Feasibility analysis report for the definition of technical scenarios, commercial plan and emissions performance of a mobile LNG electricity generator for OPS

Deliverable D6.1

Public WEB version

Deliverable responsible: Flota Suardiaz

CORE LNGas hive

Core Network Corridors and Liquefied Natural Gas

2014-EU-TM-0732-S

D 6.1 – Feasibility analysis report for the definition of technical scenarios, commercial plan and emissions performance of a mobile LNG electricity generator for OPS

Revision: Final version

Public web version

Due date of deliverable: 2017/01/31

Actual submission date: 2017/10/16

Start of project: 01 January 2014 Duration: 60 Months

Lead Contractor for this deliverable: Port Authority of Barcelona (APB)

Co-financed by the European Union
Connecting Europe Facility

Dissemination level		
PU	Public	x
CO	Confidential, only for members of the consortium (including the Commission Services)	

Revision History

Deliverable Administration and summary		
Project Acronym: CORE LNGas Hive	INEA/CEF/TRAN/M2014/1026196	
Document Identifier: TECHNICAL ANALYSIS (formato Core)_180725_web2		
Leading partner: Port Authority of Barcelona		
Report version: Final Version, public web version		
Report preparation date: 2018/10/16		
Classification: Public Web Technical Report		
Nature: Technical Report		
Author(s) and contributors: **All partners (Leading by Rafael Rolo, Suardiaz, and Jordi Vila, APB)**		
Status		Plan
		Draft
		Working
	x	Final
		Submitted
		Approved

The Core LNGas Hive consortium has addressed all comments received, making changes as necessary. Changes to the document are detailed in the change log table below.

Date	Edited by	Status	Changes made

Citation

Rafael Rolo (Flota Suardiaz) 2017 D6.1 –Feasibility analysis report for the definition of technical scenarios, commercial plan and emissions performance of a mobile LNG electricity generator for OPS. CORE LNGas Hive consortium, **www.corelngashive.eu**

Acknowledgements

The work presented in this document has been conducted in the context of the action INEA/CEF/TRAN/M2014/1026196 CORE LNGas Hive. CORE LNGas HIVE is a 60 months project started on January 1st, 2014.

The project consortium is composed by: Enagás Transporte, S.A.U. (Enagás), Sociedad de Salvamento y Seguridad Marítima (SASEMAR), Universidad Politécnica de Madrid (UPM), Universidade de Santiago de Compostela (USC), ENTE VASCO DE LA ENERGÍA (EVE), Autoridad Portuaria de Barcelona - Port de Barcelona (APB), Port Authority of Cartagena (PAC), AUTORIDAD PORTUARIA DE FERROL-SAN CIBRAO (APF), Autoridad Portuaria de la Bahía de Algeciras (APBA), Port Authority of Huelva (PAH), COMPAÑÍA ESPAÑOLA DE PETRÓLEOS S.A.U. (CEPSA), Regasificadora del Noroeste, S.A. (RdN), HAM CRIOGENICA, S.L. (HAM), BUREAU VERITAS IBERIA SLU (BVI), SIEMENS ENGINES S.AU. (OLD GUASCOR POWER SA (GP)), IDIADA AUTOMOTIVE TECHNOLOGY S.A (IAT), FLOTA SUARDIAZ, S.L. (Suardiaz), ITSAS GAS BUNKER SUPPLY SL (ITSAS), COMPAÑIA DE REMOLCADORES IBAIZABAL, S.A. (IBAI), TERMINAL DE CONTENIDORS DE BARCELONA, S.L. (TCB), Terminal Catalunya, S.A. (TC), UTE REMOLCADORES DE BARCELONA-SAR, UNION TEMPORAL DEEMPRESAS, LEY 18/1982 (URB), ASTILLEROS ARMON, S.A. (AA), GAS NATURAL SDG, S.A. (GN), INSTITUTO ENERXÉTICO DE GALICIA (IEG), Fundación de la Comunidad Valenciana para la Investigación, Promoción y Estudios Comerciales de Valenciaport (Fundación Valenciaport) (FV), Planta de Regasificación de Sagunto, S.A. (PRS), MOLGAS ENERGÍA, SAU (ME), Autoridad Portuaria de Valencia (APV), SEAPLACE SL (Seaplace), BOLUDA CORPORACION MARITIMA S.L. (BCM), Autoridad Portuaria de Bilbao (APBi), RENFE MERCANCÍAS S.A. (Renfe), Puertos del Estado (PdE), Dirección General de la Marina Mercante (DGMM), PORT AUTHORITY OF GIJON (PAG), Port Authority of Melilla (PAM), Santander Port Authority (SPA), Port Authority of Tarragona (PAT), Port Authority of Vigo (PAV), Port Authority of Santa Cruz de Tenerife (PASCT) and REN Gasoductos, S.A. (RENG).

More Information

Public CORE LNGas HIVE reports and additional information related with the project execution and results are available through CORE LNGas Hive public website at **www.corelngashive.eu**

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1. Introduction

The EPT1 Sub-activity of the Core LNGas hive project aims to provide new solutions to reduce atmospheric emissions in ports. The construction of an LNG electricity generator allows the reduction of emissions, principally particulate matter, NOx, as well as Sox or CO_2.

The construction of the shore-side electricity (cold ironing) can be very expensive and technically complex in many of the ports and docks, so the gas generator can be a viable and flexible solution. Also the generator has been classified for its marine use, so it could be used as an auxiliary engine on board, which increases the versatility of the project and its applicability in other ports and countries.

The EPT1 subactivity has involved collaboration between 3 port authorities (Barcelona, Vigo and Tenerife Port Authorities), as well as a shipping company operating in these 3 ports (Flota Suardiaz), a gas engine manufacturing company (SIEMENS ENGINES), an LNG tank manufacturing company (HAM) and a classification society (Bureau Veritas). The collaboration between companies of so different nature, although sometimes complicated, has allowed to find synergies and satisfactory solutions for all the partners, and the possibility of generating new business opportunities.

2. Objective of the study

2.1. Purpose

The purpose of this document is summarize the initial technical feasibility analysis of the shore to ship power supply system targeted in the Core LNGas Hive Subactivity EPT1, study with integrated pilot, "LNG POWERED ELECTRICITY GENERATOR MOBILE UNIT FOR ONSHORE POWER SUPPLY".

This study with integrated pilot is a sub-activity of the CORE LNGas hive project co-financed by the European Union, aiming to the development of integrated logistics and supply chain for LNG in the transport industry, particularly for maritime transport of the Iberian Peninsula.

The objective of this activity is the development of an onshore mobile LNG electric generator unit intended to supply power to a vessel when berthed. The electrical power needed to keep running HVAC, lighting, and any other onboard equipment while docked is to be provided by this onshore side generator, allowing the shutdown of auxiliary diesel generators.

2.2. Scope

This document summarize the main aspects of the project in order to carry out the initial technical feasibility analysis of the proposed development. The solution feasibility is assessed taking the ports of Barcelona, Vigo and Tenerife as location reference, where the LNG generator unit is intended to be tested and deployed.

The study presented herein is performed under the assumption that the LNG onshore supply unit is initially implemented to attend the supply of L'Audace vessel.

First of all, an outline of the different technical scenarios is provided, analyzing the most relevant aspects regarding the following aspects:

- Engine performance.
- Cooling system.
- Auxiliary equipment.
- LNG tank capacity.
- Port logistics.
- Onboard modifications.
- Module integration and dimensions.

Finally, the document details the findings of the actual emission test conducted on the auxiliary diesel generator of L'Audace vessel. The emission test results, based on probe measurement of NOx, SOx and particle emission, are compared with the initial estimates by applying theoretical emitting factors.

3. Description and justification of the adopted solution

The CO2, SOx, NOx and particle matter, pollutants emitted directly from marine diesel engines contribute to air pollution, harming human health and damaging the environment. The emission impact is greater when generated close to populated areas. Therefore, as seaport activities are held responsible as major air pollutants, human health and natural environment in the vicinity of ports are particularly affected by pollution from shipping activities.

IMO regulations have designated Emission Control Areas (ECA´s) under MARPOL convention. The NOx, SOx and particle matter emissions in these ECA's (close to populated coastal areas) are restricted. The requirements of this regulation are considered of obligatory compliance and will be strengthened in the near future. Consequently, the shipping industry is under pressure for controlling and reducing the emissions produced by vessels in these areas and specific measures are therefore required in this regard.

Reducing emissions produced by vessel diesel engines can be achieved by shore to ship power supply system. This solution represents an alternative to onboard power generation for vessels operation at port when berthed.

Beside the benefits stated above regarding the harmful emission reduction, other advantages like noise reduction and financial benefits by increasing machinery lifetime should be taken into consideration.

The preferred solution to be implemented has to meet two main objectives:

- To reduce the emissions levels and therefore improve the air quality in line with the goals and objectives of the European Clean Air policies.
- To design a feasible, flexible and cost effective solution that enables the initial development of onshore power supply systems in ports close to populated areas.

With these goals in mind, this study with integrated pilot is focused on the development of a mobile Off-grid system to be installed at port, because it gives a great flexibility, allowing the deployment of the unit in different docks, serving different types of ships within the same port facilities. This is considered the most cost effective options for Ship Owners and Port Authorities in the first stages of onshore supply developments.

The onshore generator unit is LNG fuelled, expecting therefore a reduction in emissions of NOx, SOx and particles matter in comparison to the use of vessel's auxiliary diesel generators. The estimated reduction in greenhouse gas emissions for L'Audace ro-ro ship during the stay in Barcelona port are detailed in **¡Error! No se encuentra el origen de la referencia.**, considering that:

- The ship made 50 scales in 2014, averaging 9 hours each, giving a total time of 449,4 hours per year at port.
- The onboard generator NOx emissions are 12g / kWh at 800rpm.
- 2 auxiliary of 648 kW are installed onboard, of which only operates one.

- The sulphur (S) content in fuel is 1.5 %

L'Audace ro-ro ship	Current situation (using onboard generator)	Proposed onshore LNG generator supply	Expected annual reduction
Annual SOx emission	92,6 Tn	0 Tn	92,6 Tn
Annual NOx emission	3,5 Tn	0,5 Tn Approx.	3 Tn

Table 1. Greenhouse gas emission reduction

The noise levels are also expected to be reduced, as LNG engines are designed under an Otto cycle, which as general rule, generates less noise and vibrations than an equivalent diesel engine.

This pilot project is underpinned by the following principles:

- It's a pioneer initiative, as no other project like this has been promoted in any of the Mediterranean Sea ports.
- It is a very interesting option for ports placed near big cities, whose electrical distribution networks infrastructure are not capable of withstand the new peak loads induced by big vessel berthed.
- The experience gained in a previous project in shore to ship supply carried out in the past allows the improvement of the solution. The preceding project belongs to the European BLUE CHANGE initiative, in which among other activities, a ro-ro vessel transformation design was performed for shore supply.

3.1. Operational basis of the adopted solution

The LNG powered electricity generator mobile unit developed in this project is composed by the following main components:

- One LNG fuelled genset, with an electrical power output of 826 kWe (preliminary).
- One LNG tank storage with enough capacity for attending, at least, one stay period at port (L'Audace as reference).
- A sea water cooling system.
- A vaporizer/ gas feeder unit
- The ship connection interface.
- The control unit.

All the components of LNG generator unit described above, and all the auxiliary equipment required for an autonomous operation and the seawater cooling system, are assembled in a 40' container type module, as shown in the **¡Error! No se encuentra el origen de la referencia.**. This is one of the key concepts of this solution, because with this concept the module can be easily transported from one

dock to another in order to increase the operational capacity. The preliminary dimensions of the container are 1219,2 cm. long and 243,8 cm. wide, with an estimated weigh of 22 Tn.

Figure 1. Module container of the LNG Genset (Siemens Engines S.A.U.).

The LNG tank storage and its regasification system are also implemented in a 40' container, to be easily transported.

The use of LNG as fuel allows fulfilling the environmental requirements of noise and emission reduction, indispensables to justify the implementation of this solution. The LNG filling operation can be carried out by mean of tanker trucks.

Figure 2. Module container of the LNG tanks and regasification plant (HAM).

The vessel shall be prepared for a proper shore connection, taking into account the frequency, voltages and the physical layout of the cables and connectors. The **¡Error! No se encuentra el origen de la referencia.** shows a brief sketch of the on-board components necessary to be supplied from the LNG generator unit.

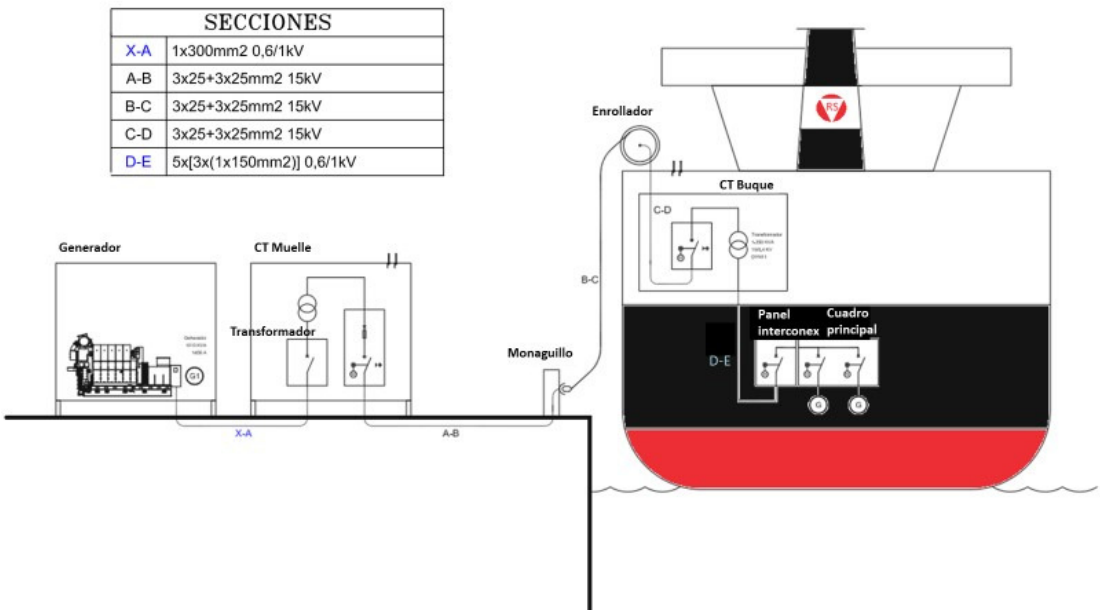


Figure 3. On board components (Suardiaz)

4. Generator unit definition

4.1. Characteristics and performance

The genset unit will operate on land but will be designed as a marine auxiliary engine approved for all purposes. That includes that all the components of the generator will be suitable for marine auxiliary application: Genset (engine, alternator, skid and control unit) and Container (peripherals, control unit).

4.1.1 Genset

The engine is manufactured by SIEMENS ENGINES S.A.U., model SGE-56SL.

Genset Type	SFGLD 560	
Mechanical engine rate power	kW	850
Electrical engine rated power (cos phi=1)	kWe	826*
Voltage	V	400
Speed	rpm	1500
Frequency	Hz	50
Capacity	L	56
Number of Cylinders		V16

Table 2. Engine general performance parameters.

The minimum value for the methane number (AVL) of natural gas is fixed at 70.

4.1.2 Container Generator Unit

The container set is manufactured by SIEMENS ENGINES S.A.U using standardized containers as basic enclosures.

The advantages of a containerized set compared to traditional power units include the following: quick installation, no need for civil engineering, accessible in remote areas, mobility, autonomy, modularity, tested and verified at manufacturing facilities.

The main characteristics of the SIEMENS ENGINES container set include:

- The container is designed as CE, (it is not ATEX) and for outdoor conditions, with a noise insulation 75dB at 10 meter, however the container unit does not require anti wave plate container as it will be located at dock (inside and

sufficiently protected). Fire detection system. Gas leak detector on the inside of the container unit.

- Genset
- Peripherals control unit will be located inside of the container. It will be assembled from modular steel floor standing enclosures properly coated, manufactured by leading brands. The main features will be to control the peripherals (gas train valve, electrical water pump, ventilation, electrical pre-lub pump, fire detection system and gas leak detector, lighting and electrical connections.
- Gas Train valve (referred to a gas supply pressure of approximately 1bar and steady and DN80).
- External lube oil system: Electric pump and a set of valves for filling or emptying the crankcase, Automatic oil level control, with an automatic sump top-up system.
- Silencer: 45-dB attenuation exhaust silencer.
- Ventilation: Two ventilation fan, sound baffles made of perforated steel panels and filled with sound attenuating material. Two sets of baffles, one on the intake side and the other on the discharge side, sound baffles on the inside of the container structure to absorb engine noise.
- Two heat exchanger plates: One for main cooling circuit and one for auxiliary cooling system, the engine side will be refrigerated by fresh water and the secondary side with sea water.
- Electrical sea water pump.
- Container unit Peripherals max. power: 20 kWe (400VaC) and 20A (24Vcc).

4.2. Main dimensions

4.2.1 Container generator unit dimensions

The preliminary main dimensions of the container generator unit are detailed in the following table:

Length	mm	12192
Width	mm	2438
High	mm	2896
Weight	Tn	22

Table 3. Container set dimensions

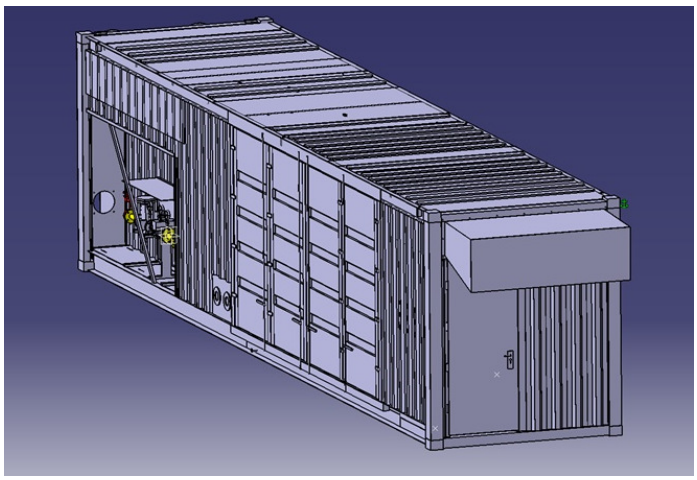


Figure 4. Generator Unit

4.3. Regulations and certification

One of the main steps in this project is the certification of the SIEMENS ENGINES genset, as well as some of the peripherals (gas train valve, silencer, electrical water pump, heat exchanger plates, and ventilation) for Marine use according to BV Class society. The notation to be considered is BV AUT-UMS. Additionally, the system configuration to be followed is ESD protected machinery spaces.

In this regard, the certification process is to be followed according to Bureau Veritas requirement and practices.

The rules used to perform this reviewing of the design are included in BV Marine rules, "Rules for the Classification of Steel ships" PtC. Additionally, due to the engine is using gas as fuel, the following rules are also applicable: NR 529: "Safety Rules for Gas-fuelled Engine Installations in Ships" and NR 481: "Design and installation of dual fuel Engine using low pressure gas"

5. LNG System definition

5.1. System description. Characteristics and performance

The proposed solution for the natural gas supply of the Project CORE-LNGas hive has been raised inside an ISO container of 40 feet to facilitate the transport inside the port. The principal pieces of equipment are the tanks of storage of LNG. They must store 10m^3 of liquid according to the initial specifications.

This solution includes two tanks of 5 m^3 for a major compactness and a better distribution of loads. It allows placing the gravity center in the central part of the ISO container, and facilitating his mobility by straddle carrier.

Other pieces of equipment have been placed in the central part prioritizing the access in order to ease his manipulation during the operation and maintenance. Towers of gasification, electrical ATEX box, station of regulation and odorization are the other pieces of equipment.

The ISO container is design to avoid the gas confinement if a leakage happens. However it is proposed to use an impoundment basing of steel to contain the LNG and protect the equipment in case of an accident.

The LNG system main characteristics are shown in the next **¡Error! No se encuentra el origen de la referencia.**:

Total LNG capacity	10 m^3
Design flow	200 kg/h
Medium flow	150 kg/h
Design pressure	8 bar
Working pressure	3 bar
Service pressure	0,9 bar
Autonomy	30 h

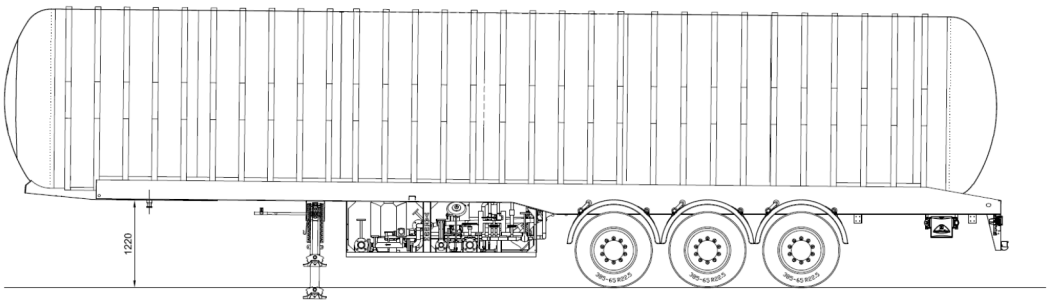
Table 4. LNG System main characteristics

<u>LNG Storage tank:</u>

- 2 units of 5m3 capacity
- LNG temperature at -160ºC
- Design pressure 8 bar
- Automatic pressure build up
- Pressure and level transmitters
- PBU to increase the pressure inside the tank

<u>Loading utilities:</u>

- Coupling ENAGAS 2”
- Earth clamp
- Top (shower) and bottom filling
- System also prevent overfilling of the tank by closing valves in case maximum level is reached inside tank
- The LNG will be discharged from a 60m^3 cistern



REPARTO DE CARGAS Y PESOS			
	KING-PIN	TRIDEM	TOTAL
VACÍO	3.675 kg	8.525 kg	12.200 kg
LLENO (max)	12.615 kg	23.885 kg	36.500 kg
LLENO (GNL tipo)	12.615 kg	23.885 kg	36.500 kg

Datos Generales	
Normativa	TPED/ADR/EN 13530
Presión de Diseño	3,5 bar
Presión de Prueba	5,85 bar
Rango de Temperaturas	Interior: -196 a +20ºC, Exterior: -20 a +50ºC
Capacidad Geométrica	60.000 lts
Materiales	Interior: Acero Inoxidable, Exterior: Acero Inoxidable
END	Recipiente a Presion: Radiografiado 100%
Producto a Transportar	Gas Natural Licuado (1972)
Grado de Llenado / Carga	(GNL-1972) - 90% / 23.072 kg

DIN A-3	Plano: Ficha Técnica	Dibujado JRE	Aprobado JRE	Nombre 08.00-102.10-GEFT-0	08.
ESCALA 1:40					
REF. 106					
Proyecto: 102.10		VAKUUM	VAKUUM BARCELONA,S.L Polígono Industrial Sesrovires Carrer Joan Oró núm 1 08635 San Esteve Sesrovires (Barcelona) www.ham.es Telf: 93 779 87 32 - Fax: 93 779 87 34		
Cisterna Criogénica tipo Europea 60m³ / 3,5 bar					

Figure 5. Scheme of the LNG Cistern

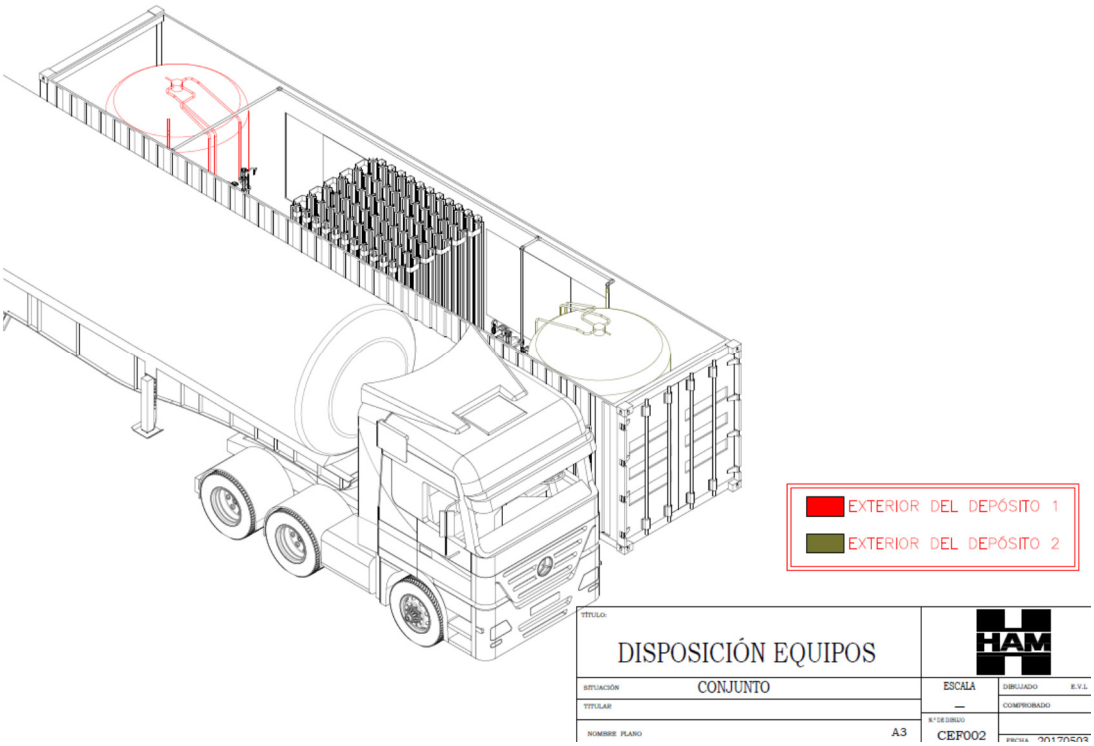


Figure 6. Disposal of the cistern during the discharge

Figure 7. Disposal of the cistern during the discharge. Port of Barcelona Pilot. (December 2017)

Regasification equipment:

- Regulation and odorization
- Regasification capacity of 180Nm3/h
- One cold safety valves that shutt-off plant in case minimum temperature of gas Temperature transmitter
- Three gas temperature transmitters in order to prevent shut down plant for instrumentation failures
- A pressure regulation line with pressure regulator Fiorentini Norval DN50. Each line is equipped with filter, isolation valves, etc.

Control equipment:

- Plant will be delivered with the control panel based on a PLC telemecanique, which gets and process different signals coming from the plant: temperatures, levels, pressures, etc. operating the plant fully automatically.
- Control panel ensures a correct function of the plant managing all warning and alarms that could happen.
- It's provided with a touchscreen for visualization and user interface.
- There is also a module Vikingegarden which send SMS to predefined list of cellular phones.
- Plant is ready to be remotely connected to HAM scada system.

Plant safety and reliability:

- Plant is programmed to shut down automatically in case that a minimum temperature of gas cannot be achieved in order to prevent any damage to non-cryogenic part of facility.
- The valve which shut plant down is duplicated in order to have redundancy (mechanical, electrical and pneumatically independent).
- The temperature transmitter actuating over cold safety is triplicated in order to avoid shut down plant by an instrumentation failure.
- The plant it's provided with safety valves which will relief pressure through a venting line.
- The venting line ends in a high point and is provided with a flame arrester.
- All piping limited by valves is provided with a thermal relief valve.

5.2. Main dimensions

The LNG system has been designed to be installed inside an ISO container of 40 feet.

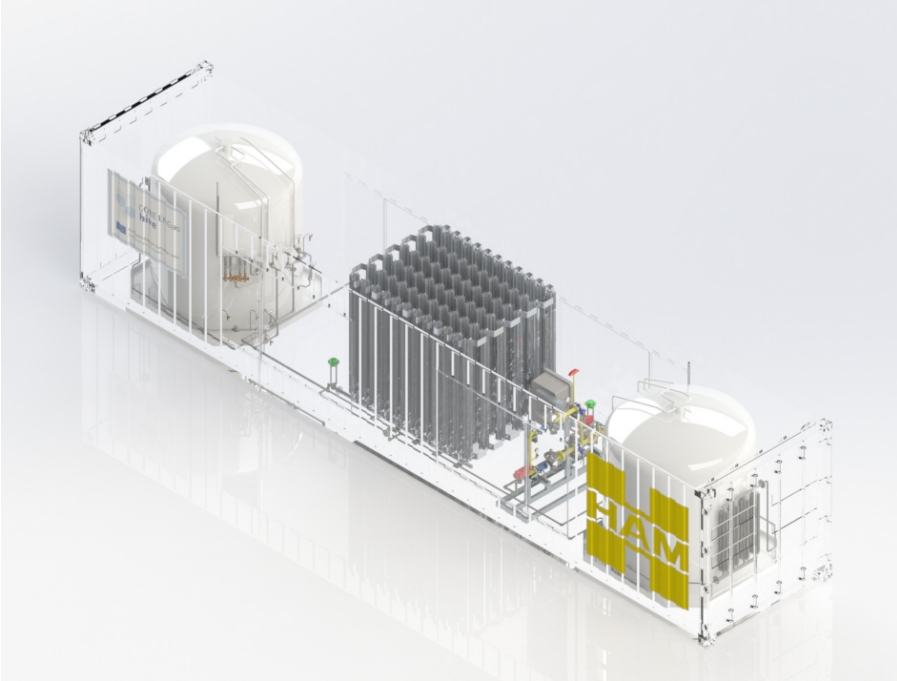


Figure 8. LNG System assembly

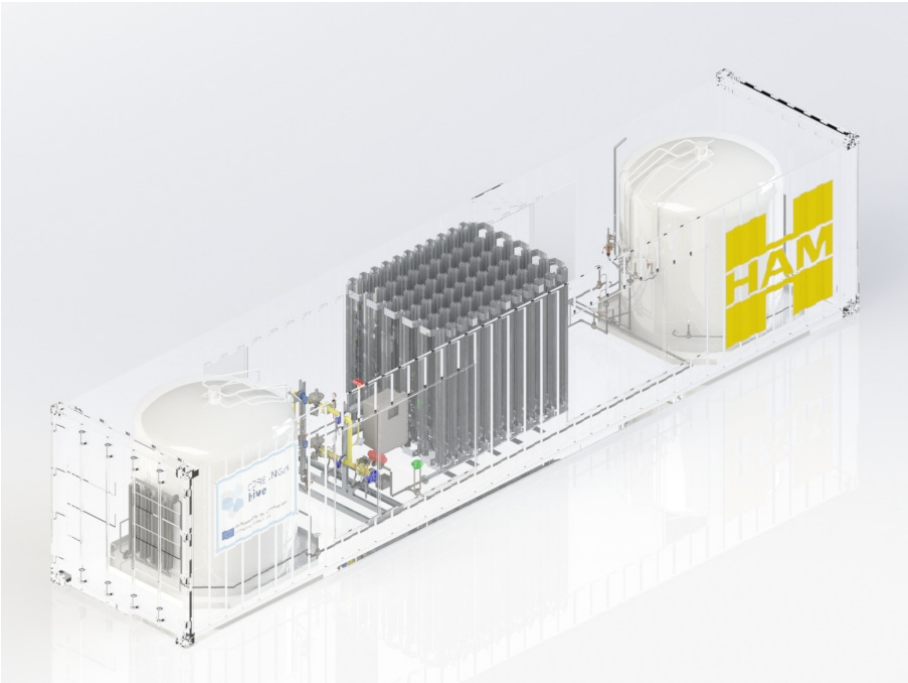


Figure 9. LNG System assembly

5.3. Regulations and certification

In order to ensure the unit compliance with rules and standards, the LNG tank's manufacturer, and, in general, the LNG components' manufacturer shall submit the information to Bureau Veritas for reviewing.

Additionally the tank and LNG components shall fulfil the requirements stated on NR529 "safety Rules for gas- fuelled Engines Installations in Ships", and the materials used in manufacturing shall be in accordance to NR216 "Materials and Welding's".

All materials shall be certified by Bureau Veritas, in accordance with the above mentioned rules.

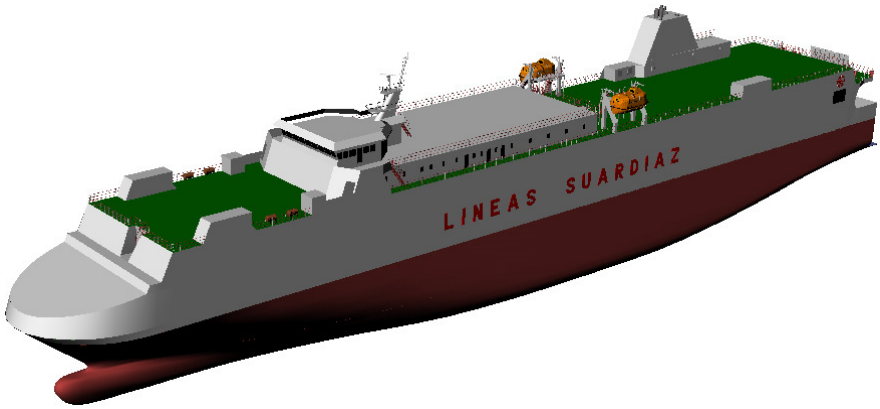
The LNG components and tank shall be tested in accordance with the requirements stated in Bureau Veritas Rules.

Finally, when all process has been followed, and fulfilled, a certificate shall be issued for each component (pipe, fittings, valves, tank, etc.).

6. Modifications on board: "L'Audace"

L'Audace vessel was built in 1999 with the Class Notation BV I HULL MACH Ro-Ro UN and designated with the IMO number 9187318. The main characteristics are detailed in the **¡Error! No se encuentra el origen de la referencia.**:

Ship Name	L'AUDACE
Ships description	Roll-on Roll-off cargo ship, moveable decks
Ownners	RO-RO MARITIME SERVICES, S.A.
Managers	FLOTA SUARDIAZ, S.L.



Length, overall	141,25 mts.	*Gross Tonnage*	15.224 GT
Length, between p.p.	132,00 mts.	*Net tonnage*	10.322 NT
Breadth, moulded	21,00 mts.	*Light ship weight*	6.410 tons.
Depth, moulded	7,00 mts.	*Deadweight*	4.695 tons.
Maximum Draft	6,00 mts.		
F.W.A.	114 mm.		

Main Propulsion	2 Engines x MAM B & W 9L 40/54 Output 8.831 HP at 550 rpm
Loaded Condition speed	Service speed at 6,00 mts draught 18,5 kn.
Ballast condition speed	Service speed at ballast draught 19,5 kn.

Cargo Capacity		*Decks area*	
- Lower Hold	17 trailers or 89 cars	*- Strong decks*	6.609 m2
- Moveable deck nº 1	77 cars	*- Movable decks*	3,728 m2
- Main Cargo deck	43 trailers or 213 cars		
- Moveable deck nº 2	150 cars	*Loading lines*	
- Upper deck	45 trailers or 214 cars	*- Trailers loading lines*	1.524 mts
- Moveable deck nº 3	198 cars	*- Cars loading lines*	5.466 mts
- Tweendeck	223 cars		
Total carriage capacity		*Maximum deck load*	
- Strong decks	105 trailers plus 223 car	*- Stern ramp*	76 tons
- All decks	1.164 cars	*- Lower Hold*	2 tons / m2
		- Movable deck nº 1	0,4 tons / m2
Free Heights		*- Main Cargo deck*	2 tons / m2
- Stern Door	5,50 mts	*- Movable deck nº 2*	0,4 tons / m2
- Lower Hold	4,60 / 2,25 / 1,90 mts.	*- Upper deck*	2 tons / m2
- Moveable deck nº 1	2,35 / 2,70 mts.	*- Movable deck nº 3*	0,4 tons / m2
- Main Cargo deck	4,60 / 2,25 / 1,90 mts.	*- Tweendeck*	0,4 tons / m2
- Moveable deck nº 2	2,35 / 2,70mts	*Load per axle on cargo decks*	
- Upper deck	4,60 / 2,25 / 1,90 mts.		
- Moveable deck nº 3	2,35 / 2,70mts	*- Strong decks*	14 tons / axle
- Tweendeck	2,25 mts	*- Moveable decks*	1 tons / axle
Special Features	The cargo spaces, designed for carriage of vehicles and rolling cargoes, are interconnected by internal ramps. Every cargo space is provided with movable decks fitted with one ramp each, except for the main cargo space where there are two		

Figure 10. L'Audace main particulars (Source: SUARDIAZ)

6.1. Current Layout

Highlighting in red the location of the auxiliary generators used nowadays for electric generation at port.

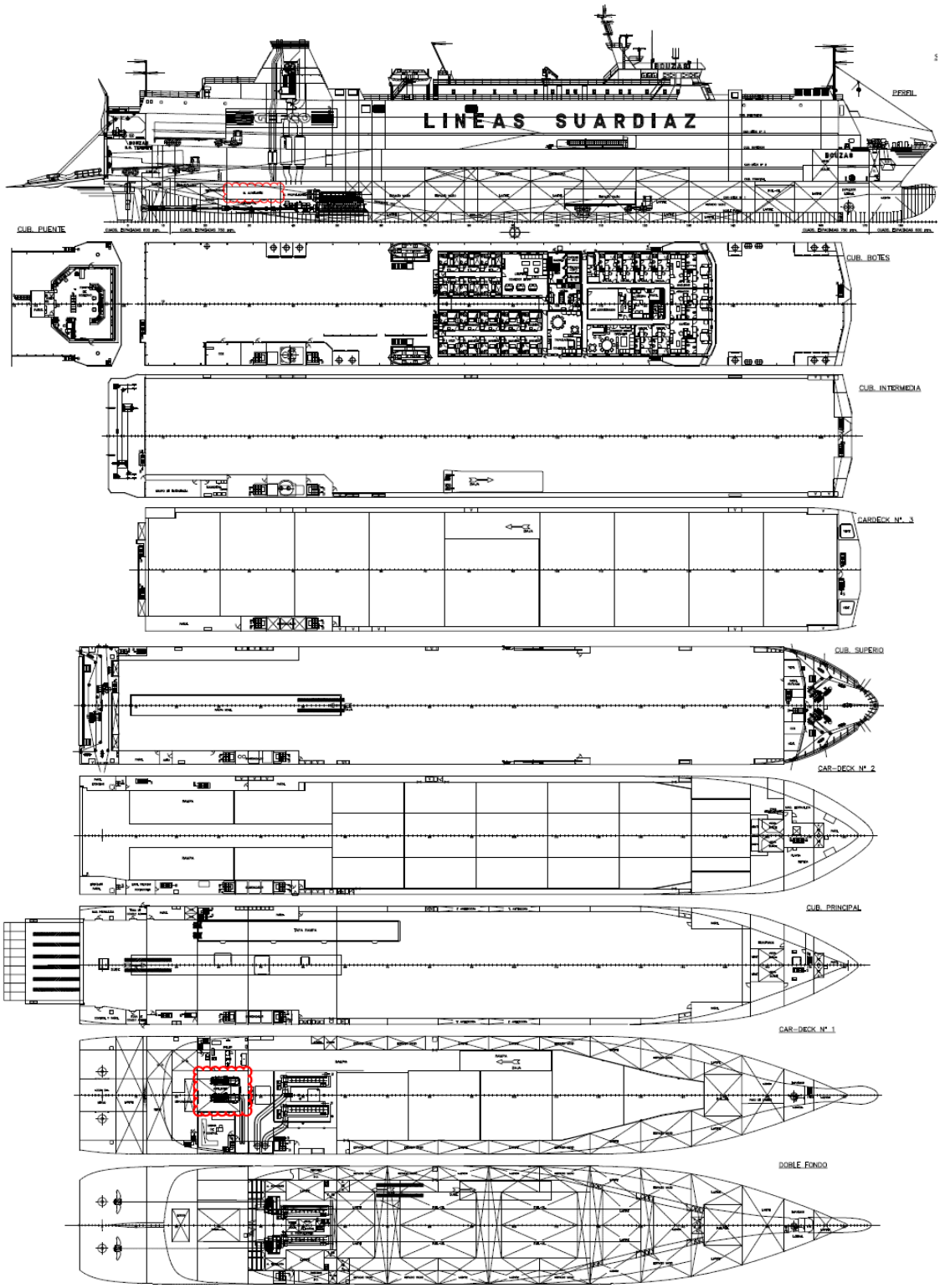


Figure 11. L'Audace general arrangement

The main particulars of the auxiliary engines installed on the L'Audace are described in the next **¡Error! No se encuentra el origen de la referencia.**:

Auxiliary Engines	2 x Caterpillar 3508B
Output power	2 x 673 kW
Fuel used sailing	HFO (3,5 % sulphur)
Fuel used at port	MGO (0,1 % sulphur)

Figure 12. Caterpillar 3508B L'AUDACE auxiliary motor

For the analysis of the onshore power supply system features, it is necessary to analyze the characteristics of the electrical systems of the ship. In the case of L'Audace, the electrical loads of ship are listed in the following table:

Electric voltage	400 V	
Lights Electric voltage	220 V	
Power frequency	50 Hz	
Power Factor	0.8	
Demand for electric power in sailing conditions	900 kW	1125 kVA
Demand for electric power with maximum refrigerated containers onboard	980 kW	1225 kVA
Demand for electric power load sailing only with vehicles	450 kW	562.5 kVA

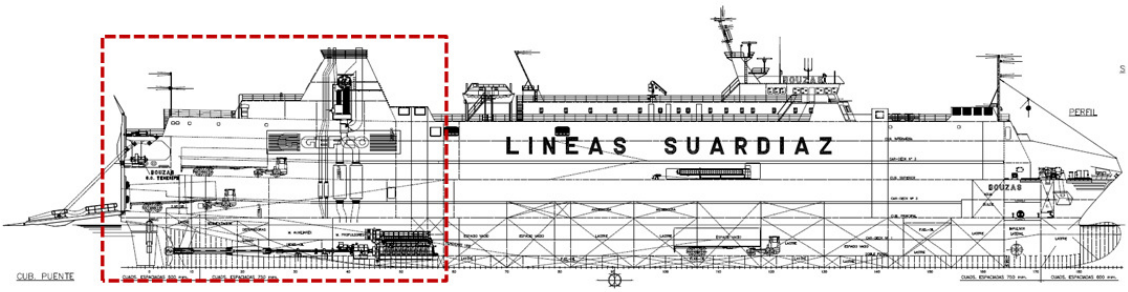
Demand for electric power in port maneuvering condition	900 kW	1125 kVA
Demand for electric power in port loading goods with the maximum number of refrigerated containers onboard	840 kW	1050 kVA
Demand for electric power in port loading goods	600 kW	750 KVA
Demand for electric power in port without operations	280 kW	350 KVA

Table 5. L'AUDACE electric loads

As shown in the table above, the greater power requirement at port coincides with the loading operations and when the ship is loaded with refrigerated containers. This maximum power demand is 900 kW or 1125 kVA considering that the power factor is 1. This is the maximum power that the onshore power generator should be capable to supply in extreme load conditions.

6.2. Future modifications

L'Audace ship is designed to have a cargo space highly optimized. The ro-ro deck arrangement implies that the main, auxiliary engines and electrical systems are concentrated and localized in the bottom of the ship itself. This makes very difficult to access from the outside with a cable from an arm extended from the pier. In the next picture the physical location of the engines and electrical systems are shown.



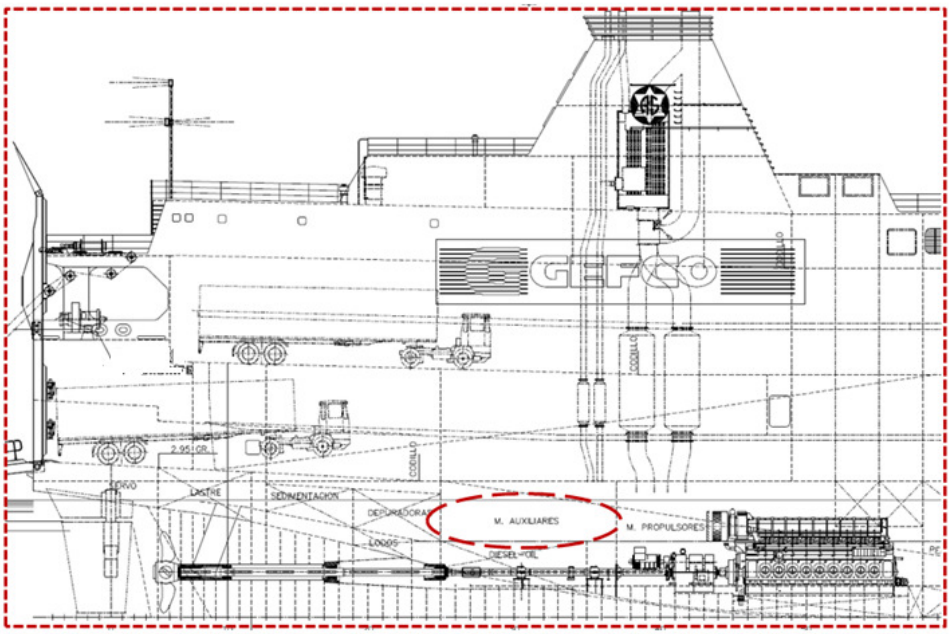


Figure 13. L'AUDACE Machinery room

As can be seen in the image above, the area marked in red is the area where the power generation systems and electrical systems are. Therefore, access to this area is complicated by an outstretched arm from the port.

Therefore, after analyzing different solutions it has concluded that the best system for supplying electric power from the outside is using a cable handling system installed on the ship itself. This is a system whose philosophy is to transport itself the necessary elements to make the connection to an onshore power supply system.

This cable handling system from the deck consists basically of the following elements:

- A motorized cable reel: This is a coil that can rotate in both directions to extend or collect the cable to the dock. This cable reel is to be securely fixed on the ship deck to prevent rolling during sea crossings or during maneuvers and extended collection of cable.
- Cable: It is the cable that connects to the onshore power supply system. This is a three-phase wire specially designed to withstand the maximum stresses and maximum power supplied.
- Extension arm: It is a small arm which has a dual purpose. On one hand serves to guide the cable forcing the cable to extended and wound in the same place. On the other hand it serves to separate the cable from the ship, approaching it to the dock, making the connection faster and easier.
- Connector: This connector is the cable termination. This is a device that allows a secure and fast connection / disconnection operation and also allows locking it. It is usually protected by a water cap that prevents the connector getting wet.

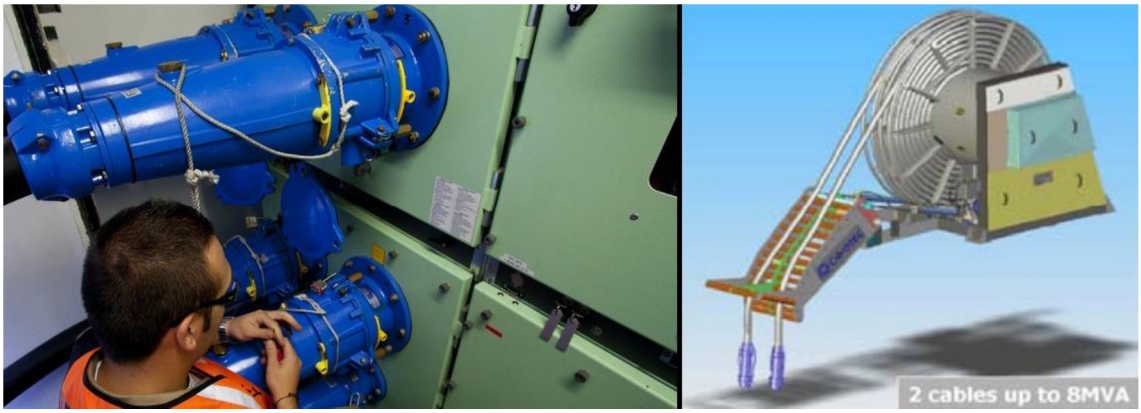


Figure 14. On board cable connection (left) and cable handling device (right)

Given the deck distribution of this vessel (the main deck of Ro-Ro ships is not a storage area of cargo, and the loading operation is carried out by a ramp at the stern of the ship), the main deck area has space available for the installation of the electrical cable handling systems. Depending on the port, "L'Audace" could be docked at portside or starboard side. This will determine the best location of the cable handling system on the main deck. An overview of the arrangement of this solution is shown in the next figure.

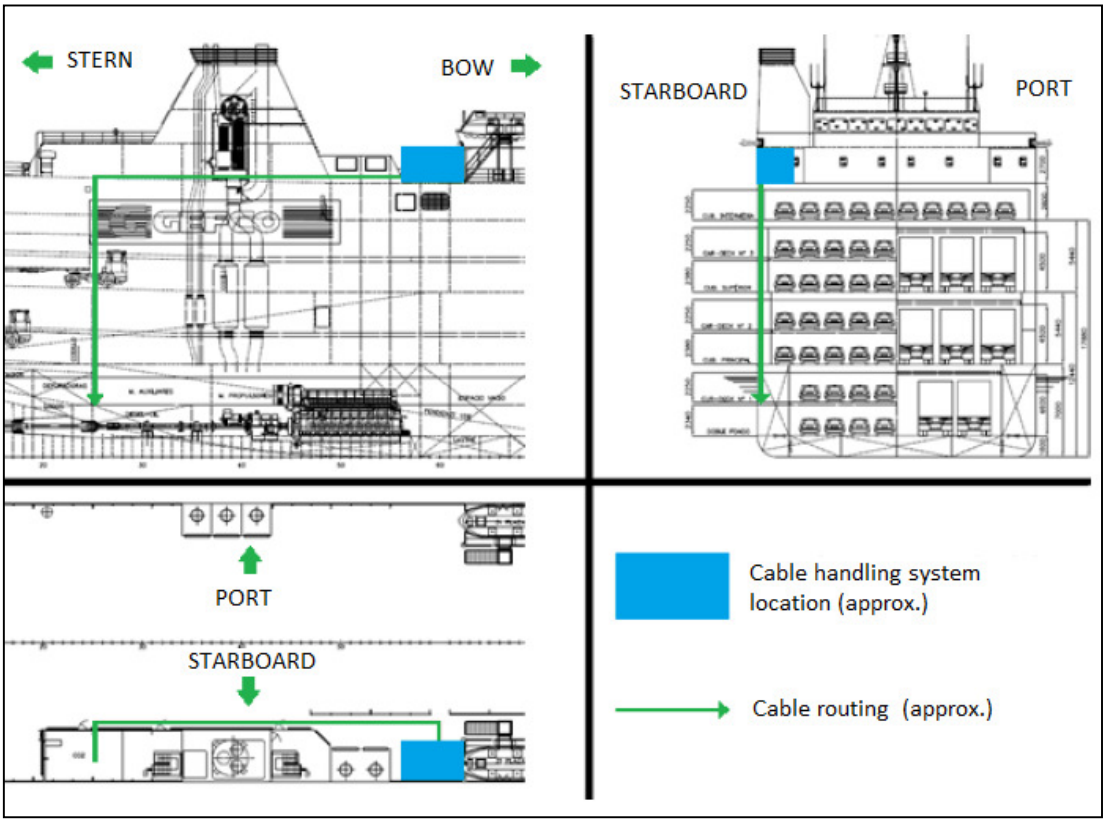


Figure 15. Cable handling preliminary arrangement

A new shore connection switchboard is to be installed in the electric control room of L'Audace, in order to connect the onshore electrical supply to the ship main bus bars.

7. Module integration

7.1. Module seawater cooling

The container generator unit is cooled by fresh water, and this fresh water is in turn cooled by the seawater in heat exchangers. The sea water system is an integrated part on the installation for service to cooling heat exchangers in closed fresh water cooling systems.

Thus the heat is extracted from the unit generator set and heat balance is maintained. For the extraction of heat, the sea water has to be carrying at a particular pressure and volume. This is done by having one main sea water electrical pumps. Some of the components of the sea water system are: sea connections, sea suction filters, sea water electrical pumps, heat exchangers.

In relation with seawater electrical pump, to choose a pump, we need to know two basic values: flowrate and lift pressure or height (or head).

7.2. Module- Ship interface

As per the protection manoeuver and synchronization will be controlled by the ship, the electrical connections in the container generator unit are:

- Five quick connect plugs (Three conductors per phase, ground connection and neutral connection).
- 24 V.c.c and 400 V a.c three-phase for auxiliaries.

Figure 16. Quick connect plugs

8. Port logistic supplies. Location

8.1. Port of Barcelona

8.1.1 LNG filling point

The Enagas regasification plant, located in *Moll de l'Energia* of Port of Barcelona, possesses 3 LNG load/unload facilities with a loading capacity up to 50 tankers per day. One of these landings will load the tank of this project.

In addition, it has the necessary infrastructure to load/unload gas tankers with a total LNG storage capacity of 760.000 m^3 and a supply capacity of 1.950.000 m^3(n)/h.

The Enagas plant started operations in 1969. Nowadays 6 tanks are working.

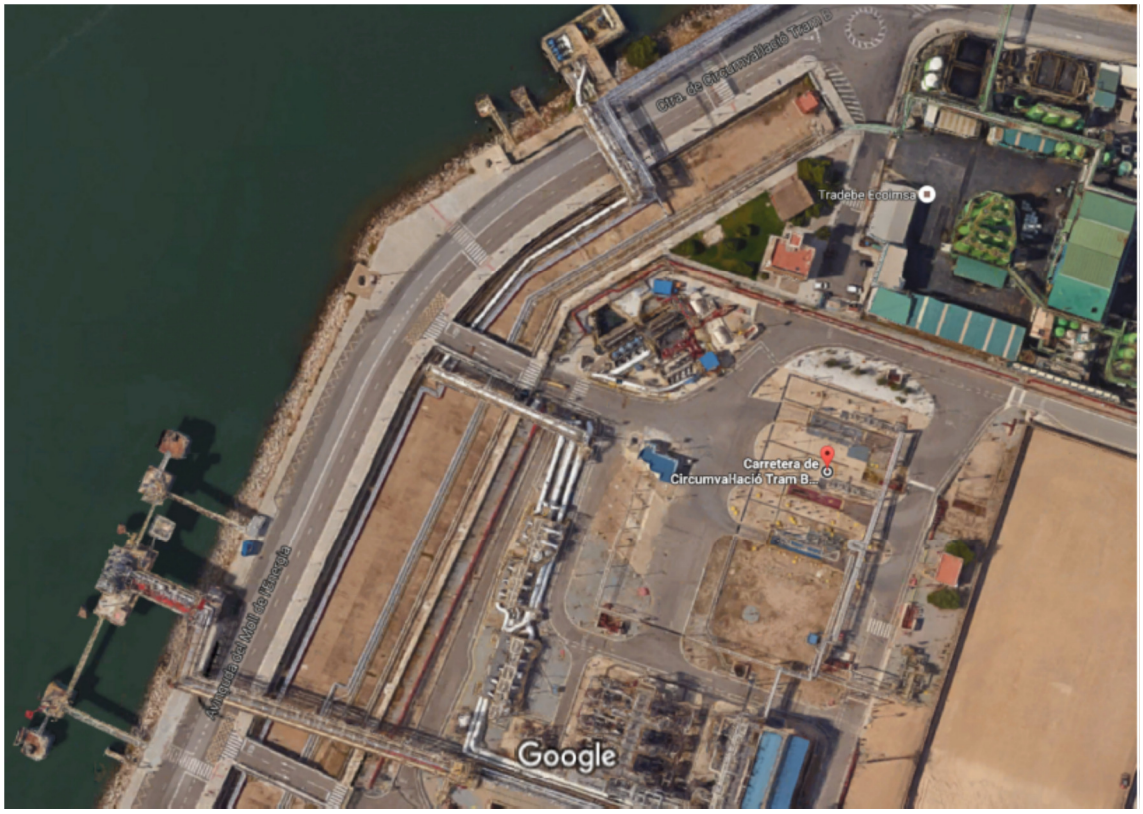


Figure 17. Location of the 3 LNG load/unload facilities

Figure 18. Enagas Regasification Plant

The following table shows the main characteristics of this regasification plant.

Nº of tanks	6
LNG storage capacity	760.000 m^3
	5.206 GWh
Supply capacity	1.950.000 m^3(n)/h
	544,3 GWh/day
Max. and min. berth	80.000 m^3
	266.000 m^3
	1 LS 1 SS: 2.000
Loading of tanks	15 GWh/day
	3 filling points, 50 tankers/day
Gas tankers discharge capacity	Small vessel ~ 3.000 m^3/h
	Medium vessel ~ 8.000 m^3/h
	Large vessel ~ 10-12.000 m^3/h
Gas tankers charge capacity	Max. 4.000 m^3/h
Pressure	Min. 30 bar
	Max. 72 bar
Transshipment	available

Table 6. Technical features of the Barcelona regasification plant (Source: Enagas)

8.1.2 Tanks – generator location at dock

The tanks and generator will be located at *Moll de Ponent* (North side), where the *L'Audace* ship berths. Due to in this wharf dock RoRo vessels, there are many trucks and semi-trailers circulating. Nearby, in concession areas of *Trasmediterranea*, open fields are dedicated to park cars, trucks or containers.

Both 40-feet container, one containing the generator and the other the 2 LNG tanks and the regasification unit, will be located in the public area, outside of the Trasmediterranea area. This public area is 15 m wide, but just 11,5 m can be used because of the circulation lane for the mooring companies close to the edge of the quay. Currently, this area is dedicated to park trailers or place containers and Marpol waste receptions containers.

A priori, both containers will be placed on the following location:

Figure 19. Location at Moll de Ponent

Figure 20. Location at Moll de Ponent (public area)

From a technical point of view, between both containers it must be a minimum distance of 3,5 m. This distance may increase after the realization of a safety analysis. The definitive location will be fixed through the risk analysis, taking into account all the usual operations carried out at the pier and at the terminal (mooring, cargo of goods, presence of dangerous goods at the terminal, etc.). In the following plan the preliminary location study is shown taking into account the distances of the ATEX zones.

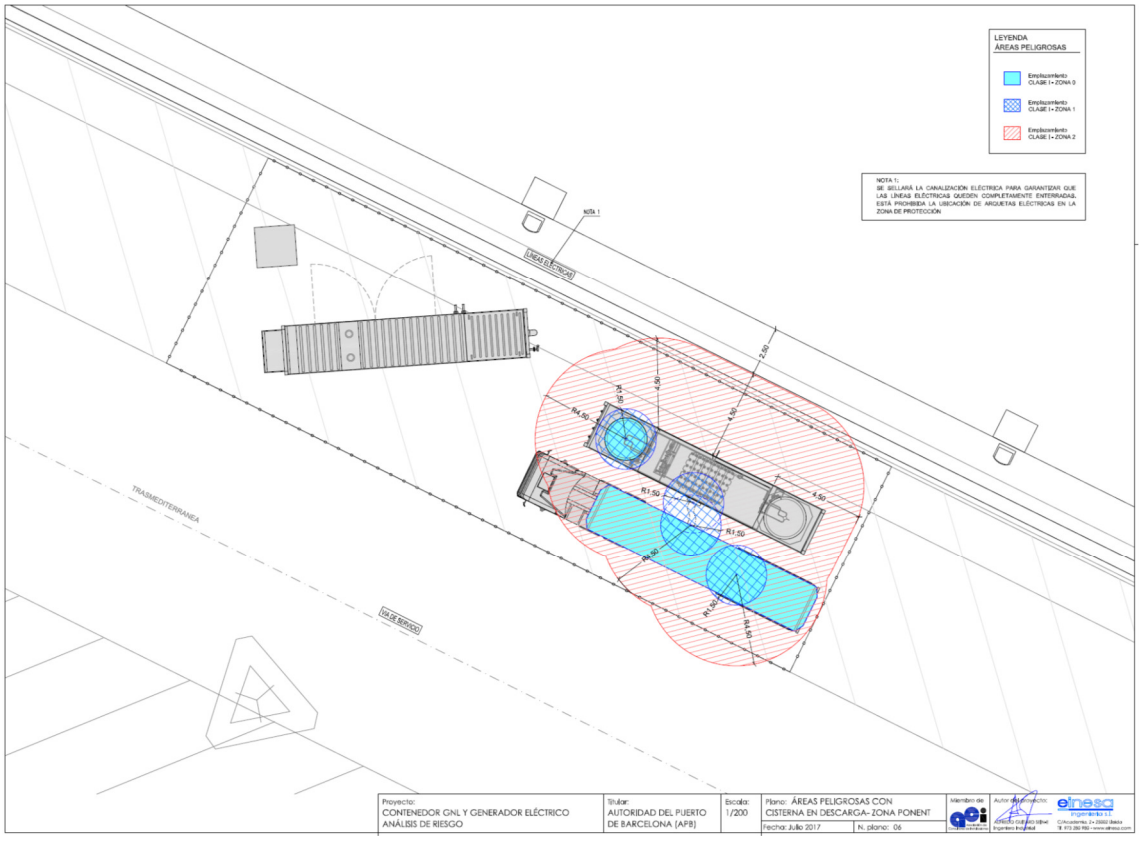


Figure 21. Preliminary study of the ATEX zones and location of the containers at Moll de Ponent (public area).

8.1.3 Tankers route from Enagas to dock

The distance between Enagas and Moll de Ponent is about 9,9 km. The tankers can drive along the *Ronda del Port* or along the *Ronda Litoral*. They only need to comply with ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road) and there is no need to have a special authorization to drive along the port roads.

The figures below show the tankers route.

Figure 22. Route from Enagas to Moll de Ponent (nord side)

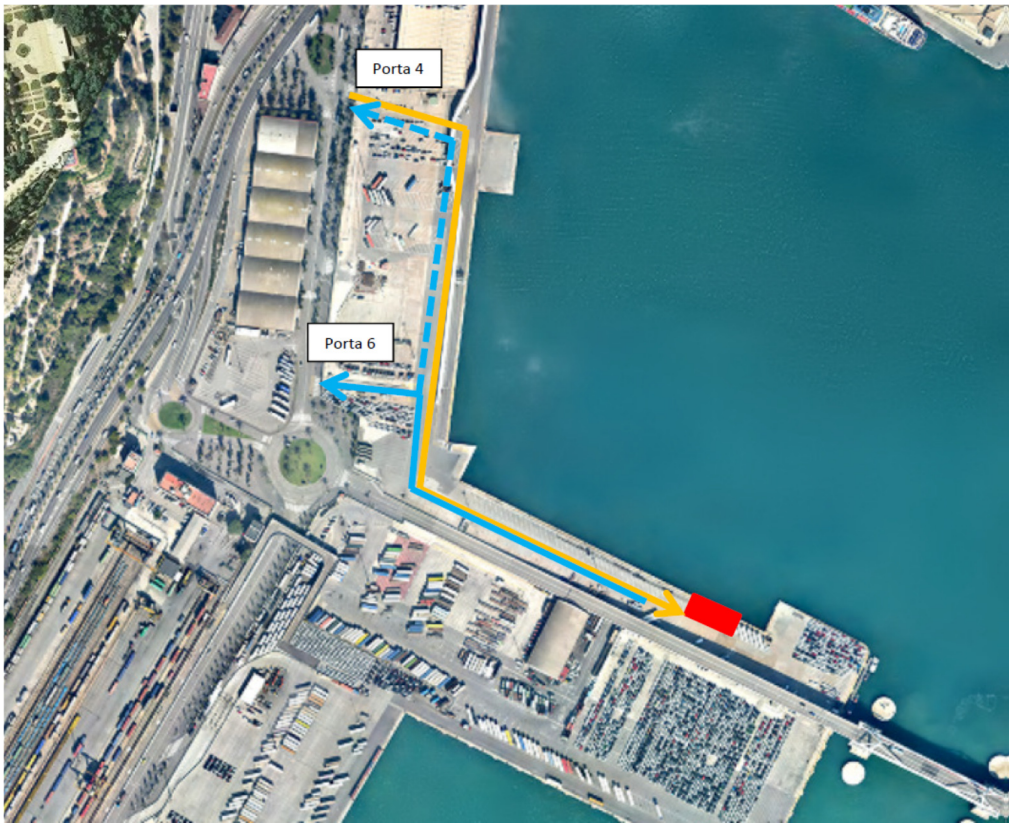


Figure 23. Route from Enagas to Moll de Ponent (nord side) along Ronda del Port. In orange, entrance route throw Trasmediterranea. In blue, exit route.

8.1.4 LNG consumption

The L'Audace call is each Friday and last 8 hours. It is expected that in the pilot phase just one tank of 5 m^3 will be filled per week, due to the estimation that the LNG consumption in 8 hours is between 3 and 4 m^3. This would avoid the appearance of Boil Off gas.

8.2. Port of Vigo

8.2.1 LNG supply location

Reganosa's regasification plant, located in Mugardos (Port of Ferrol), is provided with several loading platforms with LNG tanks, with a loading capacity of 35 tanks a day. It is in this platform where the LNG tank supply for the pilot project will take place.

Following, it is a map of the situation of the plant of Reganosa:

Figure 24. Map of the situation of Reganosa's Plant

Beneath, a summary of the features of the Plant of Reganosa, located in Mugardos (Port of Ferrol).

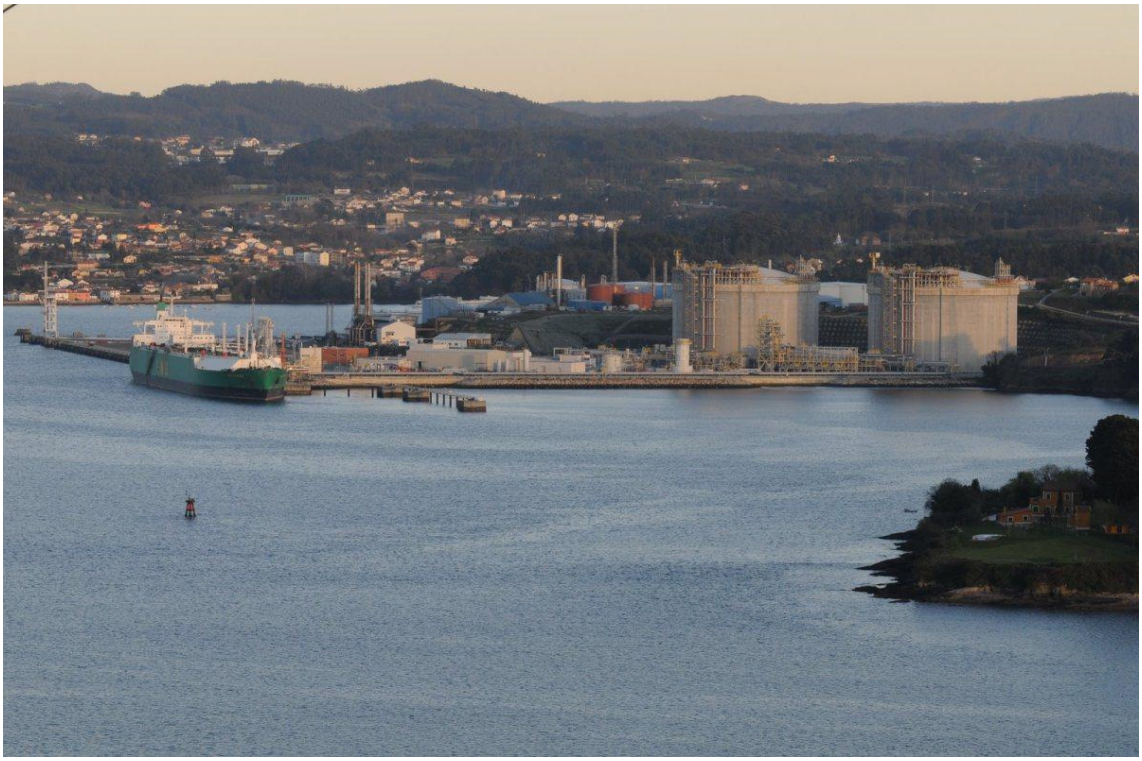


Figure 25. View of the plant of Reganosa

The plant of Reganosa Mugardos, in the port of Ferrol, launches operations in November 2007. Provides the system with a capacity of 3,6 bcm (billion cubic meters) annual of natural gas (14% the Spanish natural gas demand in 2014). Its design stands out for the utilization of pioneering solutions that guarantee the efficiency of the terminal. Its dock admits the berth of any gas vessel that make up the world's fleet. The unloading arms link with two tanks which are able to store up to 300.000 cubic meters of LNG and preserve the liquid natural gas at a temperature of -160 Cº atmospheric pressure. The stored LNG can be loaded onto vessels or tanks or sent to the regasification plant facilities. These perform the phase change to its gas state through two seawater vaporizers and a backup submerged combustion one. Afterwards, the natural gas is injected to the transport network.

Number of tanks	2
Storage capacity	300.000 m^3
Vaporizers capacity	3x160 Tn /hour
Vessel unloading capacity	12.000 m^3/hour
Vessel loading capacity	2.000 m^3/hour
Tank loading capacity	35 tanks/day
Measurement station	115,2 Gwh/d

Table 7. Technical features of the Mugardos regasification plant (Source: Reganosa)

8.2.2 Location of the set generator-deposits at the docks.

The set generator and deposits will be located at the Ro-Ro terminal, where l'Audace vessel berths. On this dock take berth Ro-Ro vessels, thus there is traffic of trucks and semi-trailers in inhabited areas. In the surroundings, in the area whose concession is Termicar, there is parking for vehicles.

The two 40 feet containers, corresponding to the generator and the LNG tanks and regasification unit, will be located in the area whose concession is Termicar.

In this area it is possible two locations, one 85 meters wide and the other 67 meters wide from the dock's ledge. The 3.5 m closer to the ledge must be subtracted, where are located bollards and a traffic lane, remaining suitable an area of 81.5 and 64.50 m wide respectively.

Lacking of a study regarding the location from a safety perspective, in which are taken into account the presence of manholes, power network, lights, roads, building, etc, at first sight, the set generator-deposits will be located in one of these two locations:

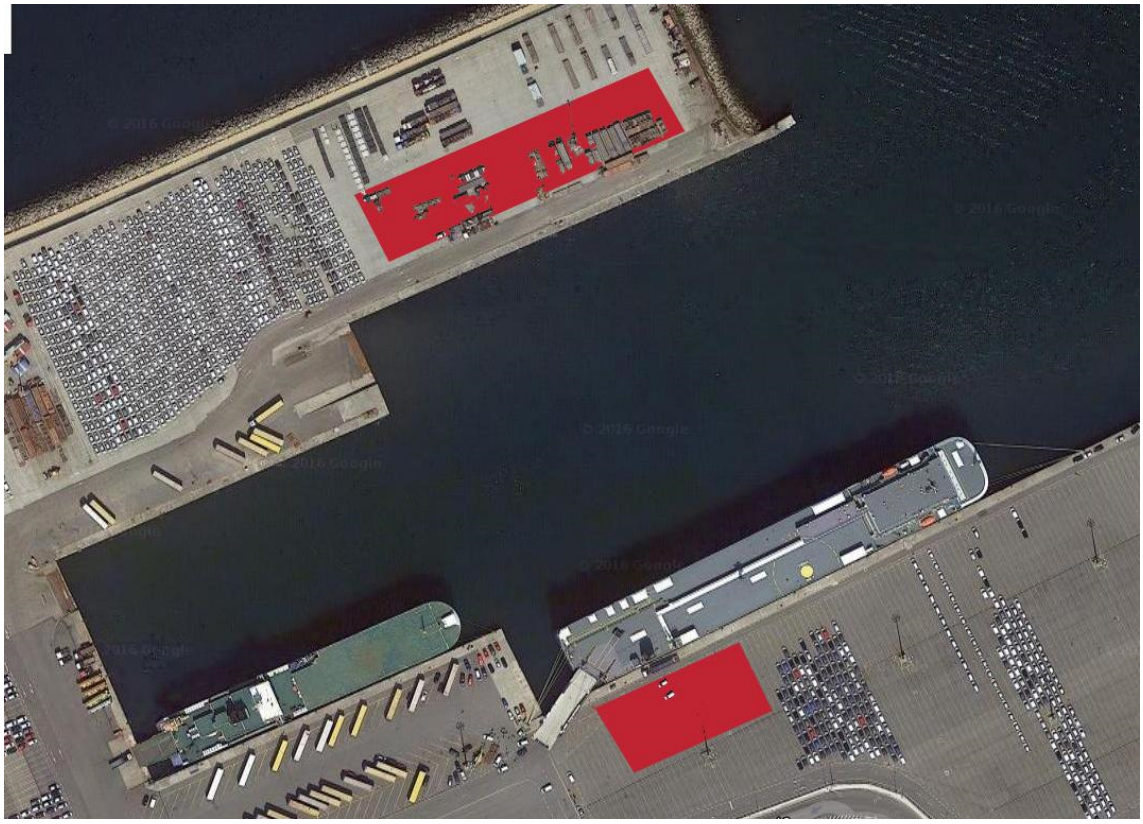


Figure 26. Location in the Ro-Ro Terminal

The containers of the generators and deposits must maintain a minimum separation of 3,5 m (distance of separation from a technical point of view, not from a safety one, which may be higher when the study has been carried out from a safety point of view).

8.2.3 Transport of the tank between Reganosa's plant and Ro-Ro terminal.

The distance between Reganosa's tank loading platform and the Ro-ro of the port of Vigo is approximately 180 Km, similarly to any other supply within the port area, supply tanks require of authorization to carry out such service, authorization issued by Sustainability Department of the Port Authority, having to comply as well with the ADR.

Beneath, it is represented the road stretch between the tank loading platform and Ro-Ro terminal:

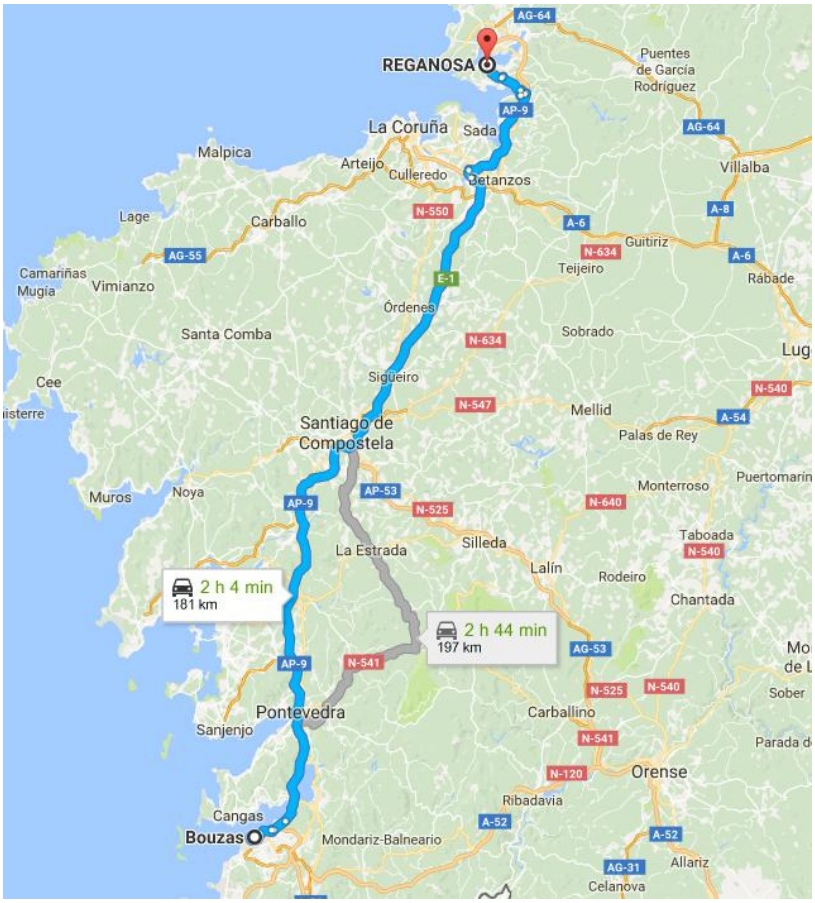


Figure 27. Itinerary between Reganosa's LNG tank loading platform and Vigo's Ro-Ro Terminal

Figure 28. Itinerary from the entrance of the Ro-Ro, two possible locations

8.2.4 LNG Consumption

L'Audace vessel will make a weekly call in Vigo, of approximately 8 hours. In the absence of confirmation from (HAM) LNG supplier it is estimated that during the pilot stage it could be filled just a deposit of 5 m^3 per week, due to the fact that it is estimated that in an 8h call there will be a consumption of between 3 and 4 m^3 of gas. In this way, the occurrence of Boil Off gas will be avoided.

8.3. Port of Tenerife

8.3.1 Point of LNG Load

The point of LNG load will be located in the Dock of Fishing of the port of Santa Cruz de Tenerife, where the cisterns will be loaded from ISO Containers.

Figure 29. Dock of fishing of the Port of Santa Cruz de Tenerife

8.3.2 Location of LNG Power Electricity Generator Mobile Unit-OPS on the dock.

The set of two containers containing the generator and LNG tank will be located in the third berthing face of the Ribera Quay in the port of Santa Cruz de Tenerife. In this area is the Terminal of TCR (Trasmediterranea). In the parcel where is the TCR Terminal, there are areas destined to temporary storage of containers, parking of cars landed, zone with refrigerated containers.

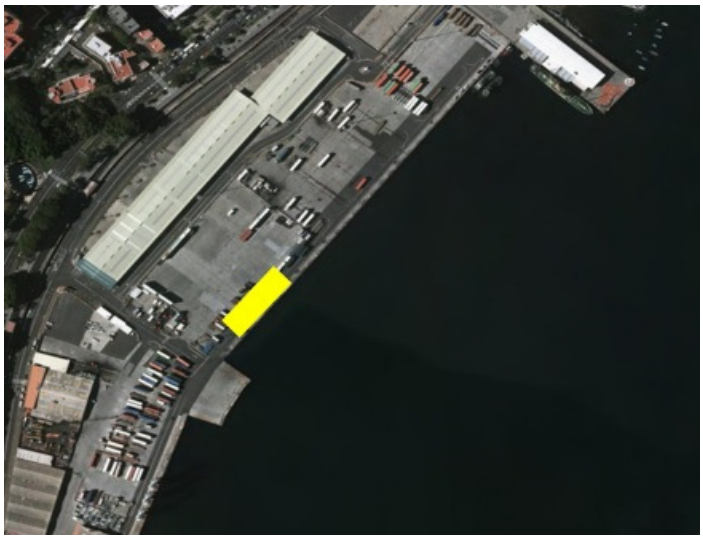
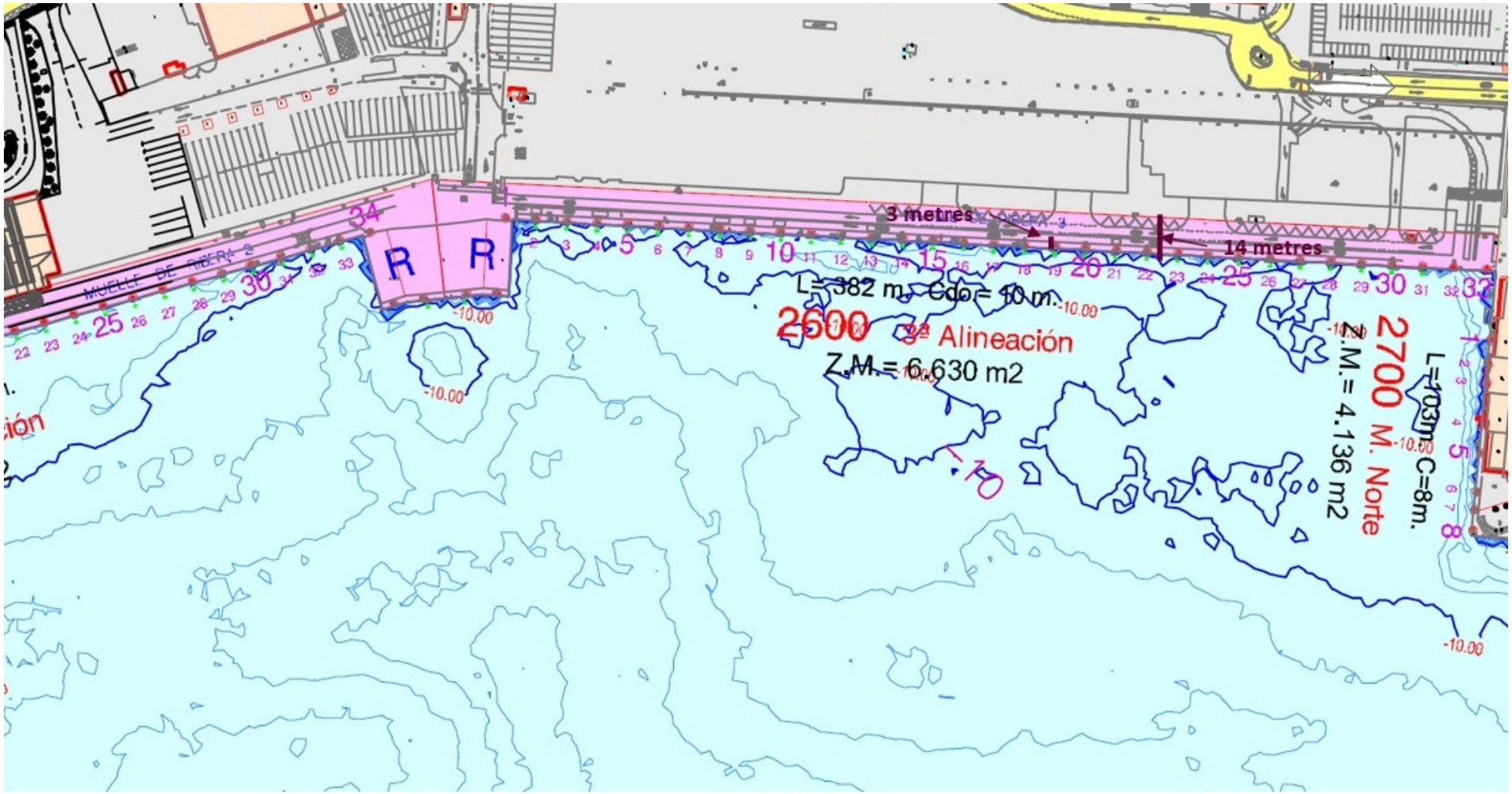


Figure 30. 3rd berthing face of the Ribera Quay in the Port of Santa Cruz de Tenerife


3 metres
14 metres
L= 382 m. Cdo= 10 m.
2600
3ª Alineación
Z.M.= 6.630 m2
2700
M. Norte
Z.M.= 4.136 m2
L=103m C=8m.
MUELLE DE RIBERA 2
R
R
-10.00

The generating unit consisting of the two 40-feet containers, one containing the generator engine and the other with the LNG tank, which feeds the engine, shall be located in the service area corresponding to the transit zone, outside the concession area. They will be removed 3 m from the end of the dock, it would be necessary to leave another 3 meters of a circulation lane, being 8 meters free.

The provisional location, pending the safety study, which takes into account the existing facilities, in the third berthing face of the Ribera Quay of the Port of Santa Cruz de Tenerife between Bollard 1 and Bollard 17, where the L ' AUDACE moors.

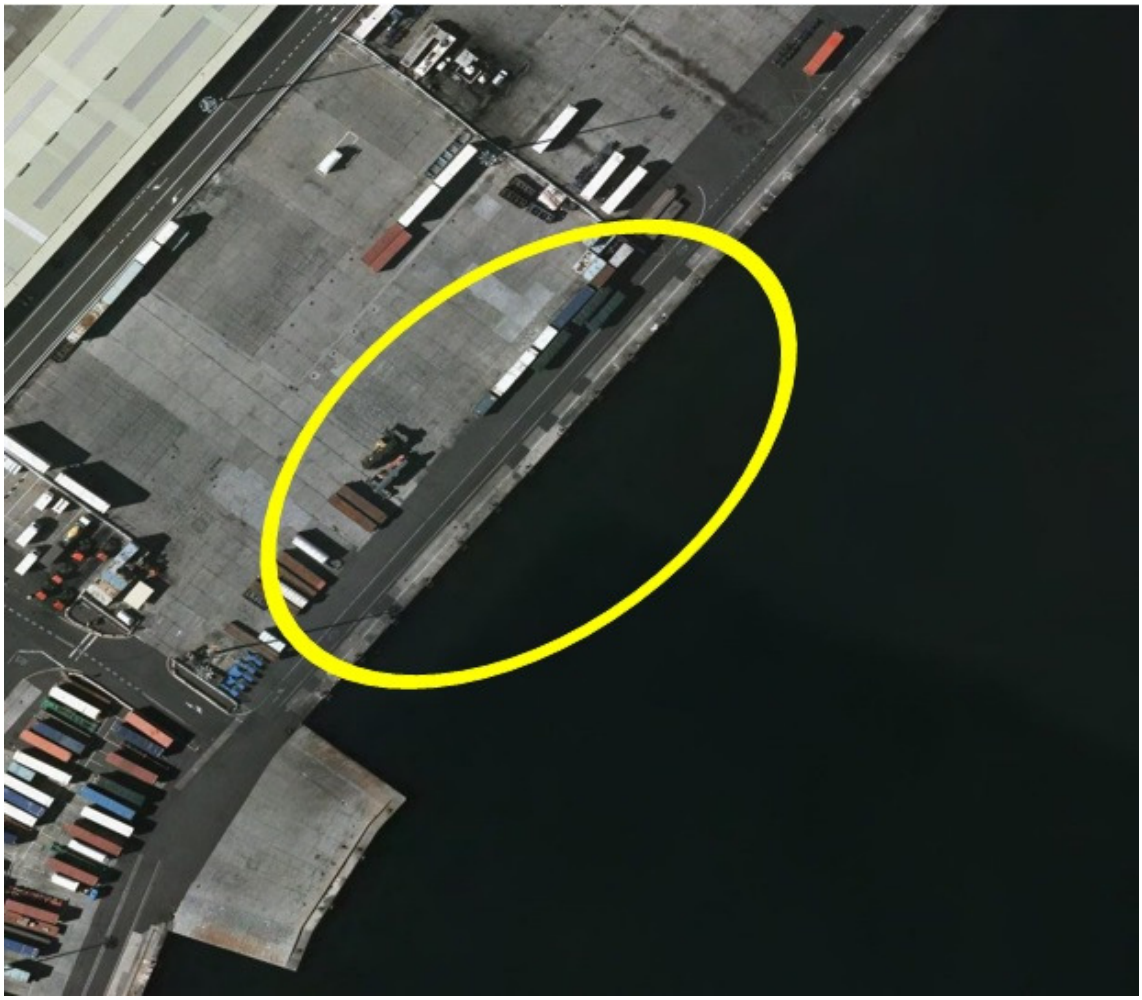


Figure 31. Provisional location between Bollard 1 and Bollard 17

8.3.3 The Route of the LNG trucks from the LNG Load point to the quay.

The distance from the LNG loading platform to the third berthing face of the Ribera Quay is about 15 km. The LNG trucks will drive along service road of the port. They do not need special authorization to drive through the interior vials of the port, not being able to park during the journey, but from the load point they will go directly to their destination in the third berthing face of the Ribera Quay.

The route of LNG Trucks from the loading point to the third berthing face of the Ribera Quay is as follows:

From the "Vía Espaldón" street in the Fishing Dock, these will pass through the service road of the port, passing through the tunnel of the service road, until you reach the Auditorium to return on the service road, North Quay, to enter the third berthing of the Ribera Quay.

Figure 32. Route from Vía Espaldón Street, where is the LNG loading platform in the fishing dock to North Quay

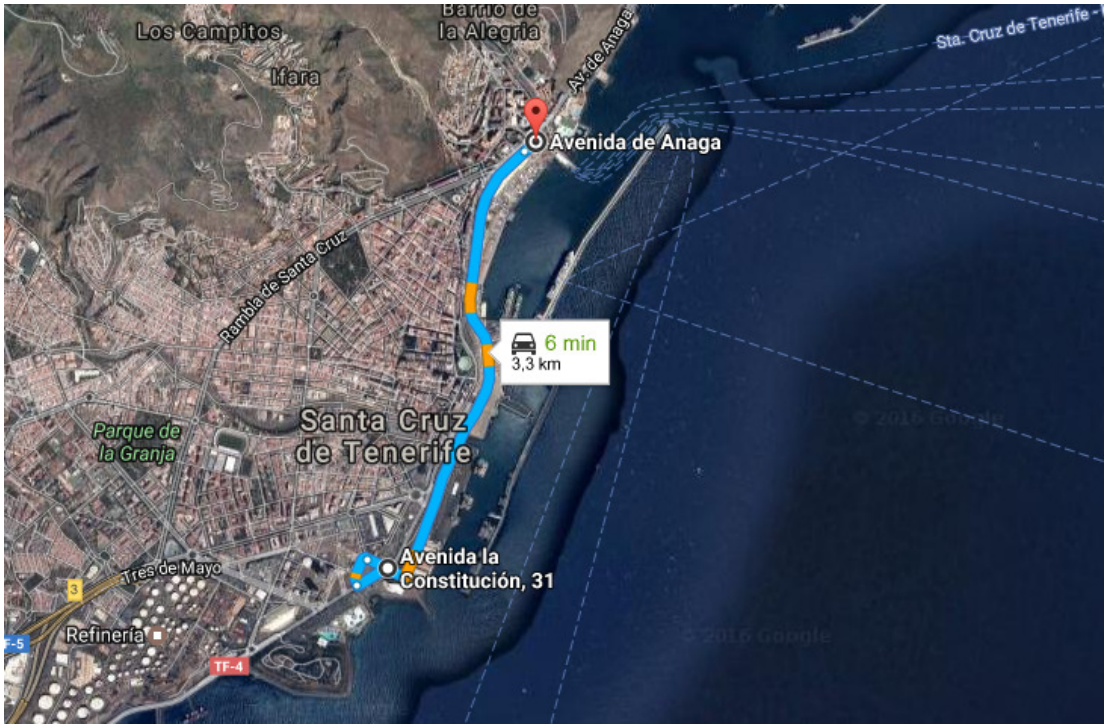


Figure 33. Route from North Quay to Auditorium.

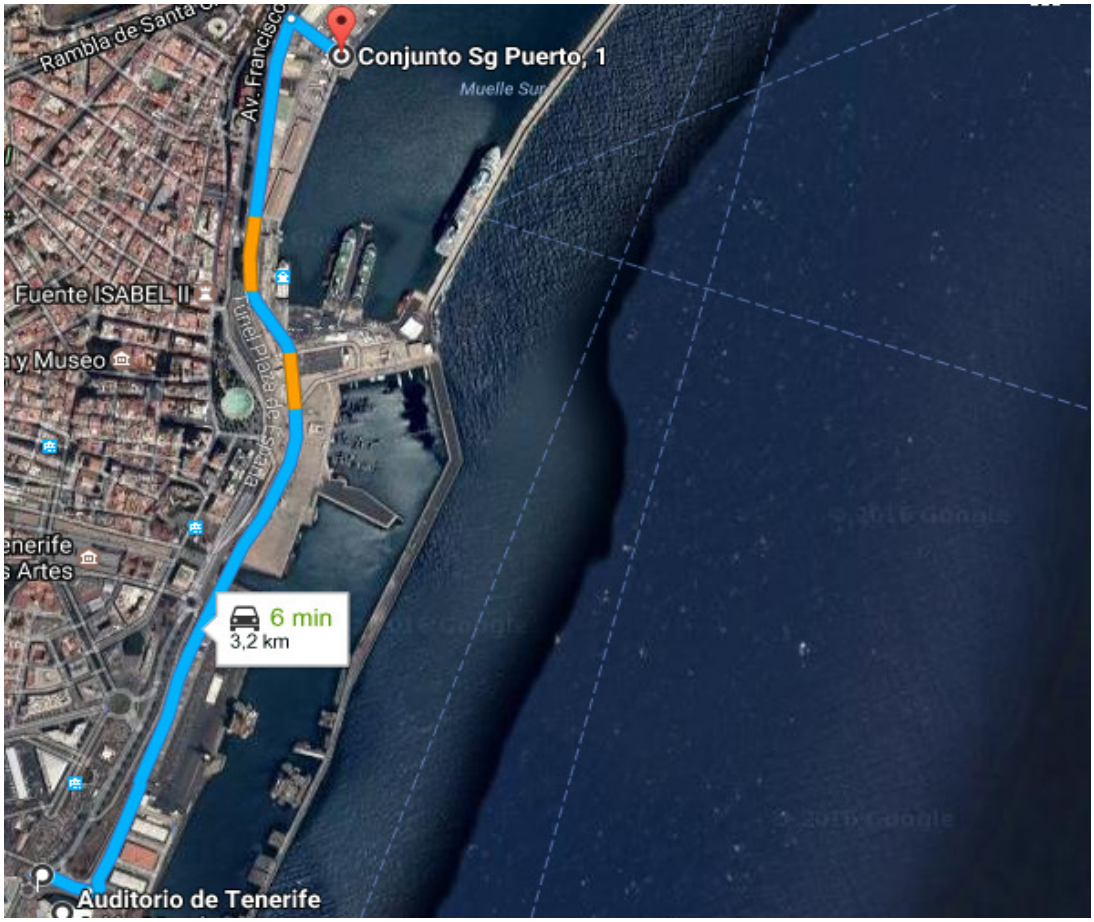


Figure 34. Route from auditorium to the Third Berthing of the Ribera Quay.

8.3.4 Consumptions of Liquefied Natural Gas (LNG)

Every Monday the vessel L`Audace docks in the third berthing of the Ribera Quay. Usually it remains moored 8 hours. It is estimated that between 3 and 4 m³ of natural gas are consumed during the scale. To prevent stratification of the gas, only one of the tanks will be filled in the pilot phase, subject to confirmation by HAM, responsible for the design of the LNG storage system.

9. Safety / Risk assessment

9.1. Port side

9.1.1 Risk identification

Aspects related with safety in gas engine operations at the dock as a vessel's auxiliary generation must be taken into account in this project due to the fact that involve an essential change in the way to proceed continuously up until now and, in case of an accident, natural gas could be questioned as a mobility alternative fuel.

Identifying the potential risks is the first step to develop the authorization framework of these port activities. We can distinguish risks related with the generator functioning, and those related with LNG tank supply operations located in a second 40 feet container, as well as risks related with the own situation of generator – deposits in the terminal and the third-party activities that are developed at the dock and have no relation with this project.

The process of authorization for LNG bunkering operations at the port of Barcelona is covered under the technical conditions' requirements (under development) and includes:

- Vessel's enforceable documents.
- Cistern and land equipment's enforceable documents.
- Risk assessment HAZID and ACR
- Operation's conditions and proceedings.

Once known the location and definitive disposition of the group of containers of the generator and deposits, risks will be identified with the support of some method of HAZID assessment or "What if…?" in which will be summoned the involved parts in operations (vessel, generator operator, deposit operator, terminal, Sea Captaincy, port, etc).

Identifying risks must comprise, as well as own hazards of the facilities, hazards that can derive from external factors like weather conditions, tides, impacts or others.

HAZID will be develop in the port of Barcelona with a general character, but afterwards each port will adjust its idiosyncrasy the identifying of risks according to operations and activities than can be within the vicinity of the expected point of installation of the generation and LNG storage units.

After HAZID sessions, a risk assessment scenarios filter must be develop, as well as determining the scope of the consequences of accidents for the chosen scenarios, defining as well phenomena such as:

- Jet Fire
- Free Jet
- Pool Fire
- Heavy Gas Dispersion
- Explosion or BLEVE (if it were applicable)

An analysis of the domino effective with the neighbored facilities must also be carried out and an estimation of the probabilities of the accident scenarios chosen, as well as prioritizing the hazards using a qualitative risk matrix in the application of "HAZID/What-If…?" techniques.

Right after, exiting safeguards must be analyzed and measures of prevention to those unacceptable risks proposed.

10. Cost analysis

10.1. Ship bonuses

The Port Authority of Barcelona increases by an additional 20% the current bonus of 50% of the Vessel rate T1 vessels contemplated in the Law of Ports for those vessels propelled by liquefied natural gas (LNG) or for those that use LNG in the Auxiliary engines or electricity during their call in the port.

In the case of the ship L'AUDACE, these bonuses will represent the following discounts:

- Scale discount
- Annual discount (considering a total of x scales)

In the rest of the ports, the bonus today would be 50% fixed by the Law of Ports.

10.2. Cost generation Natural Gas Vs diesel

During the pilot a detailed comparison of the actual costs between the operation of the auxiliary engine with natural gas compared to the diesel operation should be made. The study should contemplate the following aspects

- Price of fuels by scale (bunkering of MGO for the case of auxiliary engine and supply of LNG for the case of on shore generator).
- Indirect costs of on shore engine operation such as seawater cooling pump, electric starter, etc.
- Cost of previous and subsequent work necessary for the supply of LNG to the storage unit).
- Cost of previous and subsequent work required for the operation of on shore units (signaling, presence of firemen, if applicable, presence of surveillance, presence of terminal coordinator, etc.).
- Maintenance costs of the auxiliary engines and the replacement gas engine.

With this data, a study of differential costs between the two operating modes can be carried out. The data will be obtained in each case from the pilot tests in each port.

10.3. Business model

This section will analyze the business possibilities in a regular situation, not in the pilot phase. The possibilities of business model to be analyzed will be the following:

- SCENARIO 1: The shipping company acquires the unit (it is understood, generating unit and unit of deposits) and it is in charge of its refueling with LNG and its operation to feed the auxiliary engine of the ship. This scenario is very favorable but it will depend on the costs and the bonuses that the shipping company can get to compensate the investment and the additional expenses that must incur.

- SCENARIO 2: The AP acquires the unit and gives in rent or service to the terminal (or a third party operator) to put it into service. The terminal / operator gives the service to the ship and invoices the shipping company for its costs. The AP regulates the system so that it can work.
- SCENARIO 3: The terminal (or a third party operator) acquires the unit and is the one who renders the service to the ship and the invoice for the costs. The AP minimally regulates the system.
- SCENARIO 4: The manufacturer (or manufacturers) remain with the unit and transfer it under lease to an operator who is the one who provides the service to the ship and bills the shipping company for the costs. In this case, the AP does not regulate the system.

11. Emission test study in port: "L'AUDACE"

11.1. Emissions of the auxiliary diesel engines of L'Audace

In order to verify the reduction of pollutant emissions with the use of auxiliary engines to LNG, a previous study has been contracted to carry out the NOx and particulate matter registrations in the present auxiliary diesel engines of the l'Audace vessel

The scope of the study of pollutant emissions from diesel engines is as follows:

- NOx according to Marpol procedure on two auxiliary engines Caterpillar 3512
- Opacity measurement: soot concentration in mg/m^3 and FSN (Filter Smoke Number) in resolution of 0.01 mg / m3. This measurement is offline and will be synchronized with NOx concentrations
- Fuel flow
- Grid analyzers for the recording of electrical power.

The emissions of diesel auxiliary engines were recorded on 28 October 2016 at the Port of Barcelona.

Figure 35. Emission measurement on Diesel auxiliary engines

11.2. Theoretical comparison of emissions between a diesel engine and a gas engine

Once the gas generator is installed in the quay, measurements of the atmospheric emissions of the engine will be carried out, following the same methodology used for the study in diesel engines, in order to be able to compare the results

At preliminary level, and according to the data provided by the partner by SIEMENS ENGINES the comparison of emissions of a diesel engine vs gas engine of equal power (850 kw) of this company is:

	DIESEL		GAS	
Rpm	1800	1500	1800	1500
Pme bar	11,26	12,3	11,26	12,3
Co2 g/m_n^3	230	225	180	172
NOx mg/m_n^3	2400	2800	500	500
Particulate matter mg/m_n^3	50	65	20	20

Table 8. Comparison of emissions of a diesel engine Vs gas engine of equal power (850 kw) (Source: SIEMENS ENGINES)

12. Conclusions

Although technically feasible, the project may present some difficulties, mainly in the pilot phase (for example, authorization, safety distances, Simops or electrical panel synchronization), which should be resolved as the project progresses.

The LNG supplier, and the Spanish gas system in general, must guarantee a minimum methane number for the use of LNG as fuel for propulsion or electric generation. The normal methane number for LNG is 75 which fulfill Siemens engines gas specifications (MN70).

The logistics of LNG supply in the 3 ports is defined, although it can undergo changes, mainly in Tenerife, where in the future there may be a different alternative to the use of LNG isocontainers.

According to the theoretical data the reduction of atmospheric emissions in the generator engine to LNG will be significant, so the project will be very useful to reach the limits of air quality in the environments of the ports.

The proposed solution is flexible for all ports, wharves or ships, so we can consider that it is a project exportable to other European ports.

As a final conclusion, the participation of partners of different nature has allowed the generation of cross-knowledge that can be applied to other business projects, which can mean creating new jobs or new business opportunities for all de partners.

13. List of Acronyms and Abbreviations

ACR	Risk Analysis
ATEX	Explosive ATmosphere
BV	Bureau Veritas
CE	Conformité Européenme
ECA	Emission Control Areas
ERS	Emergency Response System
ESD	Electrostatic Discharge
EPT1	Estudio piloto Tranversal 1
HAZID	Hazard Identification Study
HVAC	Heating, Ventilation and Air Conditioning
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LNG	Liquefied Natural Gas
NOx	Nitrogen Oxides
Ro-Ro	Roll On-Roll Off
SAE	Society of Automotive Engineers
SOx	Sulphur Oxides
TCR	Terminal Carga Rodada