and Norway has 1 x 1,100 m^3 for satellite plants distribution.

Japan's LNG carriers of 2,500 m^3 are *Shinju Maru NO.1, Shinju Maru NO.2, Kakurei Maru, Kakuyu Maru and North Pioneer,* and the 3,500 m^3 vessel is *Akebono Maru.* The LNG technology for these vessels is supplied by shipyards Hyundai, and the hull works was order to three different local shipyards.

The main characteristics of Shinju Maru No.1 are[3]:

- **Built Age**: 2003
- **Length over all:** 86.29 m
- **Length between perpendiculars:** -
- **Beam:** 15 m
- **Draft**: 4.2 m
- **Depth**: 7 m
- **Deadweight**: 2,930ton
- **Gross tonnage**: 1,781 GT
- **Nominal Speed**: 15 kn
- **Storage capacity**: 2 x 1,250 m^3 LNG
- **Pumping capacity**: 4 x 300 m^3/h
- **Engine**: 1 x 2,206 kW (8 t/d HFO)
- **Bow thruster**
- **Fuel:** HFO/MDO

Although the rest of 2,500 m^3 Japanese vessels have been released up to 2013, the main technical characteristics are quite similar to Shinju Maru No.1[4].

4-4. Shinju Maru no. 1. Source: Marine traffic

3 http://opac.vimaru.edu.vn/edata/E-Journal/Significant%20Ships/Significant%20ships%202003.pdf
4 https://www.classnk.or.jp/register/regships/one_dsp.aspx?imo=9433884
https://www.classnk.or.jp/register/regships/one_dsp.aspx?imo=9469235
https://www.classnk.or.jp/register/regships/one_dsp.aspx?imo=9317200
https://www.classnk.or.jp/register/regships/one_dsp.aspx?imo=9554729
https://www.classnk.or.jp/register/regships/one_dsp.aspx?imo=9317200

Norway 1,100 m^3 vessel is called Pioneer Knutsen and its main technical data is[5]:

- **Built Age**: 2004
- **Length over all:** 69 m
- **Length between perpendicular:** -
- **Beam:** 11.8 m
- **Draft**: 3.5 m
- **Depth**: 7 m
- **Gross tonnage**: 1,687 GT
- **Deadweight**: 817 ton
- **Nominal Speed**: 14 kn
- **Storage capacity**: 2 x 550 m³ LNG
- **Pumping capacity**: 4 x 50 m³/h
- **Engine**: 2 x 910 kW LNG + 2 x 640 kW Diesel
- **Fuel:** Dual-Fuel

These vessels are not considered as a type of vessel for further analysis in this study because nowadays market is demanding vessels capable of offer a wider range of small scale services and combabilities, for this reason described vessels in chapter 5.2 fit better the ships models required for this study and only for those a detailed analysis of components' cost will be performed.

4.2.2 *Medium coaster LNG carriers*

There are some medium size LNG carriers operating nowadays around the world, mainly in Asia. But, these Asian vessels built between 1993 and 2007 have been designed and are used to transport LNG from production spots like Russia and Southeast Asia to import terminals in Japan. As these vessels were not designed for partial loadings and coastal multiple distribution, they are not of really interest for this study. LNG dedicated vessel for distribution between big LNG import terminals to LNG satellite plants are still on development to adapt to new bunkering and distribution market. Currently there are two modern vessels already in the market, Coral Energy and Hai Yang Shi You 301 equipped with anti-sloshing tanks and required equipment for optimal LNG small scale distribution.

Coral Energy main characteristics are[6]:

- **Built Age**: 2012
- **Length over all:** 155 m
- **Length between perpendiculars:** 147 m
- **Beam:** 22.7 m
- **Draft**: 4.2 m
- **Depth**: 15 m
- **Deadweight**: 12,260 t
- **Gross tonnage**: 13,500 GT
- **Nominal Speed**: 16 kn
- **Storage capacity**: 3 x 5,200 m³ LNG Type C
- **Pumping capacity**: 6 x 270 m³/h
- **Main Engine:** 1 x 7,800 kW
- **Auxiliary Engine**: 2 x 1,056 kW
- **Bow thruster**
- **Fuel:** Dual-Fuel

5 https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/magalog_lng_supply_chain.pdf
6 http://www.tge-marine.com/files/datenblatt__15600_cbm__lng_carrier_coral_energy.pdf

Hai Yang Shi You 301 main characteristics are:

- **Built Age**: 2015
- **Length over all:** 184.7 m
- **Length between perpendiculars:** - m
- **Beam:** 28.1 m
- **Draft**: - m
- **Depth**: 4.7 m
- **Deadweight**: 16,405 t
- **Gross tonnage**: 25,309 GT
- **Nominal Speed**: 16.5 kn
- **Storage capacity**: 4 x 7,500 m³ LNG Type C

Hai Yang Shi You 301 has been leased to work as a FSU in Indonesia until the planned FSU is built, so it is not involved nowadays in LNG distribution, but Coral Energy whether it is used to distribute LNG from big import terminals to medium scale terminals in Sweden or Norway. Coral Energy is chartered by SkanGas to Antonhy Veder, the owner company and has successfully realised reloads from big import terminals, FRSU and medium scale import terminals proving the great flexibility of this vessels to operate in every point of the logistic chain. Given the great success of this kind of vessel, Anthony Veder and Skangas has already placed another charter agreement for the vessel EnergICE, now in construction and expected to be delivered in Q1 2018, with a capacity of 18,000 m³ and state-of-art technology whose investment cost is estimated in a range of 70,000,000 € to 75,000,000 €[7]

4-5. M/V "Hai Yang Shi You 301 "operating as a FSU. Source: CNOOC

4.2.3 *Multi-gas carriers*

Fuels and petrochemical markets have evolved deeply in the last 20 years developing a more integrated business and setting up new production and exploration technologies like shale-gas. Integrated business implies bigger refineries close to production centres, this increases the number and quantity of final products shipped by sea to final customers.

As create dedicated vessels for every petrochemical product would not be cost-effective, companies in the market have worked in develop multi-product solutions that increase the trade flexibility and make easier to adapt market changings.

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7 http://www.nationaallngplatform.nl/wp-content/uploads/2016/03/2016-0315-Anthony-Veder.pdf

Multi-gas carriers for LNG transport have been developed for more than a decade, firstly driven by high oil prices and lastly by the shale gas business rise.

Nowadays, multi-gas carriers are profitable trading shale gas by-products or being used in conventional LPG distribution chains, but when demand for medium-scale LNG transport vessel will rise, this kind of vessel will be an early available and cost-effective solution for LNG market.

There are not a large fleet of this kind of vessels and it is mainly controlled by three companies:

- Evergas (All vessels chartered to INEOS company): 8 x 27,500 m^3 on service and 4 x 32,000 m^3 planned
- Skaugen (All vessels chartered to NorGas): 4 x 10,000 m^3 + 2 x 12,000 m^3 on service
- Anthony Veder: 1x 6,500 m^3 + 1x 7,551 m^3

Evergas has developed the biggest fleet of multi gas carriers, designing two different class of vessels Dragon class and Ineos Max, with 8 and 4 vessels each one. These vessels chartered to INEOS for 15 years[8] will transport ethane (product of shale gas) from USA to Europe market but, it can keep 2 different products in its tanks so it could import natural gas too while USA planned liquefaction plants are on service. Besides, **it is planned that four of the Dragon class will be in LNG distribution as soon as the late 4 Ineos Max vessels will be available to transport ethane from USA**[9]. These Evergas vessels can transport natural gas, ethylene, ethane, propylene, propane, DME, VCM, iso-butane, butane and butadiene. Moreover, they are capable of use ethane, natural gas or MDO/HFO as fuel using the boil-off produced inside the cargo tanks and their main characteristics are:

- **Built Age**: 2015-2017
- **Length over all:** 180.3 m
- **Length between perpendiculars:** 170.8 m
- **Beam:** 26.6 m
- **Draft**: 9.4 m
- **Depth**: 14.8 m
- **Deadweight**: 20,918 t
- **Gross tonnage**: 22,887 GT
- **Nominal Speed**: 16 kn
- **Storage capacity**: 27,566 m^3 LNG Type C
- **Main Engine**: 2 x 5,850 kW Wartsila 6L50DF
- **Auxiliary Engine:** 2 x 2,112 kW Wartsila 20DF
- **Bow thruster**
- **Fuel:** Tri-fuel

4-6 . M/V "JS Ineos Inspiration". Source: Marine Traffic

8 http://www.motorship.com/news101/ships-and-shipyards/versatile-tankers-for-atlantic-ethane-traffic
9 http://www.lngworldshipping.com/news/view,evergas-first-off-the-mark-with-ethane-carriers_44105.htm

Norgas fleet with smaller vessels is allocated nowadays in Asian spot markets trading LPG and LNG, but has signed a 7-year charter deal for three vessels with an African electric company[10], so **Norgas company has 2 x 10,000 m^3 and 1 x 12,000 m^3 available to be chartered to LNG small scale distribution or FSU.**

Anthony Veeder's multi gas fleet is composed of a 7,551 m^3 vessel, the Coral Methane and a 6,500 m^3 vessel, the Coral Anthelia. The Coral Methane was the first multi gas carrier built in the world and entered in service in 2009, chartered 15 years by Gasnor AS is dedicated to LNG small scale distribution in northwest Europe, being able to load LNG in different import terminals around Europe, according to availability and fuel prices. Nowadays, Coral Methane will be retroffited to provide bunkering services too 11. Coral Anthelia, is also chartered but in short-term -three years- by New Fortress Energy, a company in charge of supply LNG to Jamaica Public Service's Bogue power plant. The deal includes a 3-year agreement for supply LNG from Golar Artic (a big FSU moored at Jamaica) to the Bogue power plant.

4.2.4 *Bunkering vessels*

Refer to paragraph 5.2.1.

10 I.M Skaugen SE 1Q report 2017
11 http://www.lngworldnews.com/shell-anthony-veder-to-convert-coral-methane-lng-carrier-to-bunker-vessel/

5 MEANS OF LNG BUNKERING

The definition of LNG bunkering is the transfer of LNG to vessels requiring LNG as a fuel from an external storage. There are three main different LNG bunkering scenarios:

- Truck-to-Ship (TTS): is a micro bunkering, discharging unit is a LNG road tanker size approximately below 56 m^3
- Ship-to-Ship (STS): discharging unit is a bunker vessel or barge bellow to 10,000 m^3
- Terminal (Pipeline)-to-Ship (PTS): satellite terminal bunkering serves as a discharging unit and supply size is approximately 100-30,000 m^3

PTS and TTS are the most established bunkering scenarios used to date and they are both classified as onshore supply.

It is very important to establish a standard connection between Truck & Ship, Ship & Shore or between Ship & Ship.

For the bunkering solution, a connection is made between the LNG supplier and the receiver by means of a cryogen-resistant hose. The pipes are pre-flushed with nitrogen to remove oxygen and the moisture. Then the pipes and fittings are pre-cooled by LNG. Only when the pipe is cold enough, LNG will be pumped. Pumping will be achieved either by increasing the LNG tank vapour pressure or using the special cryogenic LNG pump. The loading pressure will be about 7 bar.

G**eneral steps** for bunkering are:

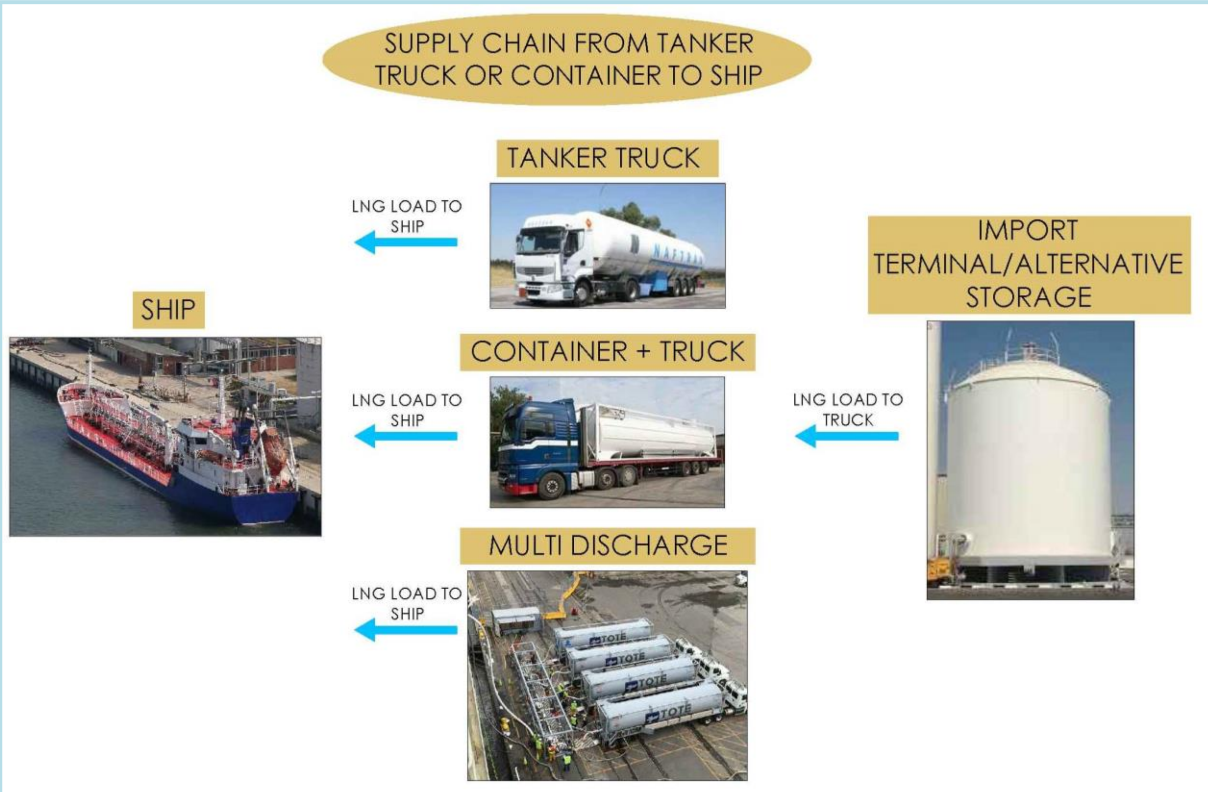
- Initial pre-cooling
- Connection of bunker hose
- Inerting the connection system
- Checking ESD system function
- Purging the connection system
- Filling sequence
- Liquid line stripping
- Liquid line inerting

5.1 TRUCK TO SHIP (CONTAINER TO SHIP)

Among the various methods of in-port bunkering of LNG-fuelled ships, Truck-to-Ship (TTS) transfer is currently most frequently used. With TTS, the LNG truck is connected to the ship on the quayside, generally using a flexible hose. This is today's the most widely used bunkering method, because of the still limited demand in combination with the lack of infrastructure and the relatively low investment costs. For these reasons, truck-to-ship bunkering is a good interim solution for LNG bunkering.

One of the main advantages of truck-to-ship bunkering is the limited investment costs for operators. The trucks can also be used for LNG distribution for other purposes.

The main drawback of LNG bunkering by means of TTS bunkering for large consumers is the limited capacity of trucks: approximately 20-50 m^3, than only can be filled up to 85% of their capacity. This bunkering method is only suitable for bunkering quantities up to 30 tonnes and is therefore only suited to smaller-sized LNG-fuelled vessels. Because of the limited flow rate, bunkering takes about an hour (around 1.000 l/min). The presence of truck and bunker processes also impacts other quayside activities like cargo and passenger handling. Furthermore, a road connection with the preferred bunkering position is required, and local safety requirements need to be met, as with any bunker operation.



5-1. TTS Process diagram - Supply Chain

For capacity reasons, truck-to-ship bunkering is most suitable for smaller LNG-fuelled vessels with limited bunker volumes, like tugboats, inland vessels, coastguard vessels and smaller passenger vessels. The suitability of truck-to-ship transfer may also be influenced by restrictions on simultaneous cargo and passenger transfer.

Conventional bunkering (MGO/MDO, HFO) from trucks is commonly performed today in Spanish and Portuguese ports. The Royal Decree 958/2002 regulates the authorization of such practices in Spanish ports. In article 5, the decree mandates Port Authorities to stablish in each port the allowed location, vessel types, and safety requirements of operations and operators. Port Authorities become then responsible of these authorizations without prejudice of competences of other competent authorities. Furthermore, the terms and conditions for operators to perform bunkering activity in the ports, should be publicly regulated under the specification of the commercial service.

Is in these specifications where the requisites for truck to ship bunkering operations are developed port by port. In general terms the three main conditions required for truck to ship bunkering are the following:

- Establish a safety perimeter. Assure regular loading and unloading of the vessel do not interfere with the bunkering operation, and avoid cargo being lifted over the safety perimeter.
- Forbid bunkering operations simultaneous to loading or unloading hazardous materials (or under other situations (ship repair, etc.) with potential risk conditions.
- Use of approved equipment and operational procedures at all time

None of the analysed specifications make specific distinctions between freight and passenger operations, both subject to the overall risk assessment required to perform bunkering operations.

Certain port authorities, such as Valencia or Baleares explicitly restrict bunkering operations to one truck at the time, not allowing MTTS operations, and stablishing safety distances among unloading and waiting trucks.

5.1.1 Manifolds for multiple loads (Multi truck to ship)

Manifolds for multiple loads are used for the connection of several LNG transport trucks so the way out of the mouth of loading of the ship is unique. They are formed by a line that acts as the discharge manifold of the trucks with multiple entries for the coupling of discharge hoses from the trucks and through an exit that will connect the charging hose to the Bunker Station of the boat.

The manifold considered in this study does not have charge pump. The pumps used for the transfer of LNG are the trucks ones, but exists alternative solutions in the market with pumping, BOG handling and other capabilities

When system of bunkering to use is the T-S and for a volume of LNG required by the ship of several LNG tanker trucks manifolds can be used.

It is necessary and very important to consider the occupation surface of tanker trucks when they connect to the manifold and download at the same time.

When the multiple discharge manifold is used with several tanks at the same time, it needs to be considered that the amount of fuel gas contained in these tanks may exceed 50Tm. Each tanker has a limitation of 40Tm in load (including the weight of the tanker truck itself) which implies an effective limitation of approximately 20Tm of s fuel gas (depending on the type of tank and the type of truck). SEVESO III Directive, Transposed by Royal Decree 840/2015 does not apply to transport and bunkering operations. Nevertheless, when the quantity exceeds 50 Tm, some of the obligations indicated in that normative can be applied to the supplier, as could be to have a proper assurance system of quality management and procedures for emergency purposes indicated there.

In addition, it will always be necessary to consider that the final permission after a risk analysis of the security measures will be regulated by each Port Authority.

5-2. Use of manifold for multiple loads

5.1.2 *Centrifugal pump skid*

When the pumps installed in the trucks do not have the capacity to undertake the bunkering to the valves, a booster pump must be used.

In these situations, there must be considered the need of using centrifugal pumps with cold head to overcome the loss of load that will occur as result of the difference of pressure between the output of the truck and the inlet of the tank

The pumps to be used shall be fitted in skid for connection to the truck. Between the output of the pump and the entrance to the vessels' manifold will use a flexible hose.

It will be necessary to calculate the distance between the truck and storage tank to choose a suitable pump in each case. Centrifugal pumps can work in a range of flows and with different head, according to their characteristical curve.

5.1.3 *Hoses for Truck-to-Ship Bunkering*

The hoses used for handling LNG and vapour shall be specially designed and constructed for the products with a storage temperature of – 196° C.

All hose strings must have sufficient length to avoid over-stressing and chafing during the bunkering process. To determine the correct hose length, ships relative freeboard changes and movements must be taken into consideration. The hose size depends on the maximum amount of fuel to be transferred in a defined time frame.

The hoses shall be handled with great care both during transportation and bunker operations. It is important to keep the hoses protected from air and humidity during transportation and to support properly when lifting to avoid damage by kinking. The minimum bending radius (MBR) for each hose must be observed.

The hose connections should be drip free and preferably quick-connect coupling to have a safe and fast connection/disconnection procedure. This type of coupling has two handles to lift, press and rotate to lock position and is designed for the fuel temperature both for functional and operational reasons.

There shall be a break-away (dry-break) coupling on each LNG hose, placed on the receiving ship's manifold to ensure that hoses do not break in case of extreme movement or emergency. The function of this coupling is to be the weakest part of the chain and to break off if forces exceed the limits. Inside the coupling, there are two quick-closing shut-off valves, which immediately close and prohibit leakage.

5.1.4 *Bunker Station (Receiving ship)*

The bunker station on the receiving ship is preferably located on a lower deck along a flat section.

The layout of the bunker station should be new standardized with placement of manifolds and size/type of connections to make the bunkering operation quick and safe.

There shall not be any sharp edges in the hose handling area. If the receiving vessel has on-board traffic near the bunker station, there should be reinforcements built-in to protect the equipment from traffic impact.

The bunker stations may have one or two hose LNG bunkering system. Two pipelines (depending of the used systems) connect the bunker stations with the LNG tanks. One pipeline is for the liquid LNG, which is partly routed in a vacuum insulated pipe. Another pipeline is for the gas return, which is used when bunkering with 2 hoses. Occasionally it only exists one pipe for the LNG charge and there is not line for gas return.

5.1.5 *Personnel Transfers*

Due to safety reasons, it is necessary to count with the driver of the truck and in addition one specialist unloader, managing the valves of the truck. In the bunker station in the ship there will be one specialist and one person of the crew of the ship. Sometimes will be necessary to count with more people as a security staff of the port.

5.1.6 *Process of bunkering Truck-to-Ship*

The bunkering process starts with the connection of the communication link (optional) between the truck and the ship. Then the hoses for the transfer of LNG between the truck and the ship shall be connected; the liquid filling hose and the gas return hose (it will be considered the use of the gas phase return pipe or hose in the bunkering operations for the discharge of multiple tanks at the same time). The reason there for two hoses is to be able to handle the raise in pressure that will occur in the receiving tank. Gaseous natural gas is led back to the truck through the gas return hose, balancing the pressure in the two tanks.

Note that the gas return is not used if the top filling reduces the receiving ship tank pressure sufficiently.

The pump in the tank on the truck is controlled by a frequency converter. The frequency converter, together with the "kick back line" on the piping system, allows the truck to adapt to different design on the receiving ship by adjusting the flow of LNG. The flow is further controlled with flow meters flow regulating control valves.

Pressure, flow and temperature transmitted are placed on the truck and the receiving ship to monitoring the bunkering process. Close by the bunkering stations there will be an electric cabinet with indicators.

When the level indicator for the receiving ship indicates that the required level is reached the bunkering shall end.

After the bunkering, sometimes and in some situations to follow the procedures of the Port Authority, the piping system and hoses must be purged with nitrogen. Both truck and ship, shall have a nitrogen supply to be able to perform purging. However, before using the nitrogen, any residual liquid in the system shall be pushed back into the tanks. This is performed using the purge tank on the LNG truck, which contains natural gas with a higher pressure than the rest of the system.

As natural gas is released into the system the liquid is flushed from the system into the tanks. Then the hoses between the truck and the ship can be disconnected

5-3. Truck to ship operation. Source: fleetsandfuels.com

When the hoses are disconnected the nitrogen is let into the piping system close to the tanks; any natural gas is then purged from the system to the vent masts.

In other situations, the purge with nitrogen will not be necessary and the operators will purge the residual gas (never the liquid gas) to the atmosphere.

Evaluation of costs in the process of bunkering Truck-to-Ship

For the evaluation of the costs of supply chain of the Truck to Ship Bunkering, the next cost elements will be considered:

- Cost of tanker truck (or cost of the container + truck).
- Distance from the storage tank to the point of charge on the port.
- Truck, ship and unloaders staff to the maneuver of charge.
- Cost of the discharge manifold for multiple trucks.
- Cost and number of hoses for LNG.

The costs associated with the investment required for the acquisition of a fleet of LNG transport tanks are not taken into account in this chapter. The existing fleet will be in charge of developing the transport and in the case that it is necessary to expand it, it will be considered a cost for the company that has the concession of transport but will never be considered a cost over the chain of supply.

For the complete characterization of the supply chain it would be necessary to assess the cost of manifolds for multiple discharges and connecting hoses.

It is important to assess intervention times to ensure that the supply chain is adapted to the real costs. For this reason, the real times of the operation will be estimated considering the difficulties of accessing a port, permits, signalling of security and other sensitive points that do not apply to an ordinary discharge of a tanker truck in a standard plant.

The average time taken for a full load of a tanker truck at a loading terminal is three hours since the tanker enters the terminal until it is loaded. The three-hour time necessary for the tanker loading operation in the LNG terminal considers both the actual loading operation, as well as the terminal entry times, the terminal's output and waiting time-outs and placement in the loading bay.

The tanker truck will return to the import terminal without LNG but with a bit of gas that will be returned to the tank. This is the same operation that will be in the auxiliary terminal.

The time required for a recharge will vary depending on the tank pressure, the internal temperature and the state of the pump for the load. In addition, human factors (terminal operator, driver, etc.)

The discharge time of the tank truck can be estimated in three hours as an average time, but it will depend on the pump of the truck, the personnel of the ship and the driver of the truck, the conditions to make the operation, the instructions of the Port Authority and many other variables. In this average time, it is included the time for the preparation of the area where the truck will be positioned, signalling according to the port authority and the preparation of flexible hoses.

The estimated price considered for the operation of TTS will consider the following costs:

- Costs of the tanker for annualized LNG (with a 20-year forecast of use).
- Cost of the tractor head considering that it has been purchased second hand with a previous use of 20,000km. Annualized cost (with a 10-year forecast of use).
- Annual cost of a driver.
- Annual fuel consumption for the truck.
- Estimated annual amount for maintenance and repairs.
- Insurance.
- Margin of transport company (covering structure expenses and profit margin).

The costs considering are the followings:

5-1. Costs for the operation TTS (I)

Cost of the tanker (investment)	250,000 €
Cost of the tractor head (investment second hand)	85,000 €
Cost of the tractor head (new supply)	120,000 €
Cost of the driver (per year)	52,000 €
Cost of the fuel consumption for the truck (per year)	22,000 €
Cost of maintenance and repairs (per year)	7,000 €
Insurance (annual)	4,000 €

Cost of the 40 feet container (investment)	137,000 €
Cost of the 40 feet container platform (Investment)	28,000 €
Cost of the skid for 4 discharges	7,000 €

All these items are estimated considering a minimum annual use of 100,000 km. If the utilization was lower, the final cost obtained by Km would increase. Considering an annual use of 100,000 km the costs are the following:

5-2. Costs for the operation TTS (II)

Cost of the tanker annualized and per km	0.125 €/km
Cost of the tractor head annualized and per km	0.085 €/km
Cost of the driver per km	0.520 €/km
Cost of the fuel consumption for the truck per km	0.220 €/km
Cost of maintenance and repairs per km	0.070 €/km
Insurance per km	0.040 €/km
Margin of Transport Company per km	0.140 €/km
FINAL COST	1.20 €/km

Once the exact data of the journeys travelled by the trucks are known, the data that relates the cost per km to the number of kilometres travelled must be interpreted and the result will be adjusted to each case. The data obtained in the previous calculation must be interpreted as a data obtained from particular circumstances and will only be indicative for an average of annual kilometres travelled in the vicinity of 100,000 km.

In addition to the cost per km, there are other costs associated with each load and download that are shown below:

5-3. Costs for the operation TTS (II)

Load of tanker-truck in the LNG terminal	150 €/load
Discharge in port	150 €/discharge
Cost for inmobility of the tanker truck (from the three hours considered in the loading or discharge operation)	50 €/h
Cost per trip to Canarias (particular case)	3,000 €/trip
Cost per trip to Palma (particular case)	2,080 €/trip
Cost per trip to Funchal (particular case)	3,000 €/trip

As immobilization times that will be taxed with an additional cost will be considered all those that exceed the three hours of loading or unloading that are caused by reasons unrelated to the performance of the driver of the tanker truck or foreign the tank truck itself. Until the TTS bunkering operations are considered within the normal operation of the port and are thus considered by the Port Authority, these immobilization times may represent a significant cost overrun.

Whether the load of the ship is carried out directly from the tanker truck or if a multiple discharge manifold is inserted, the presence of the driver of the truck or of the drivers of each truck will be necessary in the event of a multiple load, and the presence of the unloading operator for assistance to the driver and for the handling of the manifold for multiple discharge.

To estimate the cost of the manifold for multiple discharges, the equipment has been considered to allow the coupling of up to 4 tankers or 4 containers. The operation of the equipment will be carried out by the driver of the tractor that carries the skid to the point of unloading in port. It is considered that the equipment will be operative during all the time and therefore a proportional cost of a tractor unit is associated, with the associated costs of insurance and maintenance and a cost of fuel consumption lower than in the case of tankers since the equipment must be accessible near the port.

The financial reference terms used to calculate the costs are as shown below:

5-4. Financial Reference Terms

	Term amortization (years)	Type interest (%)	Residual Value (% of Capital)	Useful life (Years)
Tanker	8	4.50	15	20
Truck (Tractor Head)	8	4.50	15	10
Container (40 feet)	8	4.50	15	18
Skid Multiple load	8	4.50	10	18

The following table shows the fixed costs for TTS operations including all personnel cost terms, insurance, maintenance, as well as depreciation costs for tanker trucks, skid of manifold for multiple charges, and the same using a container. All the capital costs shown are annualized costs.

In the column of the table "Tanker + Truck" the costs of the operation of the transport tank are shown with the associated costs of the tractor. The column "Skid + Truck" shows the costs associated with the operation of the skid for multiple discharges that will be used in the case of using several tanks at the same time in a bunkering operation. To this cost it must be added the cost of the first column multiplied by the number of tanks (from 2 to 4) that are involved in the operation. In the column "Container + Truck" the indicated costs are those related to the use of a container with the tractor.

It also shows the variable costs associated with the cost per km of travel, cost per sea trip (Palma and Granadilla Posts), the costs of immobilization and the costs of loading and unloading in the import terminal.

5-5. Costs of TTS (& CTS) I

TTS & CTS COST MODEL			
	TANKER + TRUCK	SKID (4) + TRUCK	CONTAINER
OPERATIONAL FIXED COST	85,000 €	345,000 €	8,500 €
PERSONNEL	52,000 €	208,000 €	0 €
INSURANCE	4,000 €	18,500 €	3,000 €
FUEL CONSUMPTION	22,000 €	88,000 €	0 €
MAINTENANCE AND REPAIR	7,000 €	30,500 €	5,500 €
CAPITAL COST	32,925 €	140,145 €	12,694 €
DEPRECIATION	17,850 €	75,845 €	6,500 €
FINANCIAL	15,075 €	64,300 €	6,194 €
TOTAL FIXED COST	146,566 €	501,909 €	47,822 €
FIXED COSTS (€/day)	402 €	1,375 €	131 €
MARGIN (%)	28,641 €	16,763 €	26,627 €

INVESTMENT	335,000 €	173,900 €	137,647 €

The table shows the annual capital costs and annual fixed operating costs derived from the operation with a tank truck, a manifold for multiple discharges with the associated tractor unit and with a container unit with a tractor unit.

To simplify the calculation of costs, it is necessary to consider a constant that allows converting the fixed costs indicated above into variable costs that can be used in the calculation of TTS-type bunkering operations. To this end, considering a quantity of 100,000 km per year travelled by the tanker truck or by the container and tractor unit, it is possible to convert these fixed costs into variable costs having an impact on the final price of €/km, all costs included previously (capital costs and fixed variable costs of personnel, fuel, insurance, maintenance, etc).

5-6. Costs of TTS (& CTS) II

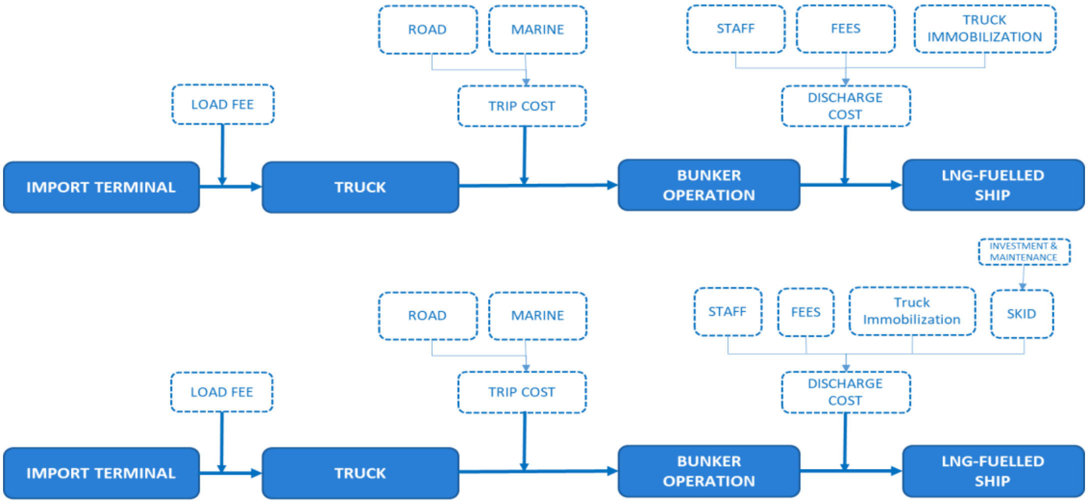
VARIABLE COSTS			
ROAD TRIP (€/km)	1,2		1,2
MARITIME ROUNDTRIP PALMA	2.080 €		-
MARITIME ROUNDTRIP CANARIAS	3.000 €		1.250 €
MARITIME ROUNDTRIP FUNCHAL	3.000 €		1.500 €
MARITIME ROUNDTRIP CEUTA	1.400 €		-
MARITIME ROUNDTRIP MELILLA	2.800 €		-
DAILY INMOVILIZATION COST	1.200 €		127 €
UNLOAD COST (€/u)	300 €		300 €

CAPACITY (m3)	50		50

REGULATED FEES AND OTHER COSTS		
Tasa	Units	Cost
Load Terminal Fee	€/MWh	1,13 €
T-3	tons suplied	0,80 €
T-A	% Business in Port	2,00%
Svedoring truck	Service	107 €
Stevedoring truck	Service	78 €

In all cases, the tax rates have been considered those related to the transport of the tanker with tractor unit or the container with tractor unit. In the case of skid for multiple discharges with tractor head has not been included in the analysis since the time to have to use that solution, the equipment should be permanently in the port where it worked.

To clarify the costs involved in single TTS bunkering and multi TTS, it has been realized the schemes in the below Figure 5-4, where main costs are summaryzed and order as the real operation would happen.



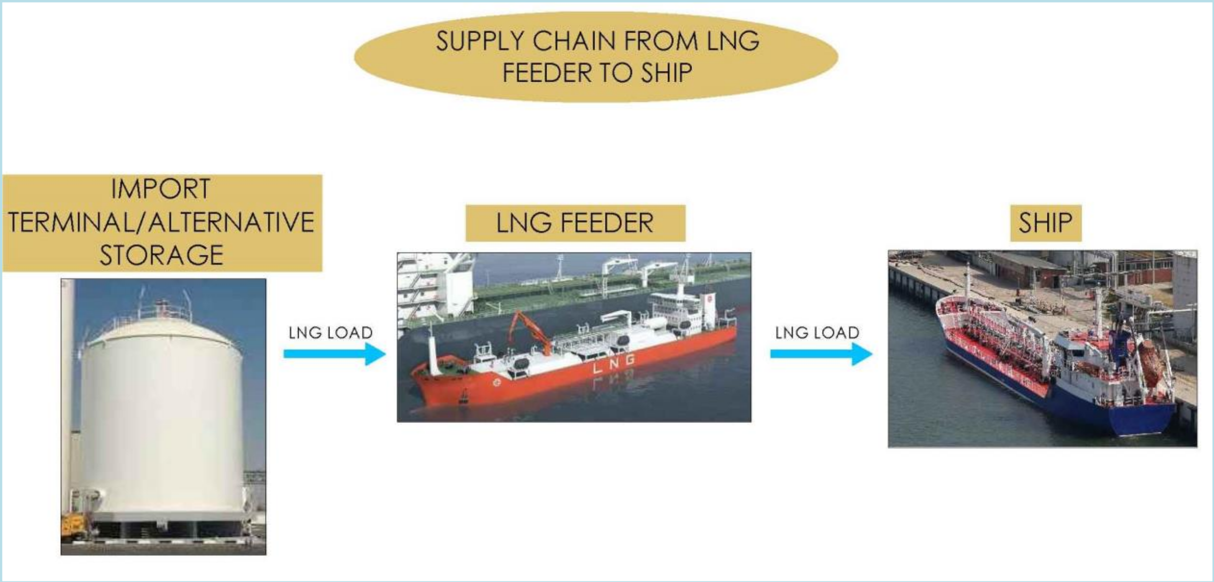
5-4 Truck-to-ship cost scheme

5.2 *SHIP TO SHIP*

Ship to ship (STS) operation is carried out between two ships, when one of the ships unloads the fuel to the other, that receives it connected by a manifold.

According to GASNAM, bunkering operation from barge in areas outside port water will only be carried out when it is not possible to do the bunkering operation inside the port. In these cases, the bunkering will be carried out with the authorization of the Maritime Authority according to the conditions dictated by the General Direction of the Merchant Marine and the Port Authority, in the anchoring area designated for ships with dangerous products, in conditions of good weather, visibility superior to 2 miles, wind inferior to force 3 (Beaufort scale) and curly sea.

STS can be carried out by two vessels at different locations: along the quayside, in movement (although is rarely) or the two vessels standing anchored or moored to several buoys. Both ships will always be made firm to each other using mooring lines.



5-5. STS Process diagram - Supply Chain

The main factor when a STS operation is performed/analysed is the bunkering vessel. An LNG vessel is a ship design to transport LNG. **Small LNG vessels** (from 100 m³ to 60,000 m³) **fit better with the present and future needs of bunkering due to:**

- **High manoeuvrability** for port movements, effective and secure bunkering services.
- **Partial cargo loading.** It is not possible in big scale membrane tanks for LNG due to sloshing and should be carefully studied for the rest of technologies, but the usage of Type C LNG tanks in small LNG carriers allows to partial cargo loading and high flexibility in bunkering and feeder services to multiple ports.
- **Bunkering services ranges.** It will range from 200 m³ to 3,000 m³, so a big vessel tank would increase BOG losses and LNG ageing.

Compared with other bunkering methods, ship-to-ship bunkering is very versatile from the point of view of capacity and bunkering location as it is possible to provide LNG far away a LNG storage area, and as it is mentioned previously can be done in a terminal, anchoring area. As the bunker vessels are moored alongside LNG-fuelled ships, this bunker method permits simultaneous cargo handling and bunkering operation, normally easier to be allowed by the Port Authority safety standards.

The main drawback of bunker vessels is its high cost. The industry is hesitant to invest in such vessels, in part because there are few alternative operations when LNG bunker demand is limited. As LNG bunker vessels are regarded as vessels carrying dangerous cargo, entering non-petroleum harbour areas must be authorized, but this can be easily solved with a proper and monitored communication between the Port Control Centre and the LNG bunker vessel.

Given the high flexibility of bunkering vessels, ship-to-ship bunkering is preferred over TTS for all types of vessels and is expected to become the main bunkering method for ships with a bunker demand of over 200 m^3. This argument implies that ship-to-ship bunkering is most suitable for vessels such as cruise, RoPax/RoRo vessels, bulk-carriers and container vessels. On the other hand, PTS from import terminals, has a great potential to offer a full range of bunkering service, requires vessels to perform a second manoeuvre to approach PTS facilities, increasing cost and extending the vessel port call.

5.2.1 LNG bunkering vessels

There is a significant gap between the large-scale LNG terminals served by large carriers to supply of natural gas and small installations for LNG as a fuel. There is a new LNG transportation market that requires small vessels which can reach regions far from import terminals with short sailing times and without design limitations for partial filling.

5-6. LNG vessels. Source: Crowley

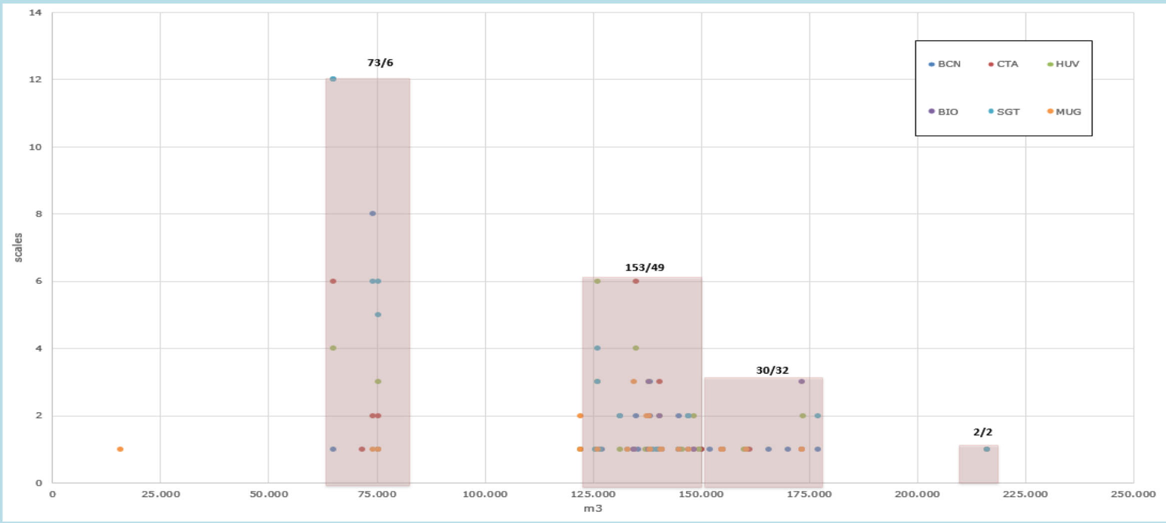
The Spanish regulation, BOE-A-2005-16830 (1.6) [12], classifies LNG vessels as:

- Small vessels: storage capacity bellow 60,000 m^3.
- Medium vessels: storage capacity between 60,000 and 110,000 m^3.
- Large vessels: storage capacity up to 110,000 m^3.

In the Annual report "Memoria del Sistema Gasista Español 2014"[13], published by Enagás, a list of all LNG vessels that made scales in Spain were reported, the gap between large and small vessel is appreciated.

[12]

[13] Memoria del Sistema Gasista Español 2014



5-7. LNG vessels in Spain, 2014. Source: Enagás

In the graph can be seen that there is a fleet of medium size vessels (these vessels are being scrapped due to their age), then there is a great number of vessels from 125,000 to 175,000 m³, finally two Q-flex made calls that year. Only one vessel below 25,000 m³ made a call in Spain in 2014. In conclusion, it can be observed the gap between small vessels and large vessels.

It is difficult to characterize the small-scale carrier fleet due to is a new market. In this study, the storage capacity will be considered the most important parameter. LNG bunker vessels studied may have capacities ranging from 1,000 m³ to 10,000 m³ depending on location, customer and bunker volume.

As noted in previous chapter, the lack of a fleet of small scale LNG vessel requires reviewing new designs that are still not providing service. Most of the ships to be described are still today conceptual designs.

The small-scale LNG vessels have been classified in three groups:

- **Multiproduct barges**
- **Single product barges**
- **Feeders**

Feeders are used for inland, coastal and sometimes intercontinental transport. Barges are used mainly for bunkering at home ports, but could be used as feeders too. When barges are used as feeders, it should be taken in account their limitations such as navigation ability, speed, autonomy, etc. Following, main characteristics of barges and feeders are described.

5.2.2 *Multiproduct LNG barge*

Multiproduct bunker vessels add LNG storage and bunkering auxiliary equipment to a conventional bunkering vessel. Low demands level in the first years of LNG bunkering services will prevent investors from expensive dedicated solutions, so **multiproduct barges could be an affordable alternative to develop the early infrastructure needed**.

Multiproduct barges would supply conventional fuels (MGO and HFO) while LNG services are not scheduled, reducing costs of LNG services by sharing investment and fixed cost with conventional bunkering services. LNG dedicated equipment costs will only be charged to LNG bunkering services.

Two multiproduct barges have been defined as a model for this study:

- **650 m^3 LNG barge**
- **1,200 m^3 LNG barge**

Larger capacities for LNG on multiproduct barges will not considered. In most cases LNG storage would be mounted over the deck and increasing capacity (e.g. 10 x 300 tanks to reach 3.000 m^3) would exceed the available deck surface of the conventional barge units.

5.2.3 650 m³ multiproduct LNG barge

The "Monte Arucas" project will be used as a reference for this size class. The public entity "Ente Vasco de la Energia" in partnership with the ship owner Ibaizabal, shipyards Murueta and Itsas Gas Bunker Supply Corporation, are working on the transformation of a multi-product barge to include LNG bunkering capacity. This project is part of the "CORE LNGas hive", it includes also the adaption of the import terminal of Bilbao Bizcaia Gas (BBG) to enable the supply of LNG to small vessels through a pipeline of 500 m³/h capacity. The import terminal and jetty re-equipment costs have been projected in 940,000 € with execution in November of 2017.

Monte Arucas was built in 2009 as a conventional bunkering vessel, it was used for oil recovery works for three years, then it was allocated to supply conventional fuels in A Coruña in 2012, this previous function gave to the vessel a **good navigability with 7 kn speed and high manoeuvrability with dynamic positioning system included[14].**

Retrofitting works are scheduled for December and are projected to last for 6 months, since vessel gets into shipyards and the first cargo trials are done in the import terminal of BBG. **The works include the installation of 2 x 325 m³ LNG Type C tanks in the top deck, and the required equipment for LNG bunkering service.**

Technical description and main characteristics of the barge are:

- **Built Age:** 2009
- **Length overall:** 74 m
- **Length between perpendiculars:** 72 m
- **Beam:** 15 m
- **Draft:** 4 m
- **Depth:** 5 m
- **Gross tonnage:** 1,590 GT
- **Deadweight:** 3,180 ton
- **Storage capacity:** 2 x 325 m³ LNG + 10 x 310 m³ conventional fuels
- **Engine:** 2 x 540 kW Guascor SF 360
- **Fuel:** MDO
- **Azimuthal propulsion**
- **Dynamic position system**

5-8. "Monte Arucas" before the conversion. Source: Shipspotting

[14] "Estrategia sobre GNL marítimo en Euskadi", Iñaki Boveda, Marzo de 2017

5.2.3.1 *1,200 m³ multiproduct LNG barge*

Suardiaz and CEPSA are collaborating to design and build a multi-product barge that includes LNG tanks to operate mainly in the Port of Barcelona to supply every kind of vessel with multiple fuels. The barge will be supplied from the import terminal of Barcelona, where already exists a dedicated small-scale berth capable of supply vessels with a minimum of 1,000 m³ capacity.[15]

The project is based on a conventional barge design and includes the adaption to provide LNG bunkering services with conventional fuel services. The transformation project is part of the "CORE LNGas hive", it is conducted by Flota Suardiaz, HAM and Port Authority of Barcelona. The retrofitted works are planned to last for 1 year, finishing in the summer of 2018; first supply trials are planned for October of 2018.[16]

The barge will have equipment to provide LNG bunkering from both sides of the vessel through a central manifold with high pumping rates and capable of provide bunkering to ships, tanks and trucks and be filled from them too. Propulsion will have Azimuth propellers with 360° rotation and bow thruster for great manoeuvrability and possibility of providing bunkering services in multiple scenarios.

Design hull conditions allows the vessel to short sea shipping and, it is equipped with 2 x 820 kW engines would be able to reach a 10 kn speed.

The cargo system for LNG will be placed on the top deck with a capacity of 4x300 m³ Type C manufacturing. Besides, the barge will have 3 segmentations for conventional fuels: 2x2,000 m³ for Fuel-Oil but MDO-ready and 1x1,000 m³ for MDO.

Technical description and main characteristics of the barge are:

- **Built:** 2018
- **Length over all:** 86 m
- **Beam:** 17 m
- **Depth:** 7.55 m
- **Gross Tonnage:** 2,743 GT
- **Deadweight:** 4,700 ton
- **Storage capacity:** 4x300 m³ Type C LNG Tanks + 5,000 m³ others
- **Engine:** 2x820 kW Guascor
- **Fuel:** MDO
- **Azimuthal propulsion with 360° rotation**

5-9. Suardiaz and CEPSA LNG vessel. Source: Suardiaz

[15] Servicios Small Scale. Enagás 2017
[16] I Conferencia Proyecto CORE LNGas hive. Estado de avance subproyectos en Barcelona

5.2.4 3,000 m^3 single product LNG barge

The vessel defined in this category is a 3,000 m^3 barge conceived by Damen Shipyards, eventually to be chartered by Shell company to operate in Rotterdam Area.

This dedicated vessel can provide dedicated LNG bunkering and feeder services to a wide range of clients and areas, reaching 10 kn speed and using Boil-off (BOG) cargo losses for propulsion and auxiliary engines.

The cargo system consists in 2 x 1,500 m^3 Type C tanks with BOG management and a bunkering rate of 500 m^3/h that is supplied by 2 pumps. If the vessel is equipped with gas engines, the navigation fuel consumption would be decreased in a 50% at full cargo load and 25% at half cargo load.

Technical description and main characteristics of the barge:

- **Length over all:** 102.6 m
- **Length between perpendiculars:** 97.8 m
- **Beam:** 11 m
- **Draft:** 3 m
- **Depth:** 5.4 m
- **Deadweight tonnage:** 2,100 ton
- **Storage capacity:** 2 x 1,500 m^3 Type C LNG Tanks
- **Pumping rate:** 500 m^3/h
- **Engine:** 4x300kW with option of MDO, Gas or both
- **Diesel electric driven with Azimuth propellers and bow thruster**

5-10. 3000 m^3 DAMEN design. Source: DAMEN

5.2.5 *Feeders*

Small scale LNG feeders are used for short sea navigation, coastal trading, distributing LNG to generation plants, industries or auxiliary terminals while keeping bunkering capabilities. **In this study LNG feeders will be used to distribute LNG from big scale import terminals to auxiliary terminals allocated in different ports, being required a high feasibility of cargo volumes supplied and high pumping rates to reduced harbour times and supply LNG to the biggest area.**

This category of LNG carriers has already some vessels built. A few ships of this type are already operating in European ports, such as "ENGIE Zeebruge", "Coral Energy" or "Cardissa" a vessel operated from Rotterdam Area by Shell but able to distribute LNG to Scandinavian remote locations too.

In order to analyse this category, three vessels projects have been identified as a model with the following capacity:

- 5,000 m^3 feeder
- 7,500 m^3 feeder
- 10,000 m^3 feeder

5.2.5.1 5,000 m³ LNG feeder

“ENGIE Zeebruge” is the world’s first purpose built liquified gas bunkering vessel (it is operated as a joint adventure between Engie, Fluxys, Mitsubisihi Corporation and NYK), it was built by Hanjin Heavy Industries in Korea. It is based in Zeebrugee port, holding long-term agreements for LNG supply from Fluxy’s import terminal where recently was commissioned a second jetty and supplies LNG to two UECC car carriers. “ENGIE” will also transport and supply LNG as a marine fuel to ships operating in Northern Europe due to his great navigability capacities.

This vessel is equipped with the latest technology to provide safe, reliable and fast services of bunkering and feeder to every kind of vessel or terminal in multiple scenarios, so it implies a higher investment cost and longer construction time than retrofitted barges. Construction began in July 2014 and ended in November 2016, resulting in roughly three years production time.

The cargo system consists in 2 x 2,500 m³ Type C tanks operating at 4 bar and manufactured with 9% Ni steel. Besides, the vessel uses a powerful bunkering and loading system with two liquid lines equipped with 4x300 m³/h pumps. This system allows the vessel to provide 600 m³/h of bunker rate and be filled at 1,000 m³/h rate.[17]

Vessel speed can reach 13 kn, propulsion system is fitted with 2x1,665 kW Dual-Fuel engines from Wärtsilä (model 9L20DF), a BOG-handling and fuel gas system with cargo compressor, forcing vaporisers and gas buffer tanks that allow to use the cargo as fuel not needing a dedicated LNG tank for it. It also fits a 160 m³ tank for MDO operation and a self-operated inert gas system with N_2.

Technical description and main characteristics of the vessel are:

- **Length over all:** 108 m
- **Beam:** 18 m
- **Depth:** 9 m
- **Draft:** 5 m
- **Deadweight tonnage:** 3,121 ton
- **Gross tonnage:** 7,403 GT
- **Storage capacity:** 2 x 2,000 m³ Type C LNG Tanks
- **Engine:** Dual-fuel Wärtsilä 9L20DF
- **Bunkering rate:** 600 m³/h
- **Loading rate:** 1,000 m³/h

5-11. ENGIE Zeebruge. Source: Marine traffic

[17] “ENGIE Zeebrugge” Technical Data Sheet

5.2.5.2 *7,500 m³ LNG feeder*

Samsung Heavy Industries Co. announced the contract to build two 7,500 m³ LNG carriers. DAMEN, Anthony Veder and Wärtsilä have developed conceptual designs of vessels with this storage capacity. The reference for this study will be the Anthony Veder design.

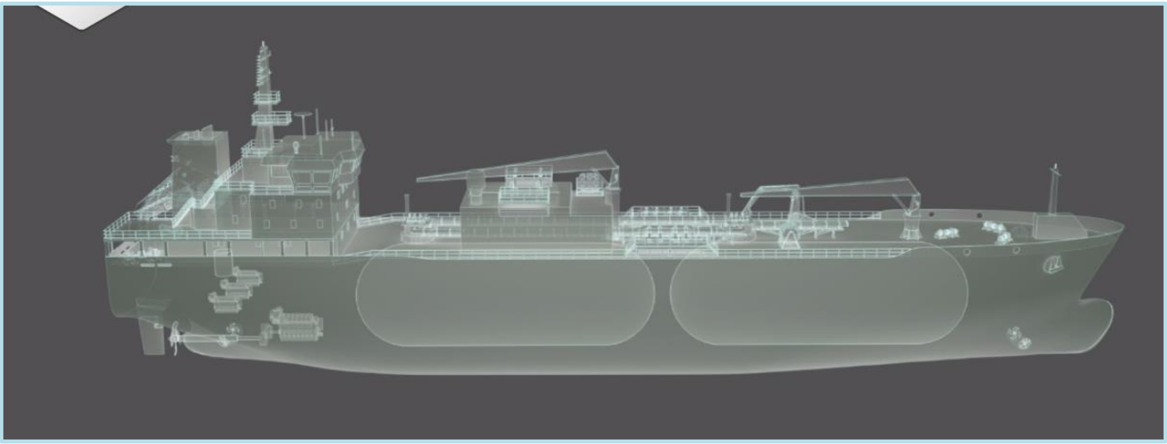
Bigger capacity vessels like this results into a **more cost-efficient loading at import terminals** and allow to supply bigger auxiliary terminals in a faster way. Fitting high and low manifolds the vessel covers a wide range of terminal and ships to transfer and receive LNG. Besides, **higher bunker rates of 1,000 m³/h reduce bunkering and loading time.**

The cargo system consists in 2 x 3,750 m³ Type C tanks operating at 4.5 bar and manufactured with 9% Ni steel.

Propulsion system and auxiliary bunkering equipment is quite similar to" ENGIE Zeebrugge" but, bigger cargo capacity increases the power required to **reach 13 kn**. It is fitted with a **3,000 kW Dual-Fuel engine Wärtsilä 6L34DF and 4 x 1,100 kW generating sets Wärtsilä 6L20DF** that could be operated with natural BOG, forced vaporized gas from cargo tanks or MDO.

Technical description and main characteristics of the vessel are:

- **Length over all:** 115 m
- **Length between perpendiculars:** 110 m
- **Beam:** 18 m
- **Depth:** 10 m
- **Draft:** 6 m
- **Deadweight tonnage:** 4,100 ton
- **Gross Tonnage:** 6,850 GT
- **Number of tanks:** 2 x 3,750 m³ Type C LNG Tanks
- **Loading/unloading rate:** 1,000 m³/h
- **Engine:** Dual-Fuel Wärtsilä 6L34DF
- **400 m³ MDO tank**



5-12. 7,500 m³ Anthony Veder design. Source: Anthony Veder

5.2.5.3 10,000 m³ LNG feeder

Reganosa and Ghenova presented their design of an innovative vessel with high energy efficiency and operational versatility with a cargo capacity of 10,000 m³

This vessel could provide a LNG hub the whole range of marine LNG services, even bunkering at open sea, thanks to the dynamic position system and two Azipod propellers that provides high manoeuvrability and extremely high self-sufficiency. It has two manifolds placed at different heights to cover a wide range of import terminals and LNG-fuelled vessels in both sides of the vessel.

The key from previous reference feeders, is the use of two GTT membrane tanks, designed by GTT industries, that allow to increase the capacity for a same space and decreased the gross tonnage of the vessel below 5,000 GT, almost 50% less than ships of smaller. Membrane tanks have worst sloshing performance that was addressed with an innovative design.

Propulsion system is fed by natural BOG, forced vaporizer or MDO. The two Azipod propellers are powered by 4 MAN Dual-Fuel engines, 2 MAN 9L28-32DFx1,800 kW and 2 MAN 8L28-32DFx1,600 kW, being able to deliver up to 6,800 kW of power with a great feasibility and good performances on partial load. **This configuration allows the vessel to sail at 14 kn cruise speed covering big areas in short times and to operate 4x500 m³/h in-tank pumps that could provide bunkering services in less than a hour to almost every LNG-fuelled vessel and be filled up in 5h in import terminals.**

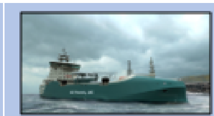
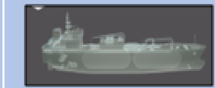
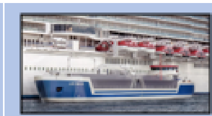
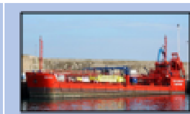
Dynamic position and high manoeuvrability systems provide safety and quality to the bunkering operation but also **increase the fuel consumption** that in this case can be higher than sailing fuel consumption.

Technical description and main characteristics of the vessel are:

- **Length over all:** 119 m
- **Length between perpendiculars:** 113 m
- **Beam**: 21 m
- **Depth:** 13 m
- **Draft**: 6 m
- **Gross tonnage**: 5,000 GT
- **Storage capacity:** 1 x 5,500 & 1 x 4,500 m³ LNG GTT Mark III tanks
- **Loading/unloading rate:** 4 x 500 m³/h
- **Engine:** 2 x 1,800 kW and 2 x 1,600 kW Dual-Fuel MAN
- **Dynamic positioning**

5-13. Ghenova and Reganosa design. Source: Ghenova

5-7. Summary of LNG vessels

Vessel	10,000 m³	7,500 m³	5,000 m³	3,000 m³	1,200 m³	600 m³
Figure						
Loa (m)	119	115	108	109	86	74
B (m)	21	18	18	11	17	15
D (m)	6	6	-	3	5	4
H (m)	13	12	9	5	9	5
DWT (tn)	-	4,100	3,121	1,980	-	3,180
GT	5,000	6,850	7,403	2,100	2,743	1,590
Speed (kn)	14	13	13	10	10	7
LNG tanks	2	2	2	2	4	2
Type of tanks	GTT Mark III	Type C	Type C	Type C	Type C	Type C
LNG Storage (m³)	10,000	7,500	5,000	1,500	1,200	600
Conventional Storage (m³)	-	-	-	-	5,000	3,100
Load/unl. Rate (m³/h)	4 x 500 - 2 x 35	1000	600/1000	500	300	250
Engine	LNG	Conventional /Dual	Dual-Fuel	Conventional/Dual	Conventional	Conventional
Investment cost (€)	**52,000,000€**	**45,000,000€**	**32,000,000€**	**20,000,000€**	**16,000,000€**	**9,522,000€**

5.2.6 *LNG vessels cost*

According to "International Gas Union 2014" a small-scale LNG vessel cost is higher per ton compared to large scale LNG vessels, a capital expenditure for small scale LNG ships is in the range of 9,000 to 28,000 €/m^3, while large conventional shipping is 2,000 to 9,000 €/m^3. Operational expenditure is higher in large scale vessels, small scale vessels have smaller crew, and engine and cruise speed are usually lower, also small-scale vessels incur in lower costs for mooring and port activities.

In this chapter, costs of the previous described vessels categories will be described.

Due to the complexity of the development of the vessels' cost structure, some assumptions are done:

Fixed cost: costs incurred whether the ship is engaged in an activity or not.

- **Operative cost**: cost incurred to keep the vessel ready to navigate.
  - **Crew cost**
    - The number of the crew members has been obtained from the product sheet of ships and has been completed with information from similar vessels.
    - Salaries have been obtained from shipping companies and compared to scores made to the sector.
    - It has been assumed:
      - Trip cost: cost incurred to move the crew to the home port per trip (375€/person).
      - Maintenance cost: cost to feed a person per day (15€/person).
      - Work clothes: cost of the clothes needed to work per year (500€/person).
      - Training: cost of training officers per year (1,000€/person).
  - **Insurance costs:** for the calculation of insurance costs have been taken as reference ships of similar characteristics (age, size, area of operation, …).
  - **Maintenance and repair costs**: for the calculation of maintenance costs have been taken as reference ships of similar characteristics (age, size, area of operation, …) and scores to companies dedicated to maintenance of ships and tanks.
  - **Administration costs**
- **Cost of capital**: consumption of the vessel during a period considered. Investment in ships has been calculated based on the information provided by companies involved in the development of the projects listed and estimates of vessels of similar characteristics.
  - Depreciation of the ships costs: estimated 20 years. Residual value has been estimated as a 15% of the investment in the ship.
  - Interest of financing credit costs: loan interest rate used is detailed in Annex 1. The financing period estimated is 10 years.

Variable costs: voyage costs, associated to the trips made by the vessel.

- **Port costs**: these costs will be estimated in chapter 6.2 when port fees are calculated, some will depend on the size of the ship (occupancy fee and T1) and other with the activity developed or the goods shipped.
- **Fuel cost**: consumptions depend not only on propulsion system, but also on whether the ships is in port, sailing or operating, so regarding the technical engine data described in chapter 5.2.1 has been written the following table, what contains a breakdown of consumption according to the activity developed by each vessel.

5-8. Consumptions by vessel

CONVENTIONAL FUELLED (t MDO/day)			
	Navigation	Operation	Port
600 m³	7	3	1
1,200 m³	11	5	2
LNG FUELLED (m³ LNG/day)			
3,000 m³	9	5	2
5,000 m³	22	7	5
7,500 m³	24	9	5
10,000 m³	40	13	7

5-9. Ship cost model

MARITIME TRANSPORT AND SHIP TO SHIP COST MODEL						
Vessel	650 m³	1,200 m³	3,000 m³	5,000 m³	7,500 m³	10,000 m³
Propulsión	MDO	MDO	DF	DF	DF	DF
GT	1590	2743	2100	7403	6850	5000
OPERATIONAL FIXED COST	843.000 €	959.562 €	842.300 €	973.193 €	1.174.063 €	1.708.900 €
PERSONNEL	510.205 €	567.560 €	510.205 €	567.560 €	697.710 €	755.065 €
INSURANCE	107.100 €	133.700 €	96.400 €	145.700 €	204.800 €	266.900 €
MAINTENANCE	195.000 €	227.000 €	205.000 €	217.000 €	230.000 €	650.000 €
PORT FEES	30.695 €	31.302 €	30.695 €	42.933 €	41.553 €	36.935 €
MOORING	24.455 €	24.455 €	24.455 €	24.455 €	24.455 €	24.455 €
MARPOL	6.240 €	6.847 €	6.240 €	18.478 €	17.098 €	12.480 €
CAPITAL COST	833.175 €	1.400.000 €	1.750.000 €	2.800.000 €	3.937.500 €	4.465.000 €
DEPRECIATION	404.685 €	680.000 €	850.000 €	1.360.000 €	1.912.500 €	2.125.000 €
FINANCIAL	428.490 €	720.000 €	900.000 €	1.440.000 €	2.025.000 €	2.340.000 €
FIXED COST MARGIN & STRUCTURE (%)	15%	15%	15%	15%	15%	15%
TOTAL FIXED COST	1.927.601 €	2.713.496 €	2.981.145 €	4.339.172 €	5.878.297 €	7.099.985 €
FIXED COSTS (€/day)	5.354 €	7.537 €	8.281 €	12.053 €	16.329 €	19.722 €
VARIABLE COSTS						
NAVIGATION FUEL (t MDO/day)	6	12	5	12	13	21
MANEUVERING FUEL (t MDO/day)	4	4	4	4	5	7
PORT FUEL (t MDO/day)	3	3	3	3	3	4
T-1 (€/SCALE)	71 €	123 €	94 €	332 €	307 €	224 €
PILOTAGE (€/SCALE)	275 €	275 €	275 €	275 €	275 €	275 €
LOAD IN TERMINAL FEE	45.138 €	46.111 €	49.294 €	52.830 €	57.251 €	61.672 €
VARIABLE COST MARGIN & STRUCTURE (%)	15%	15%	15%	15%	15%	15%

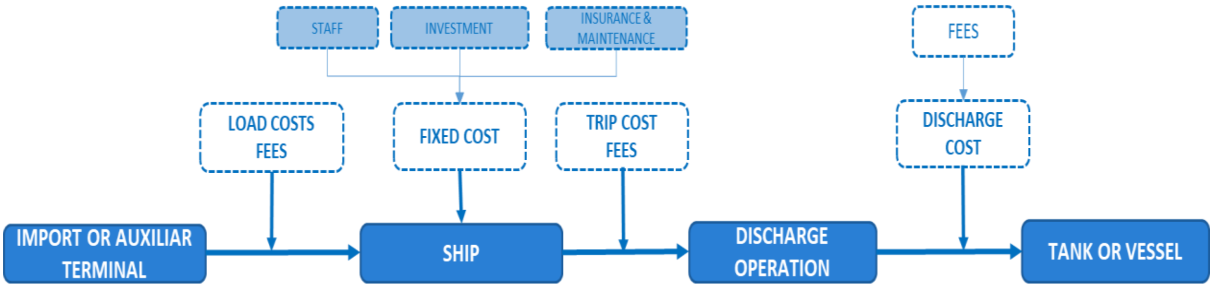
CAPACITY (m^3)	650	1.200	3.000	5.000	7.500	10.000
ACTIVITY DAYS	360	360	360	360	360	360

INVESTMENT	9.522.000 €	16.000.000 €	20.000.000 €	32.000.000 €	45.000.000 €	52.000.000 €

REGULATED FEES AND OTHER COSTS		
FEE	Units	Cost
T-3	tons supllied	0,80 €
T-A	% Business in Port	2%

5.2.4 STS cost

Summarizing, all costs involved in STS bunkering or LNG transport by sea it is has been realized a scheme showed in Figure5-14, to clarify the bunkering operation and all their costs.



5-14 STS and LNG transport by sea cost scheme

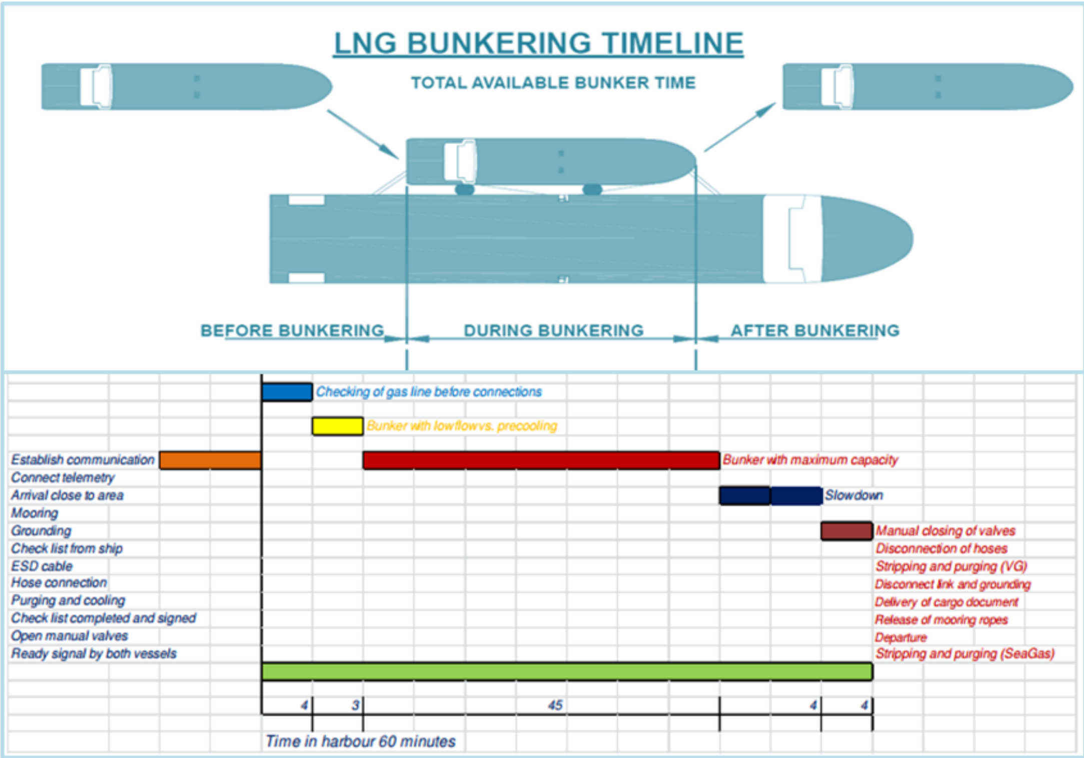
5.2.5 Bunkering time

Time to carry out a bunkering or loading operation is an essential parameter that impacts on the calculation and design of the logistic chain. It is necessary to know this bunkering time, since the stay of the ships in the port or anchored has a determined duration, and bunkering operation must be coordinated while the ship is in the port, so bunkering time has an impact on the cost of the supply chain. Minimizing bunkering times is an important requirement in the design of the LNG supply vessel and loading/ unloading systems.

STS bunkering time not only depends on pumping operative, also it should be taken in account:

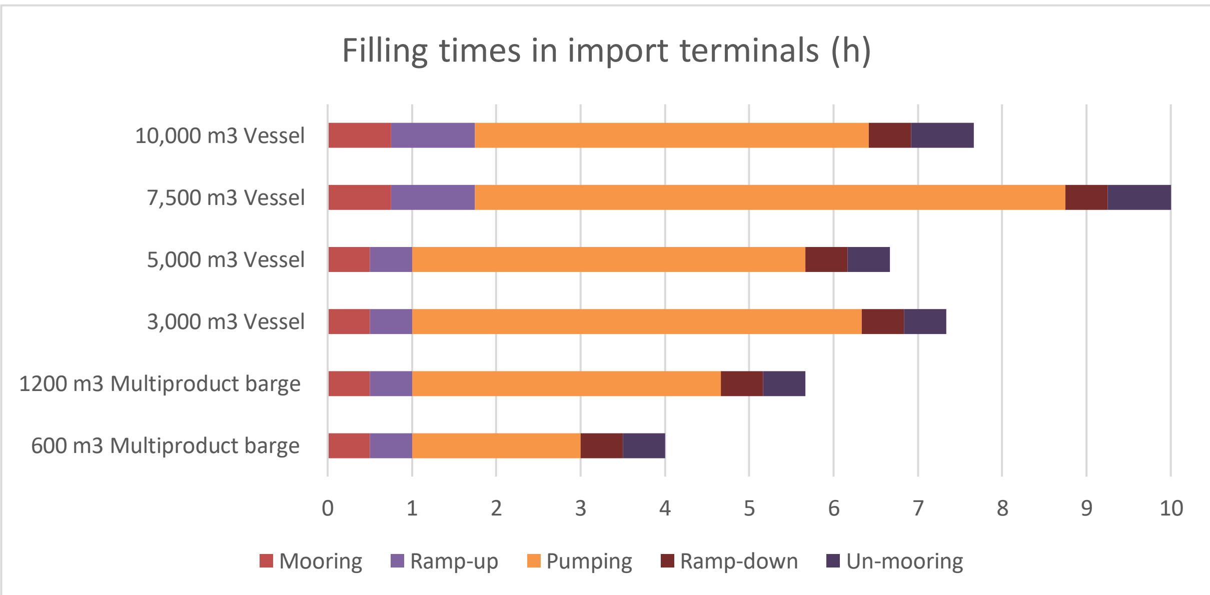
- **Pre-bunkering time**: It would include the mooring operation between ships and all technical checking before starting the bunkering operation.
- **Post-bunkering time**: It would include the unmooring operations and inertization of lines in both vessels.
- **Ramp-up pumping procedure:** It would include the time since pumping operation begins until pumping rate is maximum.
- **Ramp-down pumping procedure:** To finish the pumping operation requires a time until product stop to flow.

Studying the bunkering schedule of the first vessel bunkered by STS, "Viking Grace", an estimation of duration could be implied for a STS Service. As Figure 5-15 shows, pre-bunkering will last 10-15 minutes not include previous communications, and post-bunkering will last 15-20 minutes. So, the total bunkering operation will last 25-35 minutes in addition to pumping required times. The bunkering vessel used in this operation, the SEAGAS, a former ferry (48 m LOA) was transformed for this duty, she carries 70 tons of LNG. Regular pre-bunkering and post-bunkering operations in this report is estimated in 60 minutes, considering larger vessels and variable berthing and manoeuvring conditions.



5-15 Bunkering schedule for Viking Grace. Source Viking Lines

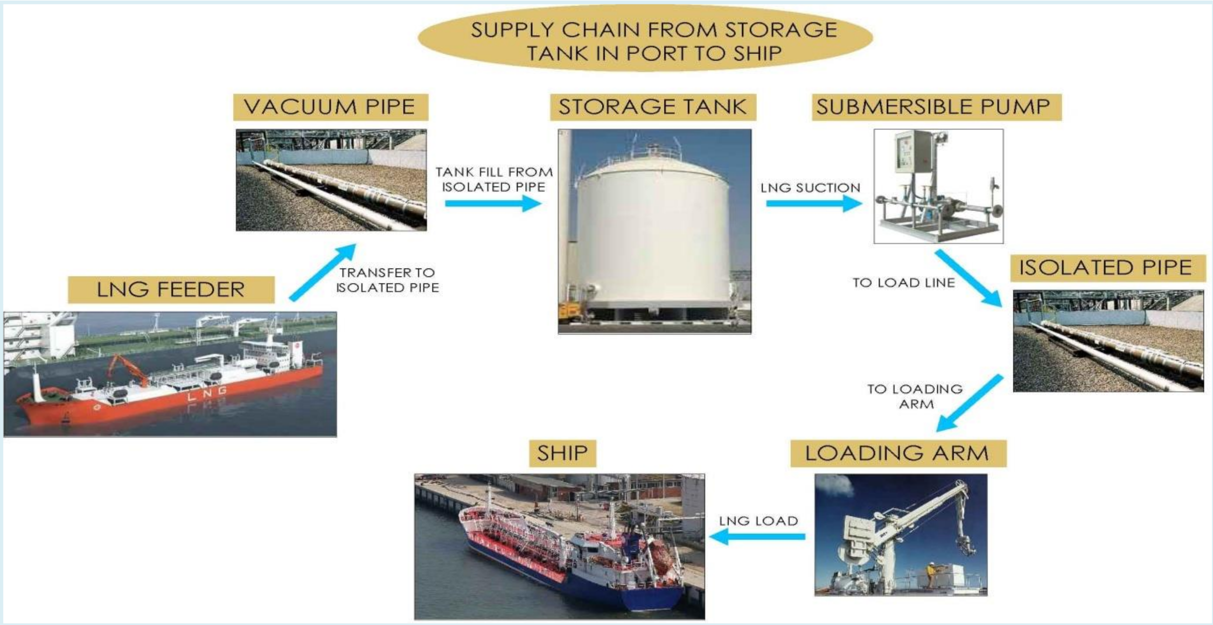
Then, every bunkering service will last 1 h at least, and depending on the amount of fuel required and bunkering rates of the bunkering vessel, the total time could vary from 1 h to 10 h. A calculation was performed **showing a full download bunkering time** for each vessel described in previous chapter and it has been estimated for each vessel as a function of total storage capacity and loading rates. As it could be seen in the Fig. 5-16, vessel usually would have to spend about 6-8 hours for a total load/download.



5-16 Filling times for vessels described

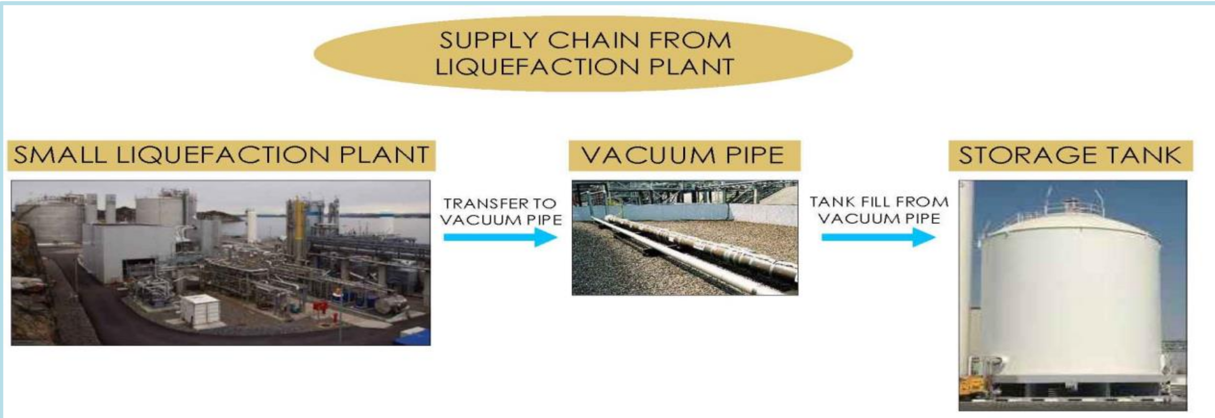
5.3 PIPE TO SHIP

Another bunkering method is shore-ship, whereby LNG is either bunkered directly from a (intermediate) tank or small station, or from an import or export terminal. Pipelines from the terminal to the quay are needed if the LNG terminal is not directly situated at the berth. Bunkering from pipelines has already being used for LNG-fuelled ships for several years.



5-17. PTS Process diagram - Supply Chain (Links to TTS, Figure 4-2)

One of the major drawbacks of this type of bunkering is the effort it takes a ship to manoeuvre to a second location on the bunker terminal (or pipeline), in terms of time and nautical services (mooring, pilots, tugs). In addition, limited berth access for larger LNG-fuelled vessels can also be an inconvenient for shore-ship bunkering. If an import terminal is to be used, the equipment would not be suited for small scale transfers.



5-18. Small Scale Liquefaction Process diagram - Supply Chain (Links to TTS & PTS Figures 4-2 & 4-8)

If ships can be bunkered predominantly at one location, and there is space available to install permanent LNG tanks within short distances, then bunkering from fixed onshore tanks is a relevant option.

Shore-ship bunkering is especially suitable for high frequency services, fixed berthing, less strict timetables and limited vessel draft. Examples include bunkering vessels, tugs, inland shipping vessels, utility vessels and fishing boats. Shore-ship bunkering may also be a good option for inland shipping, because inland vessels have the flexibility to visit fixed stations, whereas seagoing vessels do not.

5.3.1 Delivery of LNG at a terminal by jetty

A quay or jetty is needed for receiving LNG supplied by ships and, preferably, also for bunkering purposes. The terminal must be accessible by at least a minimum size of vessel, and preferably also larger vessels. Large RoRo vessels operating have lengths of around 200 m and maximum mean draughts around 7.5 m, and the ability to load such vessels from fixed lines directly from a terminal would be an advantage. To a economically fueling operative by PTS, LNG loading should be done in the same berth or jetty that the vessel is working, to avoid extra port movements. Transfer lines and ship-shore connection

LNG is transferred between the ship and the storage tank(s) by an insulated pipeline, usually accompanied by a vapour return line. The same pipeline may be used for the supply of LNG from a LNG freighter to the terminal and the bunkering of a vessel from the terminal. Due to the high temperature differential between the LNG (-162ºC) and ambient temperature, the distance between the terminal and the point of bunkering at the jetty should be short to minimize heating of the LNG. The pipeline between the quay and the terminal can be placed in an underground culvert to avoid interference with other activities.

The connection between the transfer line and the ship can be accomplished by flexible hoses. This is a viable solution for the relatively modest flow rates of LNG to be required for bunkering operations. Terminals handling large LNG vessels use hoses mounted on loading arms.

5-19.PTS bunkering

5.3.2 *Marine loading arms*

As described in chapter 2.3, one of the equipments used to perform the bunkering from the port (through the tank or the terminal) are the marine load arms for LNG.

These loading arms are designed to ensure cargo depending on the size of the ship, the loading height, the distance to the loading mouth and even the tides in the dock where the ship is to be loaded are considered.

It was commented in the chapter 2.3, that the marine loading arm allows the transfer of LNG from the storage tank to the ship.

Between the discharge flange of the marine loading arm and the inlet flange to the bunker station of the ship, the breakaway coupling shall also be used to guarantee the safety of the loading operation for the ship andthe personnel performing the manoeuvre in the port and ship.

Deplyable Manifold System with ERS (Emergency Release System) described in chapter 3.2.3. can also be presented as a viable solution.

It will be necessary to estimate the real times of the operation considering the work of connecting the hoses on board and the real time to fill the tank of the ship.

5.3.3 *Evaluation of costs in the process of bunkering Port-to-Ship*

To evaluate the costs of supply chain of the Port to Ship Bunkering, the following cost elements will be taken int account:

- Cost of the LNG tank.
- Staff of the both LNG Plant and ship to the maneuver of charge.
- Cost of loading arm
- Cost and number of hoses for LNG.

It will be necessary to estimate the real times of the operation considering the work of connecting the hoses on board and the real time to fill the tank of the ship.

5.3.3.1 *Evaluation of costs in the process of bunkering Port-to-Ship*

For the evaluation of the costs of supply chain of the Port to Ship Bunkering, also the following cost elements (OPEX) will be taken int account:

- Cost of the rent of the surface of the plant on port.
- Cost of personnel for operation.
- Cost of maintenance of the plant.
- Energy cost.
- Insurances.

In addition, all investment costs (CAPEX) must be considered as a result of the acquisition of the necessary equipment for the construction of the storage plant (tanks, pumps, loading lines, loading arms, ...)

In chapter **3.2.6 Calculation of costs for Auxiliary Terminals**, there have been exposed all the costs associated with the main equipment required for the construction of the alternative storage in ports.

During the development of supply chains, it will be verified that the operation in terms of costs of the PTS mode from auxiliary terminals, will only be recommended in certain cases when there is a concession for a private fleet.

5.3.4 Summary comparison of means of bunkering

Based on the previous analysis, the following table summarises and compares the characteristics of the different bunkering means included in this study.

5-10.Means of bunkering - Comparison

	TTS	MTTS	STS	PTS
Market Availability	High	Low	Low	Low
Project time	Low	Medium	High	High[18]
Bunkering Rate	Low (<50 m^3/h)	Low (<200 m^3/h)	High (<2,000 m^3/h)	High
Pre/post bunkering times	Medium	High	Low	Medium
Location flexibility	High	High	High	Low
Required auxiliary storage	No	No	No	Yes
CAPEX	Low	Low	High	Medium[19]
OPEX	High	High	Medium	Low
Space usage	Low	Low	Low[20]	High
Vessels type flexibility	Low	Medium	High	Medium
Scheduling flexibility	High	High	Medium	Low
Weather exposure	Low	Low	High	Medium
SIMOPS	Possible	Not defined	Possible	Not possible
Safety requirements[21]	Low	Medium	High	Medium

[18] If civil maritime works are required
[19] If civil maritime works are not required
[20] If shoreside infrastructure is not required

[21] Safety distances (IR) and technology needed

6 REGULATED TAXES AND TARIFFS

Tariffs, taxes and tolls associated to feeder loading operations, truck loading operations and for pipe supply will be analysed.

Described hereunder are the regulated taxes and tariffs for the Spanish Terminals.

As soon as the tariff model in Portugal is updated it will be incorporated in the document.

6.1 REGASIFICATION FEE

In Spain regasification fees are defined by Article 29 of Royal Decree 949/2001, on 3 August, regulate third-parties access to gas facilities and establish an integrated economic system for the natural gas industry, where it is stated:

> "Regasification fee. The service fee of regasification will include the right to use facilities required for the unloading of vessels, transport to LNG plants, regasification or loading of LNG tanks and operating storage of LNG in equivalent plant to ten days of daily contracted capacity. The contracting of regasification fee will give the right to the contracting of LNG storage service in plant, additional to the included in this fee, for the necessary capacity for vessel unloading used in the LNG transportation, with the limit of the docking maximum capacity."

While in Article 30 is given the calculation of this regasification fee:

The fee based to the use of regasification facilities will be collected by the facilities owner and will have a fixed term, applicable to the daily flow to charge by user, and a variable term according to kWh effectively re-gasified or loaded in tank, and it will be calculated monthly in accordance with the following formula:

$$P_r = T_{fr} \cdot Q_r + T_{vr} \cdot C_r$$

In which:

P_r: monthly rate in euros of billing for regasification fee.

T_{fr}: fixed term of regasification fee in euro/kWh/day.

Q_r: daily flow of natural gas to bill in kWh/day or its equivalent in LGN.

T_{vr}: variable term of regasification fee in euro/kWh.

C_r: kWh of natural gas re-gasified or supplied as LNG by tanks in the billing period.

So, the daily flow to bill (Q_r) will be:

a) When maximum daily flow in the month for the user falls between 85-105% of billing maximum daily flow.

$$Q_r = Q_{rn}$$

Q_{rn}: nominal maximum daily flow in the month.

b) When nominal maximum daily flow in the month for the user is lower than 85% of billing maximum flow.

$$Q_r = 0.85 \cdot Q_{rn}$$

Q_{rd}: maximum daily flow billed by the user.

c) When nominal maximum daily flow for the user is higher or equal than 105% of billing maximum flow:

$$Q_r = Q_{rn} + 2 \cdot (Q_{rn} - 1.05 \cdot Q_{rd})$$

Q_{rn}: nominal maximum daily flow in the month.

Q_{rd}: maximum daily flow billed by the user.

On the other hand, fixed term (T_{fr}) and variable term (T_{vr}) of the fee formula are defined in the Order IET/2446/2013, of 27 December, which establishes the fees relating the third-parties access to gas facilities and the remuneration for regulated gas sector activities.

This Order establishes fixed and variable terms of fees for: regasification, unloading of vessels, loaded in tank and LNG bunker vessels and the variable for LNG storage by user. Established in the following quantities:

6.1.1 *Regasification fee*

Fixed (T_{fr}) and variable (T_{vr}) terms of fee corresponding to the use of regasification facilities:

T_{fr}: Fixed term of regasification fee: 0.019612 €/(kWh/day)/month.

T_{vr}: Variable term of regasification fee: 0.000116 €/kWh.

6.1.2 *Unloading of vessels fee*

The fee of LNG unloading service will include the right to use facilities needed for the downloading from vessels to regasification plant.

- Huelva, Cartagena and Sagunto plants:

T_{fd}: Fixed term of LNG unloading fee: 33,978 €/vessel.

T_{vd}: Variable term of LNG unloading fee: 0.000069 €/kWh.

- Bilbao, Barcelona and Mugardos plants:

T_{fd}: Fixed term of LNG unloading fee: 16,988 €/vessel.

T_{vd}: Variable term of LNG unloading fee: 0.000035 €/kWh.

6.1.3 *Truck loading fee*

The fee of LNG unloading service will include the right to use facilities needed for the loading of LNG tank trucks.

T_{fc}: Fixed term of LNG loading tanks fee: 0.028806 €/kWh/day/month.

T_{vc}: Variable term of LNG loading tanks fee: 0.000171 €/kWh

For billing of fixed term (T_{fc}), the result of divide the loading kWh in the month between 30 will be considered as daily flow. This flow will have the consideration of nominal maximum daily flow in the month (Q_{rn}) and the procedure of billing established for the regasification fee included in the Article 30 of Royal Decree 949/2001 will be applicate.

By considering one annual contract with a common commercialization company, the calculation methodology can be simplified applying the coefficients to fixed terms, according 10.3 article.

6-1 Coeficient table for regas capacity contracted

COEFFICIENTS	INTRADIARY	DIARY	MONTHLY	QUATERLY	ANNUAL
January-17	0.25	0.15	2.3	1.91	1
February-17	0.22	0.13	2	1.91	1
March-17	0.21	0.13	1.9	1.91	1
April-17	0.16	0.09	1.4	1.21	1
May-17	0.16	0.09	1.2	1.21	1
June-17	0.13	0.08	1	1.21	1
July-17	0.14	0.08	1.2	1.08	1
August-17	0.11	0.07	1	1.08	1
September-17	0.13	0.08	1.2	1.08	1
October-17	0.15	0.09	1.3	1.36	1
November-17	0.16	0.09	1.4	1.36	1
December-17	0.18	0.11	1.6	1.36	1

For the cost of tanker load, there have been considered the tolls and fees associated with the access of thirds to gas installations and gas units in Spain for the 2017 fiscal year and published in Order ETU/1977/2016, dated December 23, (BOE 12/29/2016).

In order to have an approximation of cost of load of tanks, it has been considered an "ideal" hypothetical case, of a potential customer with a demand of 200 cisterns per year for the bunker of its fleet.

The assumptions are as follows:

1) Make an ANNUAL contract with a marketer
2) Quantity of contracted energy: 60,000,000 kWh/year (60 GWh/year)
3) Contracted Monthly Quantity (CMC) = 5,000,000 kWh/month (60/12 months), which corresponds to a daily maximum contracted flow (Qrd) considering 30 days, of 166,666.67 kWh
4) Stable consumption of 5,000,000 kWh (5 GWh/month), Real Monthly Amount (CMR), in this case, the daily flow to be invoiced would coincide with the contractor and the nominee (Qr = Qrn), 166,666.67 kWh

Calculation of the cost of the load:

Tfc = 166,666.67 kWh x 0.028806 €/kWh/day/month x 1 (annual contract coefficient= = 4,801.00 € (month))

Tvc = 5,000,000.00 kWh x 0.000171 €/kWh = 855.00 €

TOTAL = Tfc + Tvc = 5,656.00 € / 5,000.00 MWh = 1.1312 €/MWh

This price will vary according to the type of contract, the CMR, whether or not 85% of the CMC is reached, or if it exceeds 105% of the CMC, or by a change in tariffs.

6.1.4 LNG bunker vessels fee

a) Bunkering vessels services by regasification plants for LNG volume higher than 9,000 m^3:

Fixed term: 176,841 €/operation.

Variable term: 0.001563 €/kWh.

b) Bunkering vessels services by regasification plants for LNG volume equal or lower than 9,000 m^3:

Fixed term: 87,978 €/ operation.

Variable term: 0.000521 €/kWh.

c) Ship to ship bunkering service without LNG plant storage a fee of 80% the previous value will be applied.

d) For operations from cold vessel by regasification plants the following fee will be applied:

Fixed term: 71,610 €/operation.

Variable term: 0.001563 €/kWh.

Regarding official fees for the transfer of LNG to ships, it is concluded that these rates would make LNG loading in import terminals unfeasible, especially when using small capacity barges, so competent authorities are working on adapt this fees to small scale market. For this reason, this report will consider **a 50% reduction in both terms for vessels under 15,000 m^3 until a new proposal is approved.** This assumption should be revised under the findings of this project. A sensibility analysis of the impact of this tariff on the overall logistic chain cost will be performed in WP3.

6.1.5 LNG storage fee by user

The fee variable term corresponding to LNG storage will be the following:

Tv (€/kWh/day): 32.4 €/kWh/day

This fee will be applied for all the LNG storage by the user.

In addition, for short-term contracts (per month or per day) the following coefficients will be applied:

- Monthly contracts:
  - From October to March. Fixed term is multiplied by 2.
  - From April to September. Invariable.
- Daily contracts:
  - From October to March. Fixed term is multiplied by 0.10.
  - From April to September. Fixed term is multiplied by 0.06.

6.2 PORT FEES AND TARIFFS FOR PORT SERVICES

When the price of the different port fees is calculated, the economic context of each port must be considered both in Spain and Portugal.

Spanish Port Authorities can propose three correction coefficients each year, these factors will be applied respectively to ship, passenger and merchandise fees. The port authorities' independence causes a huge variation between port fees, showing wide variance among tariffs and fees in different ports. This situation obliges us to make general assumptions to assess the port fees cost and does not take in account any port especial bonification unless it has a national implantation.

A study of Portuguese tariffs has been carried out, this study is in the Annex 3. From the study, it has been concluded that the tariffs in Spain and Portugal are close, so that, as a reference in the calculation of the logistics chains the Spanish average will be considered.

Fees which affects bunkering service are described:

6.2.1 Occupancy fee (T-C)

The taxable event of this fee consists on the occupation of the public port domain, and of its soil and subsoil, associated water surface by virtue of the concession or authorization, and includes the provision of common port services related to the occupied public domain.

In the Spanish ports of general interest, according to tittle 7, chapter 4, section 2 of "Texto Refundido de la ley de Puertos Del Estado y la Marina Mercante" in the future refer as the TRLPEMM, occupancy fee is calculated as result of the land value.

Ports have different land valuations for different part of its domain. Making a land value calculation would involve studying every area price valuation (€/m²) on each port and knowing in advance the actual location where the infrastructure is going to be placed. For this study, the approach taken was to analyse the value land in zones where auxiliary terminals are more likely to be placed in the Spanish's port system and yielding an estimated average value of **11.44 €/m² per year**

Portuguese occupancy fee has been studied too, as a result, the price of the soil is in the range of values in Spain.

The annual occupancy fee according to the Spanish Port Legislation should be set as a 6% share of the land cost:

$$T - C\left(\frac{€}{\text{year}}\right) = Land\ value\left(\frac{€}{\text{m}^2}\right) \cdot 0.06 \cdot Alocated\ Area\ (\text{m}^2)$$

The evaluation of the land costs has been realized for the 7 ports and it is showed in the following table:

6-2 Land cost evaluation

	Málaga	Ceuta	Tarragona	Algeciras	Palma
Port Area	VI	F	III1	Isla Verde	West dock
Land value (€/m²)	125	112	112	95	560
Annual value of license (€/m²)	7.5	6.72	6.72	5.7	33.6

6.2.2 Activity fee (T-A)

The taxable event of this fee consists on the exercise of commercial, industrial and service activities in the public port domain, subject to authorization by the Port Authority.

According to tittle 7, chapter 4, section 3 of TRLPEMM, activity fee is calculated as function of activity developed based or a measurable unit. This fee should be stablished by Port Authorities using the general criteria provided by regulation, where the maximum limit is:

- 0.66 € per ton for liquid bulks cargoes
- 6% of revenues for business performed in the port premises
- 100% of occupancy fee

Being LNG bunkering a new, innovative business and beneficial activity for the port system, it is assumed activity fees should be in the low range, therefore **activity fees will be limited to a 2% share of the activity revenues if there is not privative land occupation and if there is privative land would be at least 20% of occupancy fee**

6.2.3 Vessels fee (T-1)

According to tittle 7, chapter 4, section 4 of TRLPEMM. This fee is paid by ship owners for the use of their vessels of the service area of the port and port facilities, that allow the maritime access to the berth or anchorage area, during their stay. It is included in this rate the provision of common services offered by the hosting Port Authority.

According to tittle 7, chapter 4, section 4, article 197 of the TRLPEMM, the vessel fee should be calculated according to the equation below:

$$T1\ (€) = \frac{GT}{100} \cdot Spend\ time\ (h) \cdot Basic\ quota\ (B\ o\ S) \cdot Correction\ factor \cdot Bonification$$

If a vessel is staying at port for long periods, vessel fees are to be measured in days and a special coefficient is added factoring the kind of vessel. For a bunkering vessel, this coefficient is established as 4,67.

Shortsea navigation basic quota (S) is 1,20 € and deep-sea navigation (B) 1,43 €, for bunkering and feeder service the (S) quota will be considered.

Correction factor accounts for the existence of a concession associated to the mooring space. This factor implies a reduction of fees to vessels with land, berths or other port infrastructure under concession. These factors are going to be considered when the vessel scales for LNG loading in regas terminals, where jetties are licensed by Spanish natural company, Enagas making the basic quota S reduced to 0,72 €.

Port Authorities can promote certain cargo traffics or port services through bonifications, reducing the fees under certain conditions. Some examples could be the reduction fees for base port cruises or reductions associated to good environmental practises. Reviewing port authorities' bonifications it is observed most of Port Authorities apply reductions associated with good environmental practices. This bonification averages 20% and can reach 50% if the vessel is fuelled by LNG like dedicated barges and vessels included in this study.

Taking all items on account, the final equation for estimate the T-1 fee for the bunkering vessel in its base port is:

$$T1\ (€) = \frac{GT}{100} \cdot 4{,}67 \cdot Time\ (days) \cdot Basic\ quota\ (S) \cdot Enviromental\ Bonification$$

$$T1\ (€) = \frac{GT}{100} \cdot 4{,}67 \cdot Time\ (days) \cdot 1{,}2 \cdot 0.5 = 2.802 \cdot Time\ (days) \cdot \frac{GT}{100}$$

The equation for T-1 in regas terminal will be:

$$T1\ (€) = \frac{GT}{100} \cdot Time\ (hours) \cdot Basic\ quota\ (S) \cdot Enviromental\ Bonification$$

$$T1\ (€) = \frac{GT}{100} \cdot Time\ (hours) \cdot 0.72 \cdot 0.5 = 0.36 \cdot Time\ (hours) \cdot \frac{GT}{100}$$

600 m^3 and 1,200 m^3 multiproduct barge that are not fuelled with LNG will not have a 50% reduction

6.2.4 Goods fee. (T-3)

According to tittle 7, chapter 4, section 4, article 211 of the Spanish Port Legislation the T-3 fee is associated to the passage of goods through the port, both on the sea and land side as well as their transport elements, berthing facilities, handling areas associated with loading and unloading of the ship, internal road, external road access, and other port facilities, including their stay in areas of the service area that are designated as transit zones by the Port Authority.

According to the Spanish Port Legislation, T-3 fee should be calculated as shown in the equation below, where the measurable unit is the amount of fuel served, the basic quota is established by Port Authorities (2.95) and a correction coefficient by nature of good served. Additionally, a reduction of 75% is done when goods are in transit.

$$T3 = measurable\ unit \cdot basic\ quota \cdot correction\ coefficient \cdot Bonifications$$

Natural gas belongs to second group of goods established by Annex III of the Spanish Port Legislation, so it has a coefficient of 0.27. Considering other bonification applied to natural gas in Port Authorities it reasonable to estimate **an average value of 0.8 €/t for goods that are not in transit (applicable to bunkering) and 0.2 €/t if it is (applicable to feedering).**

6.2.5 MARPOL fees (T-M)

Spanish ports trying to avoid illegal garbage discharge and others way of marine pollutant oblige every vessel scaling in port to pay the removal service of garbage and cargo residues according to MARPOL I and V annexes. This service includes every waste of MARPOL Annexes I and V generated on board during a week and if the vessel stays for more than that in port it would have to arrange the service with port's licensed companies for waste removal.

Calculation of MARPOL fee per call depends on the vessel size and implies a simple calculation as it is shown below:

$$T - MARPOL\ (€) = M \cdot B$$

6-3.MARPOL I and V fees coefficients

GT	M	B
0-2,500 GT	80	1.5
2,500-25,000 GT	80	6·0.0001·GT
25,000-100,000 GT	80	(1.2·0.0001·GT) +12
+ 100,000 GT	80	24

Applying to a bunkering barge or vessel with GT ranges of 2,000-5,000 GT the amount paid for a scale that includes MARPOL I and V will vary between 120 € and 240 €.

Vessels dedicated to provide port services could be exempted from MARPOL fees if they directly negotiate their residues services with MARPOL supplier in private terms, if not, they can pay every week the price for one scale to Port Authorities. Average cost of a private service of MARPOL annex I and V for a bunkering barge range will be in the range of 8,000 € – 12,000 € and will have a maximum cost of 13,000 € for a 5,000 GT barge if the service is provided by Port Authorities.

6.2.6 *Container movement tariff*

According to a recent study published by the **Spanish Port Services Observatory** [22] it is estimated that the unitary price to operate a container load or to unload a container is:

20' container: 99.56 €

40' container: 107.14 €

Adding the estimated industrial margin of 6% from the same study (pg. 56) and the hazardous goods surcharge of 25%, the estimated cost of handling a 40' ISO container would be approximately: **142€ per movement**.

6.2.7 *Truck movement tariff*

According to a 2015 study published by the **Spanish Port Services Observatory** [23] it is estimated that the average cost to load/unload a truck onto a RORO vessel is around 78 €. This tariff brought to 2017, adding margin and hazardous goods surcharge results in **105/€ per movement** for a LNG truck.

6.2.8 *Mooring tariff*

Mooring is considered a port service so is provided by external companies under the regulation of Port Authorities. Price of service normally depends on the size of the vessel berthed and the port where the action is made.

According to the 2013 annual report from the Spanish Port Service Observatory [24] the average cost for mooring a vessel between 1,000 and 10,000 GT in Spain is **121 € per mooring service**.

6.2.9 *Pilotage tariff*

Pilotage is considered a port service so is provided by an external company under the regulation of Port Authorities. Price of pilotage depends on the size of the vessel served and the port where the service is provided.

According to the previously mentioned 2013 annual report the average cost for a vessel operation between 1,000 and 10,000 GT in Spain is **275 € per pilotage service**.

[22] Estudio de la cadena de costes del contenedor 2016.
[23] Estudio de la cadena de costes para el tráfico de carga rodada en terminales españolas 2015
[24] Informe Anual de Competitividad de los Servicios Portuarios Año 2013

6.2.10 Summary of port fees on bunkering solutions

Depending on the bunkering solution the fees applied could be different. In the next tables, it is described how port fees are applied depending on the solution and the summary of costs applied to the study:

6-4. Port fees on bunkering solution

	T-C	T-A	T-1	T-3	T-M
Auxiliary Terminal	x	x		x	
CTS		x		x	
TTS		x		x	
STS		x	x	x	x
Feeder		x	x	x	x
Small-scale liquefaction	x	x		x	

6-5. Estimated Port fees

	Unit	Value
Occupancy fee (T-C)	€/m² yearly	11.44
Activity fee (T-A)	Share of Business in port	2%
Vessel fee T-1 Bunker Vessel	€·day/100GT	2.802
Feeder Vessel	€·hour/100GT	0.36
Goods fee T-3	€/t supplied	0.8
In Transit	€/t supplied	0.2
MARPOL V T-M <2,500 GT	€/scale	120
MARPOL V T-M >2,500 GT	€/ GT·scale	0.048

6-6. Estimated costs of port services

	Unit	Value
Container movement	€/movement	142
Truck movement	€/movement	78
Pilotage <10,000GT	€/manoeuvre[25]	275
Mooring	€/manoeuvre[26]	121

25 A regular scale needs 2 manoeuvres

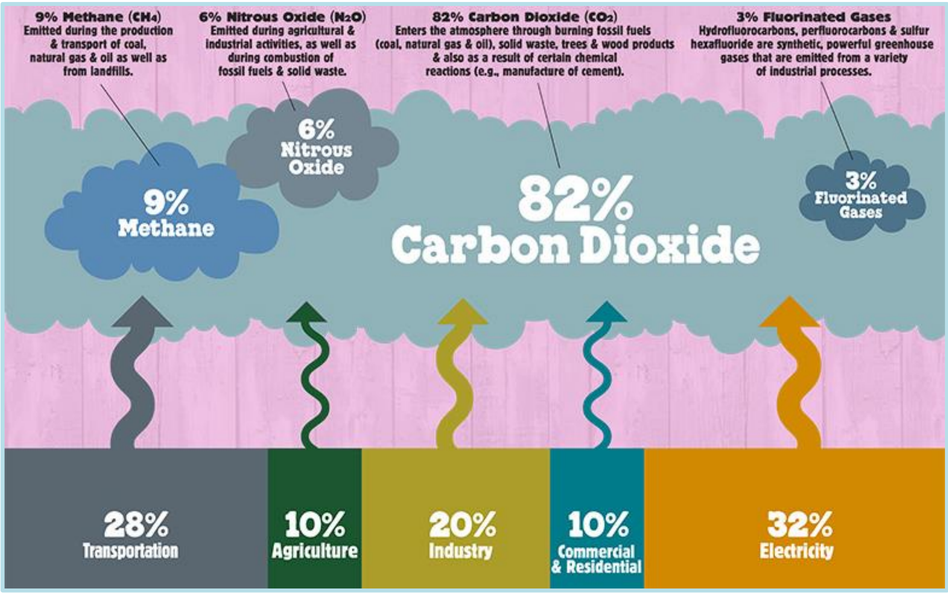
26 A regular scale needs 2 manoeuvres

7 GREENHOUSE GASES (GHG) EMISSIONS

7.1 *INTRODUCTION*

A greenhouse gas (often abbreviated as GHG) is a gas that both absorbs and emits radiation in the infrared range, commonly called thermal radiation or heat. When present in the atmosphere, these gases trap radiation in the form of heat, causing a warming process called the greenhouse effect.

Carbon dioxide and methane are the most important greenhouse gases emitted by humans, but several other gases contribute to climate change, too.



7-1. Greenhouse gas pollution Source: EPA

7.2 *IDENTIFYING AND CALCULATING GHG EMISSIONS*

Generally, GHG emissions calculation uses the following steps:

- Identify GHG emissions sources
- Select a GHG emissions calculation approach
- Collect activity data
- Apply calculation tool

7.2.1 *Identify GHG emissions sources*

For CORE LNGas Hive will be accounted for and reported emissions from **scope 1** (direct GHG emissions occur from sources that are owned or controlled by the company).

GHG emissions typically occur from the following source categories:

- **Stationary combustion**: combustion of fuels in stationary equipment such as boilers, turbines, heaters, engines, etc. This point will be described in the followings WPs.
- **Mobile combustion**: combustion of fuels in transportation devices such as trucks, trains, boats, ships, barges, vessels, etc. This point will be described in the followings WPs.
- **Venting emissions:** these are emissions which are not captured or routed from boil-off (BOG).

- **Fugitive emissions:** intentional and unintentional releases such as equipment leaks from valves, flanges, etc.

7.2.2 Select a GHG emissions calculation approach

GHG Protocol will be used for the calculating of GHG emissions. It is the international tool widely used for calculating and communication of gas emission inventory.

The Greenhouse Gas Protocol was launched in October 2001 by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI), with businesses, governments, and environmental groups from around the world for building a new generation of effective and credible programme to address climate change.

7.2.3 Collect activity data

Regarding combustion emissions, these will be calculated based on the purchased quantities of commercial fuels (such as natural gas, diesel, gasoline) in each studied chain.

In this WP1 will be studied on the one hand venting emissions, which are releases to the atmosphere as a result of the process or equipment design or operational practices. In this project venting emissions from storage, loading and unloading and pipeline transfer have been considered.

In other hand, fugitive emissions are related with any pressurized equipment that has the potential to leak where two surfaces meet in a non-welded or otherwise non-bonded manner, these leaks generally occur through valves, flanges, threaded connections, pumps or related equipment.

7.2.4 Apply calculation tool

It will be need more than one calculation tool to cover all their GHG emission sources, for this cross-sector tools will be applied. These include stationary combustion, mobile combustion and fugitive and venting emissions.

7.3 CARBON FOOTPRINT

Carbon footprint is the total of greenhouse gas emissions released into the atmosphere produced by an individual, an activity, a product or an organization generally expressed in tons of carbon dioxide.

7.3.1 Calculating carbon footprint by venting emissions

Venting emissions of CH_4 are produced when vented gas streams are not recovered, or rerouted back to the fuel gas system. It also includes operations such as blowdown from compressors or other equipment for maintenance. According to the IPCC recommendations for national GHG inventories, this category includes emergency venting that is not recovered.

Vented emissions are releases to the atmosphere as a result of the process or equipment design or operational practices. Vented emissions may come from a variety of non-fired stacks and vents, which tend to be very specific to the type of operation. However, for LNG operations the primary design characteristic is that all BOG is captured and returned to storage tanks, consumed as fuel, or fed into a boil-off gas recondenser.

Throughout the LNG operations chain, there are nominal methane emissions due to the liquefaction and revaporization of natural gas. LNG being a cryogenic liquid requires maintenance of a thermodynamic equilibrium near its boiling point. For example, for LNG storage tanks, BOG may be, less commonly, vented, if the vapor generation rate exceeds BOG compressor(s) or reliquefication unit capacity. Similarly, during LNG loading or unloading, compression is required to capture BOG which is either returned it to a storage tank, used as fuel, reliquefied, or routed it to a recondenser.

Methane are also vented or lost to the atmosphere if the BOG is not captured during pipe transfer of LNG, either during loading for transport, off-loading for storage or vaporization.

Then, it is addressed such potential natural gas emissions sources targeting primarily emissions associated with storage of LNG due to heat ingress and loading and unloading of LNG by pipe transfer.

In Table 7.1 it is listed typical loss rates for storage and loading and unloading of LNG if methane is not captured (note this is the exception, not the normal design approach). The listed loss rates provided in Table 7.1 should be used to estimate potential CH4 emissions only if these emissions are not captured. The data in Table 7.1 could also be useful to assess the potential for GHG emission reductions when operational changes are being implemented.

7-1. Typical loss rates from storage and loading and unloading

Source	Typical loss rate	Units
BOG from storage tanks[27]	0.05 %	Of total tank volume per day
BOG from vessel during shipping[28]	0.15 %	Of total ship storage volume per day
Transfer pipe loss[29]	0.00012 %	Per km LNG transfer pipe[30]

These natural gas emissions are composed, practically in this entirety, for methane (CH_4). Therefore, tonnes of CO_2e can be obtained considering that methane has a global warming potential of:

7-2. Global Warming Potential (GWP) values relative to CO2

Gas Name	GWP values for 100-year time horizon		
	Second Assessment Report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Carbon dioxide (CO2)	1	1	1
Methane (CH4)	21	25	28

27 D. Féger, "An innovative way of reducing BOG on existing or 'new built' LNG storage tanks". Proceedings LNG16 Congress, Algeria, April 2010.
28 Sempra LNG, "GHG life-cycle emissions study: U.S. Natural Gas Supplies and International LNG", November 2008.
29 B. Kitzel, "Choosing the right insulation", LNG Industry, Spring 2008.
30 Based on LNG transfer rate of 13,000 m3/h.

This table is adapted from the IPCC Fifth Assessment Report, 2014 (AR5)[31]. The AR5 values are the most recent, but the second assessment report (1995) and fourth assessment report (2007) values are also listed. The use of the latest (AR5) values is recommended.

For this project, it is considered the last Assessment Report for the calculations, it is CH4 is 28 times more global warning potential respect to CO_2 (Source: Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPPC).

For GHG Protocol will be used this figure for the calculating of Chain GHG emissions in the followings WPs.

In the following table, the carbon footprint is showed for several tank and ship storage volume and km transfer pipe, assuming emissions are not captured:

7-3. Carbon footprint. Storage and pipe. Source: ICC

Source	tCO_2e
Storage tank. 100 m^3	0.63 per day
Storage tank. 300 m^3	1.89 per day
Storage tank. 1,000 m^3	6.3 per day
Ship storage. 600 m^3	11.34 per day
Ship storage. 1,200 m^3	22.68 per day
Ship storage. 5,000 m^3	94.5 per day
Transfer pipe. 0.1 km	0.02 per transfer of 13,000 m^3/h
Transfer pipe. 0.5 km	0.1 per transfer of 13,000 m^3/h
Transfer pipe. 1 km	0.2 per transfer of 13,000 m^3/h

7.3.2 Calculating carbon footprint by fugitive emissions

Fugitive emissions are defined as unintentional emissions that could not reasonably pass through a flare or exhaust stack, chimney, vent, or another functionally-equivalent opening. Any pressurized equipment has the potential to leak where two surfaces meet in a non-welded or otherwise non-bonded manner; these leaks generally occur through valve stems, flanges, threaded connections, pump or compressor shaft seals, or related equipment.

It is based on counts or estimates of the population of different component types (valves, flanges, threaded connections, pumps, et.) and applying the corresponding emission factors to the components population to derive total emissions.

31 Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G.Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

It is easy to apply since it requires only knowledge of the counts of valves, pumps or connectors used in each chain.

Table 7.4 presents a set of default methane emission factors for components and devices in LNG storage and loading and unloading. These factors represent average emissions per hour per component. For quantifying total fugitive methane emissions for each operation, the number of components in each of the specified categories and their hours of operation will have to be considered.

7-4. Default methane emissions factors per component population in LNG storage

Component	CH_4 emission factor (t/h)[32]
Valve	0.015 per component
Pump	0.05 per component
Connectors (flanges or threaded)	0.0045 per component

In the following table, the carbon footprint is showed for each component per day, whereas each component operates 12 hours a day:

7-5. Carbon footprint. Component. Source ICC

Component	tCO_2e/day
Valve	5.04 per component
Pump	16.8 per component
Connectors (flanges or threaded)	1.51 per component

Once the chains are completed, this carbon footprint of venting and fugitive emissions will be added to the corresponding to stationary and mobile combustion. For each chain, its carbon footprint will be calculated in the followings WPs.

7.4 BIBLIOGRAFY

- Global Warming Potential Values. Greenhouse Gas Protocol, 2016.
- The Greenhouse Gas Protocol. World Resources Institute & World Business Council Sustainable Development, 2004.
- Consistent Methodology for Estimating Greenhouse Gas Emissions in LNG Operations. Energy API, 2015.
- GHG Intensity of Natural Gas Transport. ThinkStep, 2017.
- Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry. Energy API, 2009.

32 US Environmental Protection Agency, Federal Register.

ANNEX 1. CONSTANTS TABLE

ECONOMICAL VALUES		
Change $/€	-	1.15
Interest rate	-	4.5%
Truck Residual Value	-	15%
Vessel Residual Value	-	15%
Margin & structure cost	-	15%
ENERGY PRICES		
Electricity Price	€/MWh	80 €
GNL Price	€/MWh	22 €
MDO	€/MWh	42 €
BUNKERING AND TRANSPORT PRICES		
Vessel activity days	-	360
Truck Road trip	€/km	1.2 €
Truck immobilization	€/h	50 €
Truck unloader staff	€/unit	200 €
Truck unload cost	€/unit	150 €
Sea voyage 1 (truck)	From La Palma Port to Barcelona	2,080 €
Sea voyage 2 (truck)	From La Luz and Las Palmas Port fromto Huelva	3,000 €
Sea voyage 3 (truck)	From Caniçal Port to Sines	3,000 €

PORT FEES AND TARIFFS		
Vessel Load in Terminal	€/MWh	2 €
Truck Load in Terminal	€/MWh	1.13 €
General T-1	€·hour/100GT	0.72
Bunkering vessel T-1	€·day/100GT	5.604
T-1 reductions	%	-
T-1 bonifications	% (LNG fuelled vessels)	50
Land cost	€/m^2	11.44 €
T-3	€/t	1 €
T-A	Business share on port	2%
T-M <2,500 GT	€	120 €
T-M <25,000 GT	€/GT	0.048
Mooring	€/manuover	121 €
Pilotage	€/manuover	273 €
Stevedoring container	Service	107 €
Stevedoring truck	Service	78 €

ANNEX 2. ABBREVATIONS

ADR: European Agreement concerning the International Carriage of Dangerous Goods by Road

AISI: American Iron and Steel Institute

ASME: American Society of Mechanical Engineers

BOG: Boil-off gas

CE: "Conformité Européenne"

DOT: Department of Transportation

ESD: Emergency Shutdown Device

HFO: Heavy Fuel Oil

IMO: International Maritime Organization

LNG: Liquefied Natural gas

LOA: Length Overall

LPP: Length between perpendiculars

M/V: Motor vessel

MDO: Marine DieselOil

MGO: Marine GasOil

PTS: Pipe to ship

STS: Ship to ship

TPA: Tonnes per annum

TPD: Tonnes per day

TPED: Transportable Pressure Equipment Directive

TTS: Truck to ship

UNE: Una Norma Española

ANNEX 3. PORTUGUESE TARIFFS

It is going to be studied port tariffs in Portugal due to the project is developed in the Iberian Peninsula, so Portugal ports are included too. Ports studied are:

- Lisbon
- Leixoes
- Madeira
- Sines
- Setubal

In Spain, port legislation is at the state level, but in Portugal is a local legislation, so each port has its own tariffs. Portuguese ports do not include activity fee (T-A) in the use of land inside the port, as happens in Spanish ports, in Portugal only exists the tariff for the use of the land.

In every port is going to be detailed the following tariffs:

- Port use tariff
- Pilotage fee
- Mooring tariff
- Occupancy fee

Once it is now the tariffs a comparison between the tariffs in Spain and Portugal will be done.

1. Tariff for port use

TUP equals to the Spanish vessel fee (T-1).

	€ per GT
Lisboa	0.160
Leixoes	0.190
Madeira	0.120
Sines	0.491
Setubal	0.123

2. Pilotage fee

Pilotage fee equals to the Spanish pilotage tariff, it is calculated per manoeuvre according to

$$Pilotage\ fee = Cn \cdot UP \cdot \sqrt{GT}$$

Where:

	Cn
Lisboa	1
Leixoes	1.1
Madeira	1.1
Sines	1
Setubal	1

	UP
Lisboa	2.65
Leixoes	6.56
Madeira	5.90
Sines	6.12
Setubal	8.14

3. Mooring tariffs

- Lisbon

Lisbon port includes tow and mooring tariff in the pilotage tariffs.

- Leixoes

Mooring tariff in Leixoes is:

GT	€/manoeuvre
1,000-4,999	120.0503

- Madeira

Mooring tariff in Madeira is 226€ per operation and hour.

- Sines

Mooring tariff in Sines is included in pilotage tariff, towage tariff is included too.

- Setubal

Mooring tariff is included in pilotage tariff.

4. Occupancy fee

Occupancy fee equals to the Spanish occupancy fee (T-C).

- Leixoes

Unit	€
m^2 per month	2.6

- Madeira

Area per m^2 per month	€
1 - 10 m^2	115
11 - 49 m^2	10.35
50 - 99 m^2	8.63
100 - 999 m^2	8.05
1,000 – 1,999 m^2	5.75
> 2,000 m^2	3.45

- Setubal

Unit	€
m^2 per year	5.695

5. Comparison with Spanish tariffs

	Vessel capacity (m^3)	1,200	3,000	5,000	7,500	10,000
	GT	2,743	2,100	7,403	6,850	5,000
Lisboa	T1	439	336	1,184	1096	800
E		474	363	1,279	1,184	864
Lisboa	Pilotage	139	121	228	219	187
E		275	275	275	275	275
Lisboa	Mooring					
E		121	121	121	121	121
	T3	69	173	288	431	575
	Total Lisboa	578	457	1,412	1,315	987
	Total Spain	939	931	1,963	2,011	1,835

	Vessel capacity (m^3)	1,200	3,000	5,000	7,500	10,000
	GT	2,743	2,100	7,403	6,850	5,000
Leixoes	T1	521	399	1407	1302	950
ES		474	363	1279	1184	864
Leixoes	Pilotage	378	331	621	597	510
ES		275	275	275	275	275
Leixoes	Mooring	120	120	120	120	120
ES		121	121	121	121	121
	T3	69	173	288	431	575
	Total Leixoes	1,019	850	2,147	2,019	1,580
	Total Spain	939	931	1,963	2,011	1,835

	Vessel capacity (m³)	1,200	3,000	5,000	7,500	10,000
	GT	2,743	2,100	7,403	6,850	5,000
Madeira	T1	329	252	888	822	600
ES		474	363	1,279	1,184	864
Madeira	Pilotage	340	297	558	537	459
ES		275	275	275	275	275
Madeira	Mooring	226	226	226	226	226
ES		121	121	121	121	121
	T3	69	173	288	431	575
	Total Madeira	895	775	1,673	1,585	1,285
	Total Spain	939	931	1,963	2,011	1,835

	Vessel capacity (m³)	1,200	3,000	5,000	7,500	10,000
	GT	2,743	2,100	7,403	6,850	5,000
Sines	T1	1,347	1,031	3,635	3,363	2,455
ES		474	363	1,279	1,184	864
Sines	Pilotage	321	280	527	507	433
ES		275	275	275	275	275
Sines	Mooring					
ES		121	121	121	121	121
	T3	69	173	288	431	575
	Total Sines	1,667	1,312	4161	3,870	2,888
	Total Spain	939	931	1,963	2,011	1,835

	Vessel capacity (m³)	1,200	3,000	5,000	7,500	10,000
	GT	2,743	2,100	7,403	6,850	5,000
Setubal	T1	337	258	911	843	615
ES		474	363	1,279	1,184	864
Setubal	Pilotage	426	373	700	674	576
ES		275	275	275	275	275
Setubal	Mooring					
ES		121	121	121	121	121
	T3	69	173	288	431	575
	Total Setubal	764	631	1,611	1,516	1,191
	Total Spain	939	931	1,963	2,011	1,835

6. Summary

The values of the Portuguese tariffs have been average between the Portuguese ports studied.

	Vessel capacity (m³)	1,200	3,000	5,000	7,500	10,000
	GT	2,743	2,100	7,403	6,850	5,000
PT	T1	595	455	1605	1,485	1,084
ES		474	363	1279	1184	864
PT	Pilotage	321	281	527	507	433
ES		275	275	275	275	275
PT	Mooring	69	69	69	69	69
ES		121	121	121	121	121
	T3	69	173	288	431	575
	Total Portugal	**985**	**805**	**2,201**	**2,061**	**1,586**
	Total Spain	**939**	**931**	**1,963**	**2,011**	**1,835**