Worldwide experience of

Receiving Terminal - Low send-out periods

Report by the GIIGNL Technical Study Group on low send-out periods for LNG import terminals

1st Edition: 2015

Summary

In recent years, a strong decrease in LNG imports has been observed at the regional level in Europe and in North America. As a result, the utilization rate of some receiving terminals in terms of regasification capacity is lower than 20%, and in some cases the send-out level is close to zero.

The aim of this work is to point out specific technical, economic and human issues, consequences and risks related to these new operating conditions in order to gain an overall understanding of the phenomenon. It will highlight possible solutions to manage these periods and recommend corrective actions, along with some economic considerations.

This GIIGNL study identified the main processes that may be affected by low or zero send-out periods:

- LNG ageing inside the tanks,
- boil-off gas recovery and re-liquefaction,
- management of storage tanks,
- maintenance and human resources.

The results were validated by 9 European and North American GIIGNL members facing or having faced low and zero send-out periods. And the survey provided valuable recommendations to address these operating conditions.

Additionally, the study considered alternative services that a terminal may offer, such as reloading, bunker ship loading and truck loading. The possibility of providing these services, in addition to standard regasification activity, may mitigate the impact of problems arising from terminal under-utilization, but could also present new challenges.

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List of abbreviations

BOG	Boil-Off Gas
CAPEX	CAPital EXpenditure
EN	European Norm
GIIGNL	International Group of Liquefied Natural Gas Importers
LNG	Liquefied Natural Gas
MTPA	Million Ton Per Annum
NG	Natural Gas
OPEX	OPerating EXPenditure
ORV	Open Rack Vaporizer
SCV	Submerged Combustion Vaporizer

1. Introduction

1.1 Background

In 2013, the world LNG trade accounted for 236.8 million tonnes, nearly on a par with 2012 levels though still below the peak of 241.5 million tonnes reached in 2011. In spite of the fact that world LNG trade is characterized by no significant decrease, strong variations in LNG imports can be observed if the analysis is made for different areas (Europe – 27%; USA – 49%; Asia + 9,2 % comparing 2012 and 2011 data). This is due to several reasons: large increase in demand in Asia and in the emerging markets of Southeast Asia and South America, low gas demand in Europe due to a weak economy, the growth of renewables and the drop in carbon prices, the rise of shale gas in the USA, etc.

As a consequence, there are countries in which the utilization rate in terms of regasification capacity is lower than 20% and, furthermore, in some receiving terminals the send-out level is close to zero.

The longer the periods of low send-out, the greater the technical problems arising from this situation that can affect the reliability of an import Terminal. Several machines and devices must be continuously operated under unusual conditions (very low flow rates, high pressures, high gas losses) and, apart from the damage that can affect the LNG installations, in some cases, even the maintenance and operational costs that must be faced for operating the Terminal in these conditions can be significant, if compared and related to the low production level.

By undertaking a study about the maintenance and operational experience of those GIIGNL members that, right now, are already facing the problem, all members (operating an import Terminal) will benefit, as they will be better positioned to review and improve their own operations in case they have to face low send-out periods, as well.

1.2 Objectives and scope of work

The aims of the work are as follows:

• Exchange of information in order to support decisions related to optimizing the technical reliability of LNG import Terminals subjected to low send-out periods, and enable members to understand and move toward best practice to manage such conditions;

• Definition of what is meant by “low-send out” and zero send out. Identification of all the technical processes that are or can be affected by low or even zero send-out periods and of the consequent problems that can arise;

• Identification of possible risks regarding competence/skills loss and consequent suggestions;

• Benchmark of the present conditions and of the subsequent solutions that, right now, are adopted by the GIIGNL task force members;

• Analysis of all the gathered information and issue of a report detailing the findings and indicating best practices to meet the study objectives;

• Providing a basis for evaluating and minimizing the extra operating costs that can arise from a situation of low send-out.

1.3 Organization of the study and contributors

This work was done in confidence by those members of GIIGNL Technical Study Group that operate LNG import Terminals and that are or were involved in problems related to low send-out periods.

1. Introduction

Gianluca Bolzoni from GNL Italia led the task force. The activity started in March 2014 with a kick off meeting held at Snam headquarters in Milan where the Table of Contents was outlined and each member was assigned a task consistent with their field of expertise. Task Force members then kept in touch and shared thoughts and contributions until June 2015, when the final draft of the document was approved. No other publications from GIIGNL were available about this topic to be used as a foreword for this work.

Each section of the report is based on the contribution of a different member of the task force. Accordingly we would like to thank Ricardo Conde for section 2.2 (BOG Recovery – Enagas), Yovannis Mierez for section 2.2.2.7 (Re-liquefaction – Sempra LNG), for section 2.3 Nathalie Bussy (Storage tanks management – Elengy), for section 2.4 and 2.5 Michael Adedoja (Maintenance and Human Resources management – National Grid) and for section 3 James Bradley (Alternative uses of LNG – BP). Sections 1, 2.1, and 4 have been written By Francesco di Fratta and Giovanni Bonetti from GNL Italia, that also gathered and included in the work all comments and feedback from other participants. Together with the already mentioned contributors, GDF Suez NA, Southern LNG and Hazira LNG Private Ltd also contributed actively to section 4 providing answers to a questionnaire. Other colleagues helped giving valuable comments to the draft document, proposing ideas and sharing experience during GIIGNL meetings or via mail. Thus we also would like to mention Richard Ellis (BP), Elliot Decker (Freeport LNG) Philippe Bouchy (Elengy) Cornelius Martin and Jonathan Lauck (GDF Suez NA), Jason Shirley, Simon Culkin and Evans David (National Grid Plc), Jeffrey Green (Southern LNG), Secil Torun and Hugues Malvos from GDF Suez who also are respectively chairman and secretary of GIIGNL Technical Study Group.

The task force members decided to release this study for publication only available to GIIGNL members.

1.4 Low and zero send-out conditions

1.4.1 Definitions

According to the definition of GLE, also used in the Spanish Terminals, The Minimum Send-out Rate is defined as the minimum level of regasification send-out necessary to:

• Recover the Boil-Off Gas generated in any circumstance of operation;

• Keep cold all the LNG regasification facilities;

• Guarantee 100% of availability of the rest of the equipment in safe conditions of stable functioning.

An LNG Terminal is in Low Send-out Conditions when it needs to operate below its technical Minimum Send-Out Rate, whereas in Zero Send-Out Conditions a Terminal is not regasifying.

1.4.2 List of process affected

List of topics considered within this technical study:

• **LNG ageing**: problems and solutions related to the increasing density and Gross Heat Value of LNG (such as the interchangeability of the regasified LNG with the gas of pipeline network, maximum period without the necessity of a discharge, how to manage a new discharge, the ballasting in the tank with a fresh cargo of LNG in order to avoid stratification and rollover);

• **Boil-Off Gas recovery**: actions to be implemented in low and zero send-out periods to reduce the BOG generation and CO2 emissions or to optimize BOG recovery (for example: sending to gas network and, if necessary, correction process to guarantee the interchangeability of gas; using for power or thermal production; re-liquefaction);

• **Storage tanks management**: typology and characteristics of different tank technologies. How to approach the possibility of warming tanks during terminal under-utilization.

• **Operation management**: problems and solutions related to the management of the terminal's main equipment during low and zero send out periods.

• **Maintenance management**: variations to equipment's maintenance plans in low and zero send-out periods, additional activities that should be considered and how to manage LNG supply for testing operations, for startup of new machines and for cooling down of parts of the plants in zero send-out periods;

• **Human Resources management**: optimal organization of daily and on shift work in low and zero send-out periods; actions and exercises to avoid the loss of expertize or competence and to keep staff morale high;

• Alternative uses of LNG: alternative ways to use the LNG with the aim of increasing turnover of stock, thus increasing plant utilization (such as reloading or the implementation of small scale LNG activities in a Terminal) and the related challenges/benefits this approach may produce.

2.1 LNG Ageing

2.1.1 General description

During storage periods a fraction of the LNG is evaporated into BOG because of heat leakages on tanks and pipes. If LNG is kept recirculating in pipes, a large contribution comes also from the pumps' energy. The process of BOG formation is also influenced by changes of ambient conditions, especially the pressure which often determines directly the pressurization level of tanks.

Heat leakages: heat transfer through tank walls, floor and roof is one of the major contributors to BOG formation, which is different from case to case depending on tank typology and environmental conditions. An overview of tank technology and relative insulation is given in section 2.3. In addition to the heat transfer in storage tanks, a major contribution to BOG production is given by the recirculation of LNG when pipes and plant sections have to be maintained at cryogenic temperatures. In this case, along with heat transfer through piping insulation, the energy dissipated by pumps, the effect of friction, turbulence and other minor thermodynamic effects when LNG is recirculated increase the LNG energy content producing further BOG.

Barometric pressure drop: Barometric pressure drop can give a huge contribution to the boil-off rate. Storage tanks are operated generally over a small range of gauge pressures. Typical LNG storage tanks are kept in the range of 1,030 to 1,250 mbar absolute pressure. Depending on pressurization system, when ambient pressure drops, the absolute pressure in tanks may fall as well. As a consequence, the equilibrium condition of the two-phase LNG mixture stored in tanks tends to change. To restore the equilibrium condition, the evaporation rate increases and heat is removed from the interface whose temperature decreases by approximately 0.1 °C for every 10 mbar drop. In practice, the effect of atmospheric pressure drop is strong only when pressure changes rapidly, but more often changes in environmental conditions have a characteristic time length of a few hours.

The effect of pressure can be different from case to case, depending on each terminal technology, while heat leakages are always present. In order to evaluate the interaction between the external environment and the stored LNG, a theoretical evaluation of the phenomenon is possible by modeling the insulation and the heat transfer across tank walls and other equipment. Nevertheless this approach may not be worthwhile and is still approximate. From the point of view of plant managers, the amount of BOG generated is an immediate and very handy piece of information to quantify the phenomenon. An alternative way to measure the impact of BOG related losses is to express the Boil Off Rate (BOR) with respect to the stored quantity. Thus a simple definition of BOR[1]

[1] The BOR definition used in this work make the BOR parameter strongly dependent on the stored quantity. An alternative approach is to make the evaporation rate relative to the tank volume instead of the stored liquid volume to make the parameter less variable. However, the phenomenon of heat ingress into thanks and consequent BOG generation depends on many variables like tank typology, tank geometry, external conditions, as well as the amount of stored LNG. In fact, depending on the liquid height inside tanks, temperature gradient and heat transfer coefficient in both liquid and gas region change. Thus, the heat transfer mechanism depends also on the stored volume and a rigorous approach should consider it. Both definitions have pros and cons and must be handled carefully. Even though the attempt to quantify the phenomenon and to obtain significant figures has been not completely successful, definition and results have been presented as they are. Future works should consider the mentioned weakness of

is the percentage of the vaporized gas volume with respect to the initial LNG volume.

$$BOR\ (\%) = \frac{Volume\ evaporated\ per\ day}{initial\ Volume} = \frac{(Vinitial - Vfinal)/days}{Vinitial} * 100$$

This parameter has been used to quantify losses of LNG carriers' tanks. The BOR is a time dependent quantity, and thus can be an instant value or an average over a time window. Following the approach stated by the equation above, the calculated BOR is the average daily evaporation rate during a generic storage period. Typical values of BOR ranges from 0.10 % to 0.30 % per day. It is clear that the type of containment and the quality of its thermal insulation directly affects this parameter which should be as low as possible. BOR values are also influenced by the ambient condition, especially the pressure, and it depends also on the stored quantity, thus it is always important to look at these numbers critically. In spite of its weaknesses the BOR parameter is a simple indicator that can give to plant managers a quick and intuitive feeling about the overall situation of tanks during storage periods allowing comparisons in terms of relative losses, with particular reference to tank insulation status or in order to compare performances for different tanks typology. Moreover, being defined as an evaporation ratio with respect to the stored quantity it could be directly employed in simple forecasting models.

The following example is the plot of daily BOR for both tanks S1 and S2 in a European terminal, taken each day in July '14 and January '15.

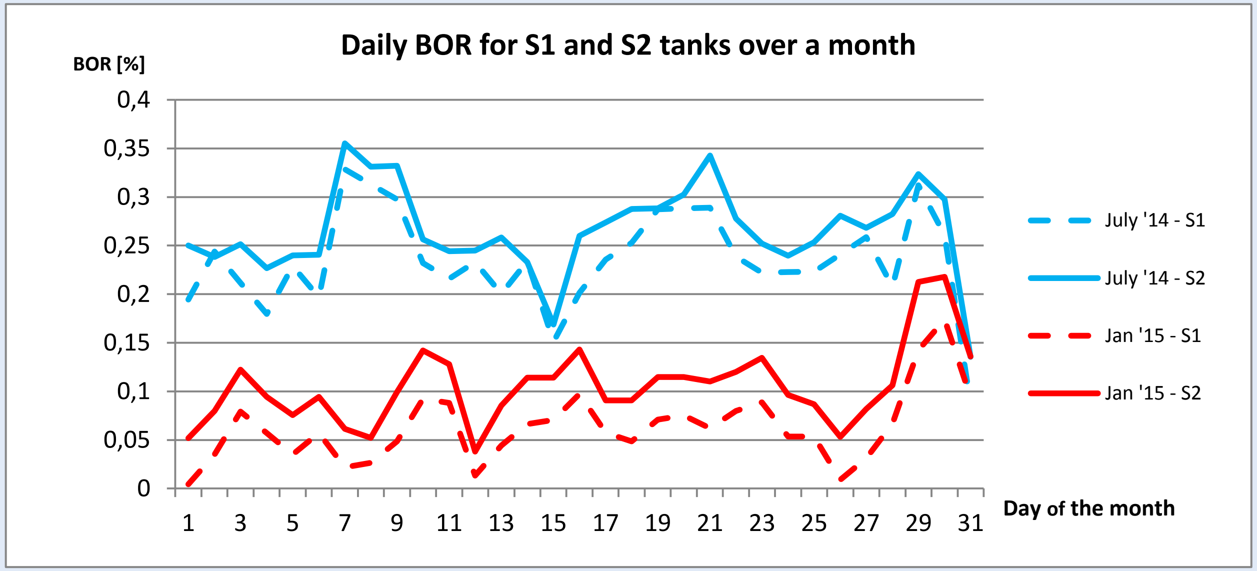

Figure 1 - Daily average BOR for 2 tanks of a European terminal

	BOR [%]		LNG evaporated [m^3/day]		LNG stored [m^3/day]	
	S1	S2	S1	S2	S1	S2
July '14	0,23%	0,26%	26,25	38,29	11140	14370
January '15	0,06%	0,10%	26,55	41,31	42370	39290

Table 1 - Montly average of daily BOR, evaporated volume and LNG stored for S1 and S2 tanks.

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this parameter and eventually consider a more sophisticated and precise approach.

The plant has been in zero send-out condition during those periods, with LNG at rest in tanks and no recirculation. Mean daily values for BOR, liquid evaporated, and liquid stored over these months are reported in Table 1. Tanks structure is the same and also the quality of LNG left stored in tanks was quite similar (before ageing). Comparing the two tanks, it is evident that BOR of tank S2 is always higher. Further investigation of tank status confirmed that part of the insulation of S2 tank has deteriorated and restoring actions have been planned and are currently ongoing. The effect of changes in pressure is clearly evident looking at the daily variation on the plot. Leaving that aside, another aspect comes up: in July '14 the relative evaporation rate was much higher than in the more recent observation. This is due to seasonal change of external conditions and the different LNG volume stored in tanks. Even looking at the absolute value of evaporated liquid it is not straightforward to separate the effect of different liquid heel and external weather to the overall BOG generated.
Since LNG is a mixture of components with associated differences in boiling point temperatures (see the table below), its evaporation rate is an evolving process: the components with the lowest boiling point (nitrogen and methane) tend to evaporate earlier than heavier hydrocarbons resulting in different BOG composition.

Component	Boiling point (atmospheric pressure)
Nitrogen	-196 °C
Methane	-161 °C
Ethane	-89 °C
Propane	-42 °C
i-Butane	-12 °C
n-Butane	-1 °C
i-Pentane	+28 °C
n-Pentane	+36 °C
Hexane	+69 °C

Table 2 – Boiling point at atmosferic pressure of main LNG components.

The change of BOG composition over time gives clear evidence of this thermodynamic phenomenon: in the first days after a fresh discharge, BOG composition is high in nitrogen (which obviously depends on discharged LNG quality) and methane, with traces of heavier components. As the ageing proceeds without fresh LNG addition, the nitrogen presence in BOG vanishes and vapor tends to be almost pure methane. The example given in table 3 shows the change in BOG composition over time after a recent LNG unloading in a terminal affected by "zero send out" condition. After periods of prolonged zero send out BOG is still almost pure methane, with traces of nitrogen and other compounds. However, even if numbers are small, the trend of composition evolution is different. As long as the ageing proceeds, the concentration of heavier components in the mixture increases, starting with ethane (see table 4). The significant presence of heavier hydrocarbons in BOG is never reached, unless tanks warm up and the temperature rises a few degrees above the -160° level. The example of table 4 shows the contribution of main components in BOG at the terminal for the last few weeks of a one year long zero send out period.

	12th Dec	18th Dec	29th Dec	05th Jan	12th Jan	19th Jan	26th Jan	02nd Feb	09th Feb	16th Feb	25th Feb
CH_4	**88,3083**	**89,7586**	**91,9267**	**92,8535**	**93,7804**	**94,4805**	**95,4360**	**96,2170**	**96,7480**	**96,9040**	**97,3240**
C_2H_6	0,5630	0,2158	0,1329	0,1626	0,0736	0,1391	0,0279	0,0260	0,0278	0,0248	0,0247
C_3H_8	0,0456	0,0309	0,0265	0,0144	0,0001	0,000	0,000	0,000	0,000	0,000	0,000
N_2	**10,9832**	**9,8986**	**7,8243**	**6,8827**	**6,0580**	**5,2996**	**4,4657**	**3,6907**	**3,1614**	**3,0091**	**2,5916**
O_2	0,0950	0,0927	0,0861	0,0828	0,0805	0,0766	0,0708	0,0663	0,0633	0,0623	0,0595

Table 3 - Molar fraction of main components in BOG after a fresh discharge starting from 12th December 2014. Traces of oxygen comes from the fresh LNG discharged.

	01st Dec	08th Dec	15th Dec	22nd Dec	29th Dec	05th Jan	12th Jan	19th Jan	26th Jan	02nd Feb	09th Feb
CH_4	**99,9540**	**99,9500**	**99,9400**	**99,9360**	**99,9280**	**99,9330**	**99,9290**	**99,9260**	**99,9260**	**99,9140**	**99,8910**
C_2H_6	**0,0440**	**0,0480**	**0,0580**	**0,0640**	**0,0630**	**0,0670**	**0,0710**	**0,0740**	**0,0740**	**0,0860**	**0,1090**
C_3H_8	0,000	0,000	0,000	0,000	0,0090	0,000	0,000	0,000	0,000	0,000	0,000
N_2	0,0020	0,0020	0,0020	0,000	0,0090	0,000	0,000	0,000	0,000	0,000	0,000
O_2	0,000	0,0090	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Table 4 - Molar fraction of main components in BOG after almost one year of zero send out, from 01st December 2013.

The loss of methane is reflected in the liquid phase which becomes progressively more dense. This is generally known as LNG ageing, or weathering. Its effects become of utmost importance for long periods without fresh LNG addition in tanks. Following the change in composition, the effect of the ageing process is that the in-tank temperature and especially the density increase. In one terminal, which experienced a very long period of zero send out, this trend has become very important, reaching high values in February 2014. When the terminal started to be in zero send out the density in the two tanks was 446 kg/m^3 and 449 kg/m^3. After one year of zero send out, the densities became 480 kg/m^3 and 534 kg/m^3 respectively. The following plot shows the LNG ageing in the terminal at a glance.

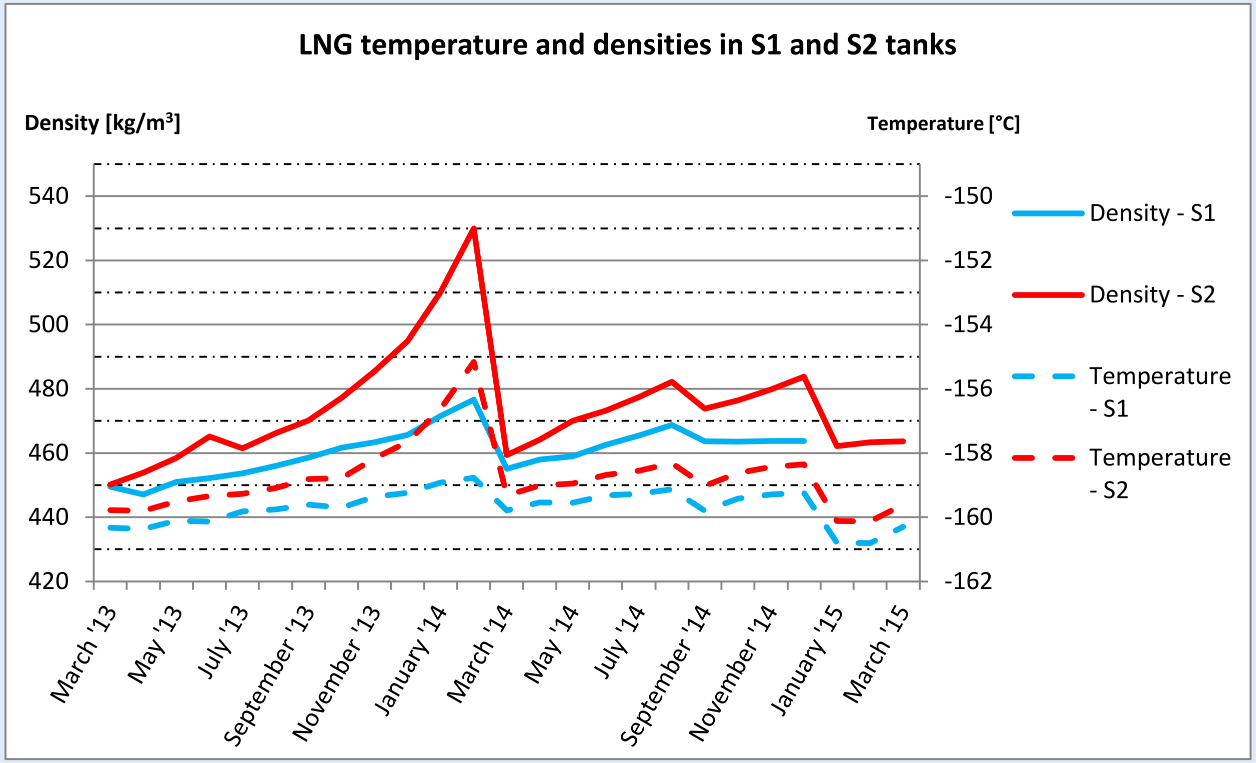


Figure 2 – The effect of LNG ageing on temperature and density

Looking at the chart, it is possible to note the effect of a blending of the tanks' contents in June 2013 and the impact of three fresh discharges in February, August and December '14. It is also interesting to note that the speed of ageing increases as time elapses and temperature and densities depart significantly from their original values.

Leaving aside the BOG recovery and management, in the light of this scenario there are three main concerns related to LNG ageing in zero send-out terminals:

• Aged LNG processing and interchangeability: it becomes more difficult to meet network quality requirements after long periods of zero send-out.

• LNG quality evaluation: generally the evaluation of LNG in tanks becomes more difficult and less accurate;

• Higher probability to have stratification and rollover phenomena.

2.1.2 LNG processing and interchangeability

Depending on LNG quality, it may be that sometimes BOG composition does not satisfy network quality requirements. This could happen mainly in two circumstances. First of all after a fresh discharge, when the nitrogen content in BOG could exceed the maximum allowed for the network. In these cases propane or LNG ballasting becomes mandatory in order to prevent vent/flaring. The problem is of minor importance for terminals during regasification, but becomes more relevant when there is no LNG recirculating, because ballasting with liquid may be unfeasible and normally the recondenser is not operating. Moreover if the ballasting system is designed to operate during regasification it may be that its sizing is inappropriate for zero send out operation: namely it is not capable of providing small LNG quantities at adequate pressure for BOG correction. If there is not a dedicated system for low flow-rate ballasting, it is in principle possible to exploit main pumps and equipment; unfortunately the additional BOG generated with them makes the overall balance of this solution unsustainable, from both the energetic (with environmental consequences) and the economic point of view. Fortunately the natural evolution of BOG composition over time leads towards a gas mixture that loses nitrogen at first and progressively becomes almost pure methane. Accordingly, the problem of interchangeability tend to be "naturally solved" even when there is no chance for correction. However, depending on the fresh LNG qualities and quantities, the period of non-compliance of BOG characteristics with network requirements could last for a few weeks and without correction or alternative recovery the consequent venting/flaring would produce non negligible environmental emissions and economic losses. BOG characteristics presented in table 3 are a good example of this case and are summarized graphically in the following chart.

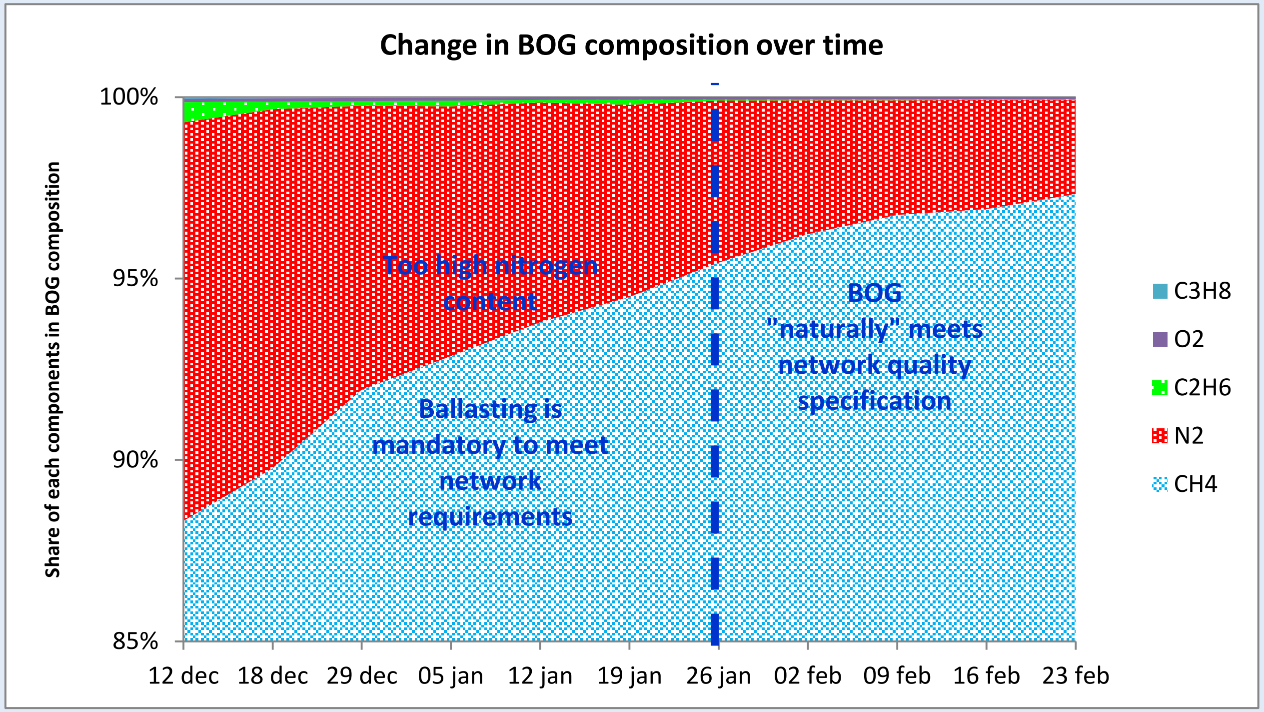


Figure 3 – Molar fraction of main components in BOG after a fresh discharge in starting from 12th December 2014

	12th Dec	18th Dec	29th Dec	05th Jan	12th Jan	19th Jan	26th Jan	02nd Feb	09th Feb	16th Feb	25th Feb
N_2 [mol. %]	10,9832	9,8986	7,8243	6,8827	6,0580	5,2996	4,4657	3,6907	3,1614	3,0091	2,5916
Wobbe [MJ/m^3]	43,467	44,089	45,419	46,039	46,565	47,082	47,622	48,147	48,507	48,611	48,897

Table 5 – Effect of N2 content in BOG on Wobbe Index. Min. acceptable Wobbe for the terminal considered in the example is 47,31 MJ/m3at 15°C and 101,325 kPa.

Rigorously speaking, in general quality restrictions are not given on nitrogen content but on the superior Wobbe Index. Nevertheless, it is the nitrogen content that has the greatest effect on Wobbe Index. In fact, after the nitrogen drops below acceptable limits, the Wobbe Index increases over the minimum threshold and the BOG produced during zero send-out generally respects network specification.

The problem of interchangeability can rise again after LNG ageing in a different and somewhat stronger way. It has been explained in this chapter that the longer the zero send-out period is, the denser the LNG stored in tanks becomes because of changes in composition. When density rises too much in tanks it is not crucial for tanks themselves, but it could be a problem for gas processing and some plant equipment like pumps. In fact, after excessive ageing, the ultimate density value could lie far beyond pumps design range, resulting in loss of process performance. Moreover, in the worst case scenario it might happen that because of the higher density pumps are not able to reach the network maximum operational pressure, or because of motors and other automatic protection system, are not even able to start and keep on safely running.

Still, looking at the experience of the terminal being considered, LNG pumps have a design density range of 440 – 480 kg/m^3. In February 2014, just before the discharge of the maintenance cargo in tank S2 the density reached a maximum of 534 kg/m^3. Pump start-up was difficult and submerged in tank pumps for S2 tank did not restart immediately. Many uncertainties arise after extremely long periods for non-running equipment and there is an unavoidable loss of confidence about equipment status. Thus, it is difficult to infer conclusions and explain why the pumping system did not respond promptly. However, the evidence is that after some blending with fresh, lighter new product the pump started and no anomalies in any operational parameters were detected. For the same model of pumps installed in S1 tank, everything worked out perfectly; the LNG density in that case was approximately 480 kg/m^3, in line with the upper limit of design density range. The most likely cause of the issues encountered thus remains the high density of the aged LNG.

Another relevant problem due to LNG ageing is related to the shift of the fluid's critical point. The critical point shifts towards higher pressure for aged LNG (LNG rich in heavy hydrocarbons). Even though none of the operators that participated in this study have experience with this, there is awareness that a significant shift of critical point could affect and potentially damage vaporizers. The vaporization process normally occurs above the critical point, where the LNG behaves as a supercritical fluid. As LNG weathers, the critical pressure increases. If this value become too close to the vaporization pressure, it might not be guaranteed that vaporization actually occurs in the supercritical region, potentially resulting in two phase flow phenomena. If this happens, there is risk of generating surge, vibrations, fatigue and ultimately failure of equipment.

Besides these aspects, the main problem after excessive ageing remains the capacity to fulfill gas quality specification in order to guarantee interchangeability with the network, meeting customers' needs. Some terminals have a correction system capable of diluting gas with dry air or nitrogen to reduce heating value and Wobbe index of heavier products. If the Wobbe index of the weathered LNG goes beyond the technical capacity for correction, the terminal might not be able to satisfy network requirements in case of very high production rate. For example, one of the member's terminals commercially guarantees correction of LNG with high Wobbe index up to 53,17 MJ/m^3. Safety margins and technical redundancy allows the terminal to go beyond it, but it is clear that operators cannot exclude this aspect in their strategy definition. If Wobbe index becomes too high it is still possible to correct the gas for the network, but terminal's operational capacity would be driven by the sizing of the correction system and not by pump and vaporizers. Where the quality specifications for the network, along with Wobbe index, fixes maximum levels for N_2, O_2 and CO_2 this possibility could be even more stringent. Before the discharge of a cargo in 2014 the Wobbe index for aged LNG stored in S1 and S2 tanks was estimated to be approximately 54,25 MJ/m^3 in S1 and 58,27 MJ/m^3 in S2 tank. Concerns on gas interchangeability do not concern only forecasts of future terminal production activities. Even the arrival and unloading of new fresh cargos becomes critical, because it can be difficult to correct the large amount of BOG produced during cooling and transfer operation. Even receiving a fresh and very light cargo for strong blending with the aged product would lead to a tremendous waste of gas in the first part of the unloading operations, before the mixing will become effective and it will be possible to restart at least partially the regasification activity. The severity of these operations must be accurately evaluated case by case and terminals operators should work on ageing forecasts in order to minimize such kind of inconvenience. It has also to be remembered that besides technical and operational constraints, this problem can affect also the commercial strategy of the terminal because for the operator it could become mandatory to impose further restriction on product acceptability, going towards light products at least for plant restart operations. It is also clear that introducing further commercial restrictions for a terminal that already suffers ageing for prolonged zero send out makes the overall situation even worse.

Where the ageing speed was found to be different for the two tanks, LNG weathering has been mitigated at first by mixing tanks' contents. In the end, since there were no better perspectives from shippers' side, the Terminal Operator decided to go for a small fresh discharge in February 2014. The discharge has been performed at very low flow rates in order to minimize BOG production and without using the recondenser. The huge difference in density between the fresh cargo and the weathered LNG strengthen rollover worries and attention for the safety of discharge which has been completed successfully.

In conclusion, the problem of gas interchangeability must be considered from an overall point of view, case by case according to:

- The initial LNG quality in storage;
- The expected duration of the zero send-out period;
- The quality specifications of Natural Gas requested at the terminal, different in each country;
- Characteristics and capability of the available correction systems of terminal.

These elements are the basis to define the best strategy for plant management. Knowing the LNG quality and restrictions for gas correction, the operator can make ageing forecasts. If possible, mixing of different LNG stored can help mitigate the weathering. After that, according to plant functionality and the market scenario, the operator can only choose between tank warming or request a fresh small LNG cargo with appropriate quality for blending and restore operational margins.

2.1.3 LNG Quality evaluation

In normal and low send-out conditions, the composition of LNG is generally measured by gas chromatography. In zero send-out condition, an LNG Terminal which provides alternative services in addition to the regasification for gas network (direct supply of power plant, reloading, truck loading, loading of bunker ship, etc.) often have a circulating stream of LNG that can be sampled for analysis when an in-tank pump is running. However, without additional services and no chance to discharge LNG from tanks, if terminal's operator does not keep recirculating flows for cooling, the composition of LNG generally cannot be measured. In principle, in every terminal it is always possible to turn on pumps and discharge some liquid, but the cooling phase and the huge production of BOG make this operation uneconomic. In this case, the most common strategy is to estimate LNG composition with numerical models. Generally models requires as input data the last available characteristic of LNG (quantity, composition, pressure and temperature), and actual BOG composition, temperature and quantity. Through a proper method (for example the Klosek-McKinley (KMK) method) the evolution over time of the stored LNG composition and its density are calculated. The accuracy of the prediction is monitored by comparison between the estimated density and in tank measurements which can be used also to update and adjust model results. Even though models are quite accurate, they are naturally affected by errors. As long as the period of zero send-out progresses without measurements, modeling errors propagate, increasing uncertainty on the estimated LNG composition. The accurate measurement and/or prediction of LNG composition is fundamental in order to carry out a safe discharge, with particular care in stratification and rollover prevention, and in blending operations. The precise knowledge of LNG composition is also fundamental for LNG trade which is based on gas energy content and quality. Uncertainties and errors regarding the composition of the stored products are unavoidably reflected in energy and mass balances, and thus in stock valuation.

2.1.4 Stratification and Rollover

Stratification occurs when the LNG in the tank forms layers with different compositions, densities and temperatures. Layering occurs mainly because of inadequate mixing of the fresh LNG cargos into receiving tanks containing LNG with different properties. Depending upon the nitrogen content, boil-off activity, and heat leaks, stratification may also develop spontaneously within the homogeneous liquid volume of the tank. In this mechanism (also called "auto-stratification") the un-stratified liquid gains heat at the walls of tank, rises by convection and flashes upon reaching the surface. An unstable stratification could evolve into the so called Rollover phenomenon. During the zero send-out periods the risk of stratification increases because of LNG weathering which could lead to huge density differences like in the example presented previously. Moreover, if the cargo is discharged very slowly to reduce BOG production the effectiveness of fresh product mixing in tank can be reduced, depending on the kind of nozzle adopted in the terminal. When rollover occurs pressure inside storage tanks may rise to excessive levels and the safety valves could open venting LNG vapour into the atmosphere at an undesired and uncontrolled rate.

2.1.4.1 Preventive measures

The most effective methods for preventing rollover rely on monitoring of LNG density and temperature over the height of the tank. Nowadays the most common instruments used for layer detection are Level Temperature Density (LTD) travelling gauges. The LTD travelling gauge is an instrument capable of measuring temperature and density over the entire depth of the liquid. It can also detect directly the position of the liquid – gas interface. The LTD measurements can be used in rollover prediction software which gives the operator an integrated predictive tool with real time validation. Generally this software relies on thermodynamic modeling of the liquid phase, coupled with heat transfer through tank walls. In the absence of a layer detection instrument, multiple temperature sensors located at fixed intervals can give an alternative indication of layering, but they cannot be used to generate a continuous profile from top to bottom of tank. Generally both tools are implemented. Once the size and characteristic of layers are detected, it is possible to evaluate the potential danger and especially choose the most cost-effective corrective action, such simple recirculation in tanks or mixing with LNG taken from other tanks.

2.1.4.2 Receiving LNG cargoes

When it is established that an LNG cargo has to be unloaded into a terminal's tanks after long lasting zero send-out periods, the operator should focus also on the increased potential risk of rollover, due to mixing of LNG with different densities. While the density of the aged product is high, the density of the incoming cargo is likely to be much lower.
Chemical composition and density of LNG in the cargo, that depends on cargo origin, must be known first, and also the characteristics of the aged product in tanks must be known, (to the best of the available possibilities – see 2.1.2). This information, especially the difference in density of the two liquids, should be used to evaluate the potential for stratification and to promote LNG mixing during unloading. For example, choosing bottom-filling or top-filling injection respectively for liquids lighter or heavier than the LNG stored in the tanks. In case of unloading a maintenance cargo during zero send out, the discharge could be done very slowly to minimize BOG production. In this case, the effectiveness of mixing of the two LNGs in the storage tank could be compromised, because of the low velocity (flow rate) of the incoming stream in the tank (for example through jet nozzles).
During the unloading, it is necessary to continuously check the density and temperature over the height of tank and eventually make corrective actions, i.e. running in tank pumps to activate in-tank recirculation to avoid layering. Finally, it is also recommended to monitor LNG density in tanks some days after the discharge, until the stable condition of LNG is ensured.

2.1.5 Impact on safety and environment

The most dangerous consequence of LNG ageing could be a rollover accident. Rollover causes the rapid release of large amounts of vapour leading to potential over-pressurization of the tank. The tank relief system may not be able to handle the rapid boil-off rates and the storage tank will fail leading to the rapid release of large amounts of LNG to the atmosphere which has safety and environmental implications.
However, even if this dramatic accident is avoided, all the problems related to BOG generation, especially when correction or recovery are not technically feasible because of

the ageing effect, would result in a waste of resources and flaring/venting.

2.1.6 Economic considerations

The loss of inventory and any other kind of loss due to LNG ageing has an economic impact. Moreover, if the operator decides to buy a maintenance cargo, even though small, he will face further extra costs. Hence, in order to minimize losses, extremely thorough decision making is required, considering both the terminal status and market forecasts. In the worst situation, if a terminal cannot wait any longer for a LNG supply, the operator could be forced to buy a maintenance cargo to refresh the aged LNG without any chance to wait for future and potentially better market condition. In the end, it must be remembered that for a terminal in zero send out, the cost of a small maintenance cargo is likely to be bigger than OPEX savings which mainly comes from the reduction of terminal's energy consumption.

2.2 Boil-Off Gas recovery

2.2.1 General description and specific technical problems

In low send out periods one of the major issues in a receiving terminal is BOG management. Most terminals use a recondenser to recover BOG, which is an absorption column where pressurized liquid and BOG are sent and mixed. The column capacity depends mainly on the flow rate of LNG available and on the thermodynamic conditions of both LNG and BOG flows. As a consequence of that, when terminals operate in low send out, the availability of liquid LNG processed is reduced; moreover, in zero send out condition the LNG availability for the recondenser can even be null. In such conditions, when it is not possible to recover all BOG, the recommendation is to minimize BOG generation at first and then look for other ways to recover it.

2.2.2 Corrective actions

The term "preventive" might be inappropriate in this context, since it is impossible to avoid LNG evaporating and turning into BOG. Thus, it could sound odd to talk about preventive and corrective measures. Nevertheless, it is still possible to approach the problem from two points of view. The first is on the side of BOG production minimization, and the second is about BOG recovery. According to this logical order, the possibility to reduce the amount of BOG generated will be shown first and, afterwards, ways to increase the recovery.

2.2.2.1 BOG minimization

In this section a set of recommendations will be provided in order to minimize BOG generation:

- **Increase working pressure**: The Boil Off generated is inversely proportional to working pressure; so by increasing pressurization, the total BOG generated will be reduced. This general principle could be applied to virtually any plant section, keeping in mind safety and design limits of equipment and protection systems. Great care has to be taken in order to exploit available margins to increase the working pressure while avoiding undesired consequences. This possibility should be evaluated case by case, considering design criteria and applicable codes and safety requirements.

- **Pressure control in tanks**: The above mentioned principle has great potential if applied to tanks. Usually the original design of the BOG system in a terminal is intended to keep the whole system in communication, and thus at the same pressure. This means that BOG generated in ny part of the system increases the pressure everywhere and, in the same way, when BOG is recovered pressure decreases in every point of the system. A proposal raised in the frame of this study group, is the installation of pressure control valves on each BOG tank circuit. This equipment, together with pressure transmitters will allow pressure to be controlled independently in each tank. It could be useful, especially before ship unloading, because operators could reduce at minimum the pressure in tanks before the discharge, allowing maximum BOG recovery and storage during transfer operations. This action is recommended in European norm EN-1473 as a good practice. Adaptation of an existing plant to introduce this improvement could be done in many cases using existing on-off valves or hand valves. Normally these valves are butterfly or ball valves and their bodies are not designed for control purposes. The result of this operation will not be as accurate as if it was done with a specific control valve, but it could be good enough for our goal which is to introduce pressure control and optimization in tanks with less invasive intervention on the plant.

- **Reduce the LNG necessary to keep lines cold**: It is a common practice in LNG terminals to circulate LNG through the whole system to keep all equipment in a cold state, avoiding the large generation of BOG released when items are cooled from their warm state. Nevertheless, in long periods of low and zero send-out, the overall production of BOG due to continuous recirculation becomes much more significant than the quantity generated in case of plant restart. Accordingly, the need for optimization arises and the quantity of LNG circulated has to be minimized. Pump control, with proper adjustment of valves and the installation of orifice plates can help reduce the LNG used for this purpose. Orifice plates will create a differential pressure in the circuit, decreasing the amount of LNG recirculating through the lines and then, the amount of BOG will decrease.

- **Warm-up parts of the terminal not needed as a consequence of the low send out**. According to terminal utilization forecasts, and plant modularity, the most effective way to reduce LNG recirculating and BOG production is to leave in a warm state some equipment and sections of the plant. More specifically, while choosing items to be warmed-up, priority should be given to:
  - Pipelines of spare in-tank pumps,
  - Spare high pressure pumps
  - SCV´s and ORV not in use (if they are required, notification is required a few days in advance)

  It is also possible to consider the heating of a complete tank provided that enough capacity is guaranteed to respect terminals' commercial requirements. This could significantly decrease the total amount of BOG generated. A few examples regarding this aspect are given in section 3.5.

- **Insulation**: Proper design and installation and, afterwards, correct maintenance of pipes assures that BOG generation is minimized.

2.2.2.2 Recondenser optimization

In low send out periods, the amount of LNG vaporized is very limited so it is crucial to optimize the recondenser to recover as much BOG as possible. The first (and obvious) target should be to try to send through the recondenser all the LNG available in circulation. Second, try to push the column operating conditions towards a point of maximum BOG recovery. One way to do that is to increase the pressure level of the column: the bubble point temperature will increase providing the liquid stream with a further energy gap to absorb the BOG. While doing so, it has to be assured that bubble point is never reached; otherwise vapor and bubbles could reach LNG high pressure pumps, which can be severely damaged.

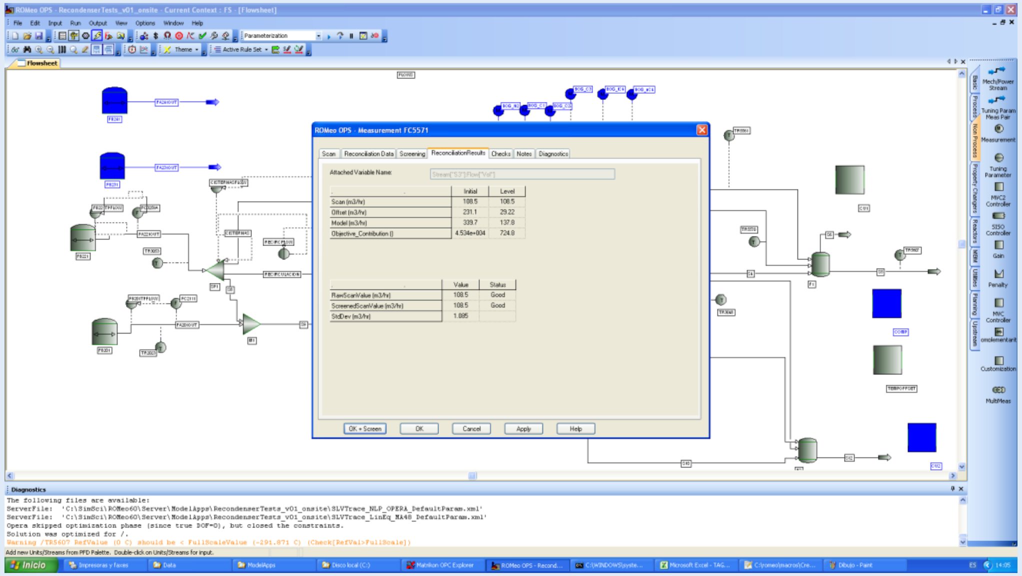


Figure 5 – Example of On Line Process Simulator for equilibrium pressure adjustment.

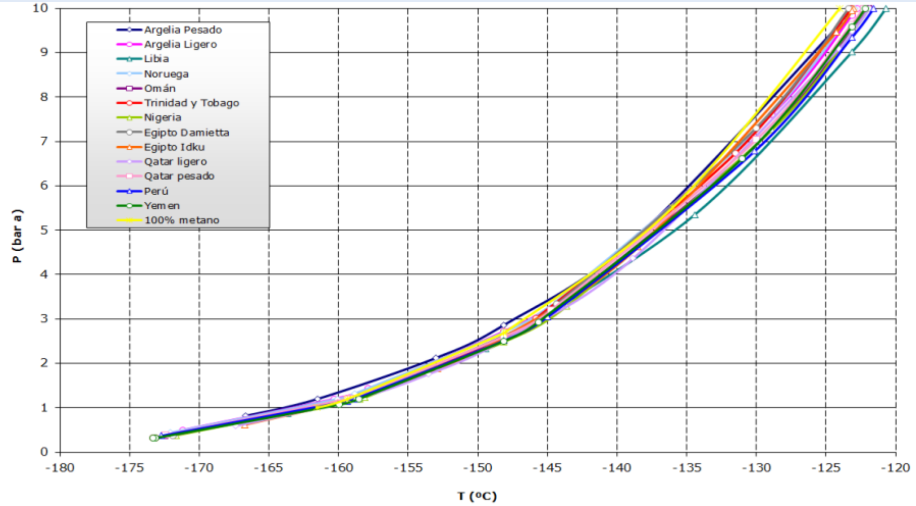


Figure 4 – Variation of LNG bubble temperature and pressures for different natural gas compositions.

Therefore it is mandatory to keep a safe operating margin with respect to the pumps suction head requirements. This measure can be achieved most effectively if the definition of the operating pressure is supported by the use of an On Line Process Simulator.

This tool includes thermodynamic models that allow equilibrium condition to be established accurately, taking into account also the chemical composition of the LNG. Thus, real time measurements of LNG quality allow the simulator to define accurately the bubble point of the mixture and to adjust the operating margins in line with the quality of LNG being processed.

The third action is to cool as much as possible the BOG sent to the recondenser. The effect obtained is the same as that of pressurization: the increased BOG versus LNG ratio. Three examples of measures to introduce and enhance BOG pre-cooling follow:

- Remove insulation from BOG piping along the line that goes from compressors to the recondenser. This is an easy measure to promote heat dissipation towards external environment. Before doing so the safety of personnel that access these areas and that can directly touch pipes has to be taken into account. The effectiveness of this intervention may be limited depending on operating temperatures, environmental conditions and pipeline length. Moreover, it has to be considered that many compressors have coolers already installed on their pressure side.

- If not available, install a BOG cooler between compressors and recondenser. The heat exchanger could be fed by seawater or it could be also an air coolers. Accurate cost and benefit analysis is required to define the optimal solution.

- Cool the BOG before it reaches compressors. This measure could potentially increase also compressor efficiency if the machinery design range can withstand the new condition; it needs to be verified by the manufacturer. In this case, because of the sub-zero temperatures, the intervention is possible only using LNG as coolant. Therefore, more than the other options, great care must be taken in the process design, because further LNG circulation would increase BOG production and because this measure could be in contrast with the aim to send all the available LNG stream to the recondenser.

In conclusion, there could be some margin for BOG cooling and all these examples could be combined and used together. In order to make the best choice, the problem must be considered from an overall point of view of this part of the process, from the tanks to the exit of the column.

2.2.2.3 Compression to gas network

By compressing the boil off to network pressure, it will be possible to recover boil off independently of the send-out. During regasification BOG recovery is not an issue, thus several plants simply lack the capacity to compress BOG to network pressure. Adding compressors increases plant modularity and flexibility of operations. The introduction of gas compressors to send BOG to network must be coupled with network quality requirements (see par. 2.1.2). For BOG with too low heating value it could be necessary to introduce ballasting, for example adding a desuperheater in which LNG is sprayed into the BOG stream. This operation must be followed by a knock out drum to eliminate any condensate in the gas stream that could damage the compressors if not removed. It is also important consider the gas temperature in compressors discharge. As is well known, compression increases gas temperature and this has to be taken into account in the phase of process definition and design.

2.2.2.4 Internal consumptions

Consuming BOG in SCVs, flare pilots and so on can be a good solution to recover boil off and, at the same time, save fuel gas. Installation of additional pipes to connect the BOG system with these consumers will be required.

2.2.2.5 Local network

If the terminal is feeding low pressure local networks, the BOG can be collected directly there. In fact, existing BOG compressors like those that feed the recondenser are generally able to feed the LP local network. This solution could be implemented with minor impact on existing plant compared to the installation of new compressors to feed the HP network.
For example for a local network of 10-16 barg; firstly it is necessary to decrease the send out to a minimum value that could be processed by existing compressors. Then, self-regulated pressure valves and minor equipment have to be set to new operating parameters. Gas correction and interchangeability issues must be considered carefully as must gas temperature. For example, in a few European terminals, during low send out scenarios, the BOG temperature tends to increase and the discharge of compressors easily reaches 80 °C, which might be not compatible with network requirements.

2.2.2.6 Process heat or power generation

The BOG can also be used to generate power or heat. Regasification plants often have power generators fed with NG and sometimes with BOG, or they can be added and integrated in plants with minor modifications. Another option is to produce process heating for SCV or to HVAC systems. Depending on specific regulations of the country, it may be possible to sell the power, the heat or both.
Like many of the others, this kind of solution needs proper evaluation from an overall point of view of each specific plant.

2.2.2.7 Re-Liquefaction

2.2.2.7.1 Purpose

The purpose of the BOG Liquefaction Project taken as an example is to liquefy BOG generated from the Terminal’s absorbed heat and return the resulting LNG back to the storage tanks. Normally, during extended periods of low send out, a Terminal requires maintenance cargos of LNG to maintain the LNG storage tanks cold and operational. Without these cargoes, the tanks will eventually de-inventory and the whole system will warm up. A facility as described in this document will avoid the need for maintenance cargoes, eliminate product aging and prevent inventory loss. The flexibility gained by the proposed Project will enhance the viability of other opportunities at the Terminal.

2.2.2.7.2 Design basis

The liquefaction facility will be designed to condense a certain volume of BOG to a saturated liquid pressure lower than the operating pressure of the tanks and supplied with enough head to be able to return the liquid BOG (LNG) to the storage tanks.
The BOG will be delivered to the liquefaction facility from the terminal’s existing equipment. The process to liquefy the BOG shall comply with all LNG Industry codes and standards.

Interconnection with existing piping, instrumentation, power, and ancillary services will be generally required.
The Nitrogen concentration for design is an important factor, as the power requirement increases considerably with the nitrogen concentration in the BOG; however each case

will be addressed as per the terminal needs. A typical BOG composition is presented in table 6.

Component	Molar Fraction
N_2	0.0100
CO_2	0.0000
CH_4	0.9895
C_2H_6	0.0005

Figure 6 – Typical BOG composition.

BOG is normally at very low pressure and the liquefaction is generally carried out at high pressure, indicative that compression will be required in the process.

2.2.2.7.3 Technology selection

Table 7 presents a series of different general types of processes classified by cycle type; there are several commercial names/patents in the market and each project should be evaluated individually for the best technology fit for each need.

CYCLE TYPE	PRINCIPLE	COMMENTS
Pre-cooled Joule-Thomson (JT)	A closed-cycle refrigerator (e.g. using Freon or propane) pre-cools compressed natural gas, which is then partially liquefied during expansion through a JT valve	Relatively simple and robust cycle, but efficiency is not high.
Nitrogen Refrigeration –Brayton Claude	Nitrogen is the working fluid in a closed-cycle refrigerator with a compressor, turbo-expander, and heat exchanger. Natural gas is cooled and liquefied in the heat exchanger.	Simple and robust cycle with relatively low efficiency. Using multiple refrigeration stages can increase efficiency.
Cascade	A number of closed-cycle refrigeration loops (e.g. using propane, ethylene, methane) operating in series sequentially cool and liquefy natural gas. More complex cascades use more stages to minimize heat transfer irreversibility.	High-efficiency cycle, especially with many cascade steps. Relatively expensive liquefier due to need for multiple compressors and heat exchangers. Cascade cycles of various designs are used in many large-capacity peak-shaving and LNG export plants.
Mixed Refrigerant (MRC)	Closed cycle refrigerator with multiple stages of expansion valves, phase separators, and heat exchanger. One working fluid, which is a mixture of refrigerants, provides a variable boiling temperature. Cools and liquefies natural gas with minimum heat transfer irreversibility, similar to cascade cycle.	High-efficiency cycle that can provide lower cost than conventional cascade because only one compressor is needed. Many variations on MRC are used for medium and large liquefaction plants.

Table 7 – Overview of liquefaction technologies – Adapted from USA Pro/California Energy Commission with modifications.

CYCLE TYPE	PRINCIPLE	COMMENTS
Open Turbo-expander	Classic open Claude cycle employs near-isentropic turbo-expander to cool compressed natural gas stream, followed by near-isenthalpic expansion through JT valve to partially liquefy gas stream.	Open cycle uses no refrigerants other than natural gas. Many variations, including Haylandt cycle used for air liquefaction. Efficiency increases for more complex cycle variations.
Turbo-expander at Gas Pressure Drop	Special application of turbo-expander at locations (e.g. pipeline city gate), where high-pressure natural gas is received and low-pressure gas is sent out (e.g., to distribution lines). By expanding the gas through a turbo-expander, a fraction can be liquefied with little or no compression power investment.	This design has been applied for peak-shaving liquefiers. Under development
Stirling Cycle (Phillips Refrigerator)	Cold gas (usually helium closed cycle using regenerative heat exchangers and gas displacer to provide refrigeration to cryogenic temperatures. Can be used in conjunction with heat exchanger to liquefy methane.	Very small-capacity Stirling refrigerators are catalog items manufactured by Phillips. These units have been considered for small-scale LNG transportation fuel production.
TADOPTR	TADOPTR = Thermoacoustic Driver Orifice Pulse Tube Refrigerator. Device applies heat to maintain standing wave, which drives working fluid through Stirling-like cycle. No moving parts.	Currently being developed by Praxair and LANL for liquefaction applications including LNG transportation fuel production. Progressing from small-scale to field-scale demonstration stage.
Liquid Nitrogen Open-cycle evaporation	Liquid nitrogen stored in dewar is boiled and superheated in heat exchanger, and warmed nitrogen is discharged to atmosphere. Counterflowing natural gas is cooled and liquefied in heat exchanger.	Extremely simple device has been used to liquefy small quantities of natural gas. More than one pound of liquid nitrogen is required to liquefy one pound of natural gas. Nitrogen is harmless to atmosphere. Economics depends on price paid for liquid nitrogen.

Table 7 – Overview of liquefaction technologies – Adapted from USA Pro/California Energy Commission with modifications.

2.2.2.7.3.1 Mixed Refrigerant Cycle (MRC)

A general description for the Mixed Refrigerant Cycle (MRC) is presented in this document as reference; this is one of the most used cycles with different patents and proprietary designs. The MRC process employs a single mixed refrigerant loop to accomplish the gas liquefaction with a refrigerant that is a mixture of hydrocarbons and nitrogen. The mixed refrigerant is compressed and circulated in a closed loop by the refrigerant compressor. After compression, the refrigerant is cooled and partially condensed before entering the LNG cryogenic heat exchanger and finally achieving maximum cooling after an expansion valve sub cooling process. The natural gas liquefies in a separate pass of the LNG cryogenic heat exchanger and is returned to the LNG tanks via an existing LNG header in the terminal.

The terminal BOG is compressed to the required pressure for the process, generally about 70 bars or higher. In order to remove any rust or debris from the pipeline this type of facility normally requires the feed gas into the LNG heat exchanger to be filtered due to the nature of

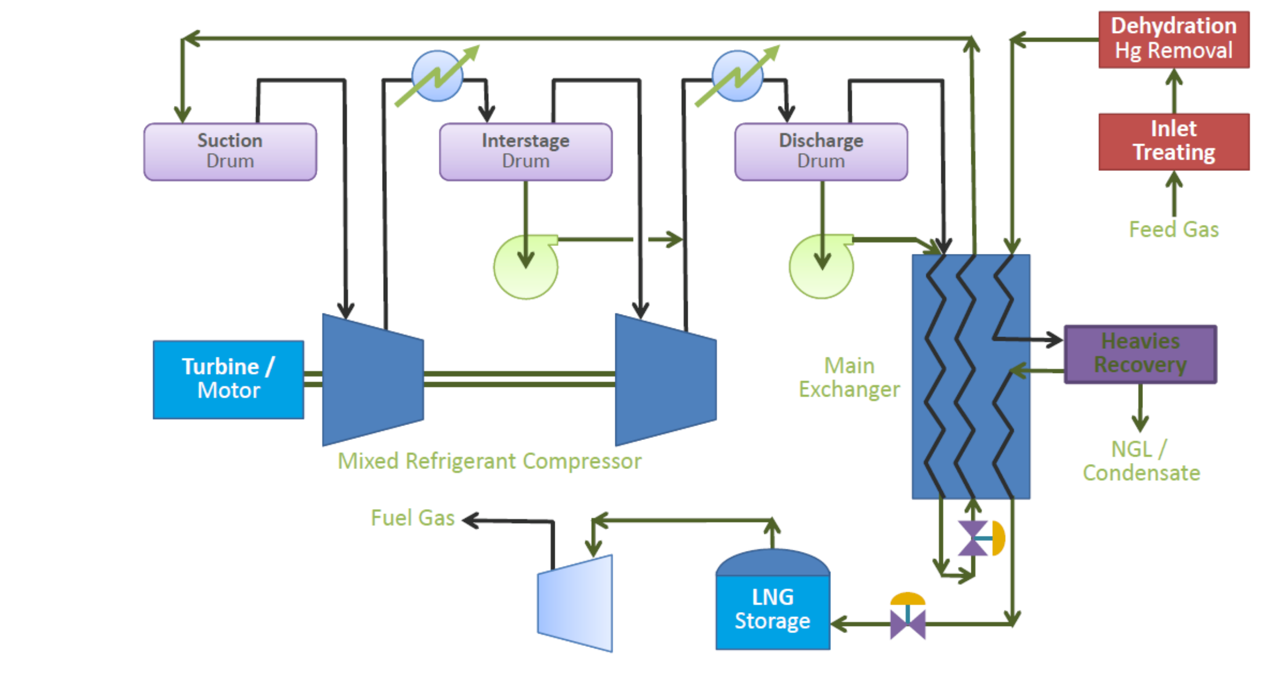


Figure 6 – Schematic of the process described in this chapter and installed in one of the terminal that contributed to this work.

their design. Two 100% filtration devices are generally required to avoid down time during filter change out. The filters are designed following the LNG Cryogenic heat exchanger manufacturer specifications. The inlet gas (BOG) coming from LNG tanks is not expected to contain any contaminants that may freeze or foul the cryogenic LNG equipment, so pretreatment is limited to inlet gas filtration. The feed gas passes through the LNG Cryogenic heat exchanger and is completely condensed and sub-cooled to the specified temperature. The LNG exiting the LNG cryogenic heat exchanger is flashed in a drum or valve to a pressure high enough to overcome the LNG tanks hydraulic head. The MRC process is a closed loop refrigeration cycle in which the refrigerant is compressed with a multi stage unit, driven by an electric motor or gas turbine depending on the case. Refrigerants are stored in individual make-up tanks to adjust composition or simply to recharge the system. The refrigerant also flows through the LNG cryogenic heat exchanger to provide adequate cooling to liquefy the BOG feed gas through the LNG cryogenic heat exchanger. The refrigerant vapor returns to the refrigerant compressor to initiate the refrigerant compression cycle. There are different configurations of the MRC from different licensors that can be considered and applied depending on each particular need.

MAIN COMPONENTS

- Inlet gas Handling
- Feed compression equipment (If not existing)
- Inlet filters
- Liquefaction System
- Refrigerant compressor
- Refrigerant coolers
- Refrigerant drums
- Refrigerant pumps
- LNG cryogenic heat exchanger
- Refrigerant Make up System
- Refrigerant make up drums (varies depending on the technology selected)

ANCILLARY SYSTEMS

- Flare KO drum or HP flare header/system
- Fuel Gas
- Utility Nitrogen
- Instrument and Utility Air
- Utility and Potable Water
- Oily Water System
- Fire water system
- Spill containment system

CONTROL & SYSTEMS

- DCS
- Fire and gas detection systems
- Low temperature detection system
- PLC

These types of facilities occupy 0.5 to 1 acre for 10-20 MMSCFD of BOG generated on the terminal. Each case will require an individual siting study. Access roads are required for refrigerant delivery.

Project critical path is normally driven by the delivery of long lead items like the compressor package and LNG cryogenic heat exchangers.

It is important to identify which permitting agencies would regulate this type of facilities in addition to the ones that normally regulate the LNG business. There are hydrocarbons that are not normally found in a regasification terminal that can potentially require a different permitting approach.

2.2.2.7.4 Operation and Maintenance

Operation and maintenance manuals to address specific procedures for the safe operation and maintenance of the liquefaction facility are to be prepared or existing ones modified. These procedures will be part of the existing terminal Quality Management System (QMS) in place. Procedures address safe startup, shutdown, cool-down, purging, etc., as well as routine operation and maintenance. Depending on the case, these procedures or modification of existing may require approval from the regulator. New equipment will have to be incorporated into the maintenance management system program for programmed and compliance maintenance.

Generally the LNG Regasification Terminal has full-time staff to operate the facility and conduct routine maintenance and minor overhauls, a facility like BOG liquefaction will not require additional personnel for operation and maintenance and no changes to the facility training programs are anticipated as a result of a BOG Liquefaction Project. Major overhauls and other major maintenance are usually handled by hiring specialized contract maintenance personnel trained to perform the maintenance work to certain equipment.

2.2.2.7.5 Operating cost structure

The O&M cost structure shown below reflects the major components of the cost for an electric motor driven unit; this structure may vary depending on power unit cost characteristics at each area.

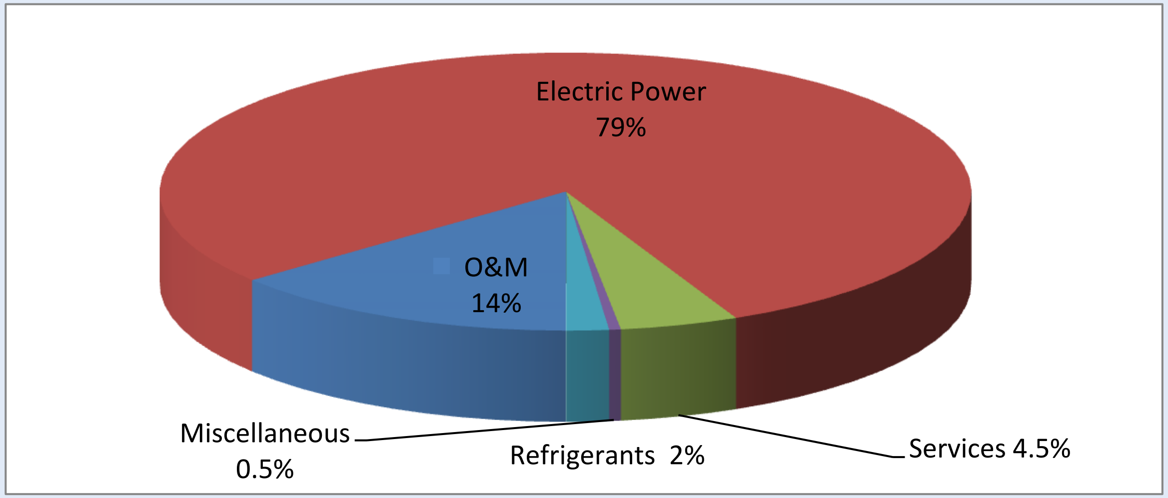


Figure 7 – Operating cost structure for a liquefaction system

2.2.2.7.6 Applicable codes and standards

It is important to follow general industry codes, standards and recommended practices for LNG terminals, upstream gas processing facilities and similar infrastructure. The specific list of codes and standards of any proposed project will be developed during the detailed design phase. Good engineering practice and recognized technologies are basic for a safe and reliable operation of the facility. Construction, operation, and maintenance of a BOG Liquefaction Project will be in accordance with all applicable Federal, State, and other local agency permits and approvals.

2.2.2.7.7 Opportunities

Once the LNG regasification terminal has the liquefaction facility operating, a series of additional benefits can be described beyond the main purpose of preventing loss of inventory and ageing of the product.

1.Capability of lowering the BOG system pressure beyond operating pressure to gain time for planned maintenance periods. Generally no venting is required during those periods.

2.Minimize send-out during ship unloading/loading process, a certain volume of BOG will be liquefied and only the balance of the BOG generated during ship unloading/loading will require send-out during the transfer operation. This opportunity is important during reload operations where saving LNG is critical.

3.Storage service without product aging: a shipper may have interest in storage service for a long period of time while conserving LNG quality and quantity. This service will be available with a BOG Liquefaction facility operating.

4.When zero send-out mode is no longer required, the BOG Liquefaction facility can continue being used to generate HIGH quality Methane for fleet fuel or other commercial needs.

2.2.2.7.8 Conclusion and recommendations

The addition of a BOG Liquefaction facility to an existing regasification Terminal is a minor construction project compared to the initial construction of the terminal. In general the EPC for an application of 10-15 MMSCFD can be completed in 30 months; of course each case is different and requires proper studies and evaluation. It is important to perform an independent technology selection study to properly decide the one applicable for the required service. This process will required a supplier of refrigerant grade hydrocarbons with the capability to maintain the proper inventories through the year. The personnel's training is key for the start-up of the plant. It is highly recommended to incorporate the operating group early during the commissioning stage of the project and integrate with the construction team to assist in the activities and in parallel deliver training supported by field work.

2.2.3 Impact on safety and environment

Obviously, all the LNG stored will eventually be either burned and released to the atmosphere as CO_2 or released as NG (e.g. leaks or over pressures releases). It does not matter it was firstly LNG, then BOG and then LNG or NG again. However, when BOG is recovered for other uses instead of been burned in the flare, on the whole we are avoiding CO_2 emissions.
Besides, burning gas in the flare has a social impact to the area that it is especially significant when there are towns closed to the plant. In addition, the presence of large inventories of other hydrocarbons and hazardous refrigerants on site introduces further risks that must be considered.

2.2.4 Economic considerations

BOG recovery has an economical cost which must be taken into account when choosing between recovering it or continuing to work the same way.

In the case of the Spanish market, due to regulation changes regarding auto consumptions, BOG recovery will be a key fact in following years.

It cannot be forgotten that nowadays plants compete against each other, so those with less LNG reductions during unloading and downloading operations will be nominated to more operations.

2.3 Storage tanks management

2.3.1 Introduction

In Europe LNG terminal operators have had to deal with low nominations since 2011. In this new context, never met before, new questions emerge, which include LNG tank management. In case of very low levels in the tanks, what should be the operational actions to recommend? Is it possible to regularly warm up and cool down the tanks, which are not usually designed for this purpose? What are the operational actions to recommend (minimum heel, control of tanks temperature…)? These are some questions this chapter aims to address.

Furthermore questions about LNG ageing and possible rollover can arise if the tanks are maintained full or partially filled.

2.3.2 Different types of tanks

Different types of storage tanks are operated in the world by LNG terminals operators: single containment, double containment, full containment, membrane containment, in-ground tanks (either semi-buried or underground tanks).

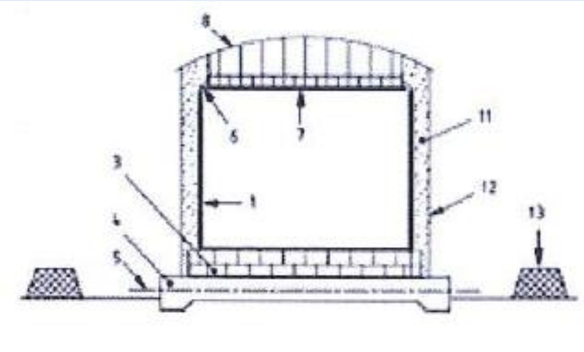
These storage tanks do not all have the same characteristics, which are dependent on their technology, age and location, and cannot be operated in the same way during low send-out periods.

Considering the fact that in ground and semi-buried tanks are most common in Far East Asia, currently not concerned by low send-out periods problems, this technology will not be treated in the following study.

Figure 8 – Example of different tank typology. From left to right: single containment, double containment, full containment, membrane tank (primary container)

2. Current Challenges – State of art

A single containment tank consists of a cryogenic steel self supporting (i.e. capable of containing all the LNG hydrostatic head) primary container, able to maintain the LNG in normal service, and a steel secondary container equipped with a hemispherical dome roof.



1 primary container (steel)
3 bottom insulation
4 foundation
5 foundation heating system
6 flexible insulating seal
7 suspended roof (insulated)
8 roof (steel)
9 external shell insulation
10 external water vapour barrier
11 loose fill insulation
12 outer steel shell (not capable of containing liquid)
13 bund wall

Figure 9 –
Example of single containment self supporting tank

The secondary container, in normal service, contains the products vapors, and holds the insulation. In case of leakage, the non-cryogenic steel secondary container cannot hold the LNG, which is collected in a large containment area all around the tank (earthen berm, concrete wall). Another solution for single containment tanks, in which the roof is integrated to the primary container, can be found in Japan and Europe. The inter-wall space is either kept under nitrogen atmosphere, or under gas atmosphere (gas is circulating through the manholes at the top of the tank).

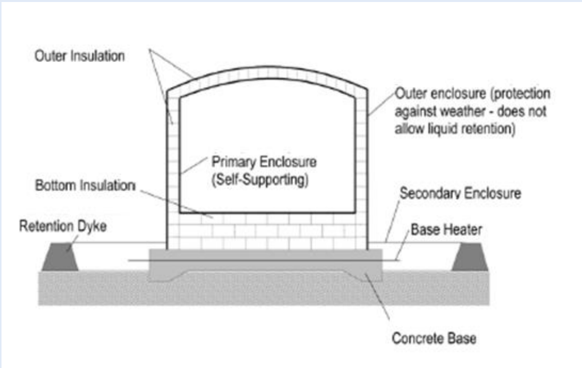
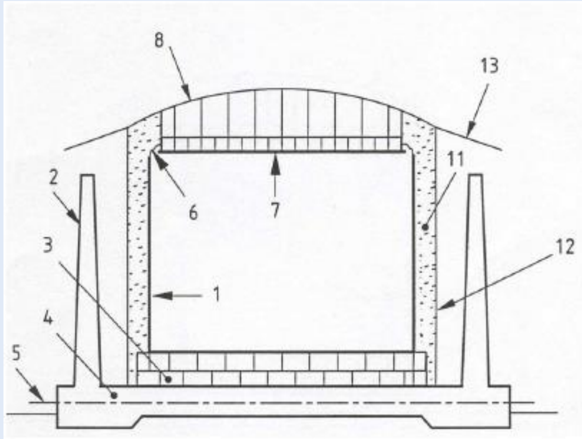


Figure 10 – Example of single containment tank

A double containment tank consists of a cryogenic steel self supporting (i.e. capable of containing all the LNG hydrostatic head) primary container, able to maintain the LNG in normal service, and a steel secondary container equipped with a hemispherical dome roof. This container, in normal service, contains the

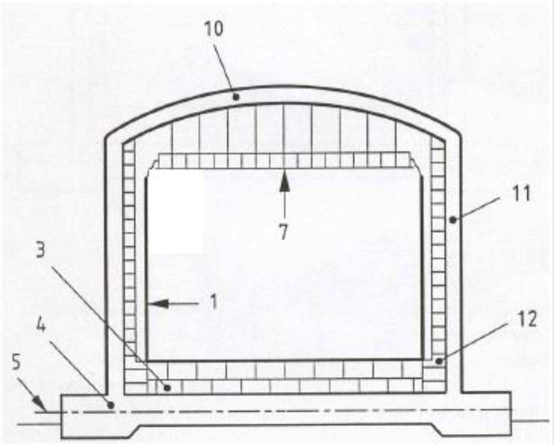


1. Primary container (special steel)
2. Sidewall (concrete)
3. Bottom insulation
4. Slab
5. Slab heating system
6. Flexible insulating seal
7. Suspended Deck (insulated)
8. Hemispherical dome roof (standard steel)
11. Wall insulation
12. Outer shell (standard steel)
13. Rain shield cover

Figure 11 – Example of double containment tank

products vapors, and holds the insulation. In case of leakage, the non-cryogenic steel secondary container cannot hold the LNG, which is collected in a concrete retention tank built all around the tank.

A full containment tank consists of a cryogenic steel self-supporting primary container capable of maintaining the LNG in normal service, and a

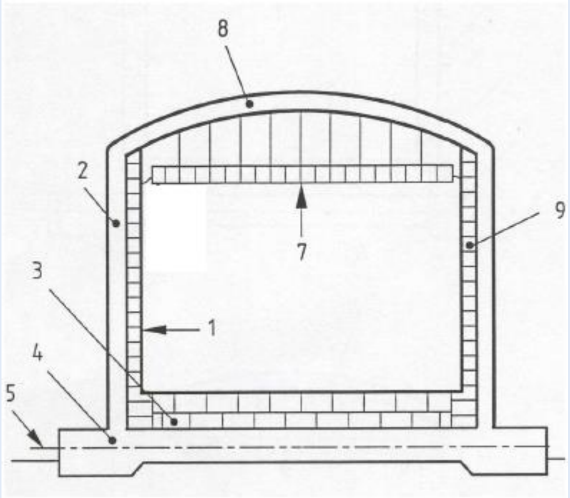


1. Primary container (9% Ni steel)
3. Bottom insulation (load bearing cellular glass)
4. Slab (concrete)
5. Slab heating System
7. Insulated suspended Deck (aluminium & fibreglass)
10. Hemispherical dome roof (concrete)
11. Sidewalls (pre-stressed concrete)
12. Wall insulation (loose fill perlite)

Figure 12 – Example of full containment tank

pre-stressed reinforced concrete secondary container equipped with a hemispherical dome roof, built close to, and creating a close cell around the inner tank. This container, in normal service, contains the products vapors, holds the insulation, protects the primary container against different hazards (fire, flying objects…) and is capable, in case of leakage of the primary container, of holding the entirety of the LNG and controlling the venting of vapor.

The membrane containment tank is derived from LNG tanker technology, successfully applied in more stringent maritime conditions and approved by major classification societies. The design philosophy is based on the separation of structural and tightness functions. Tightness of liquid and gas is ensured by a membrane primary container (corrugated stainless steel for Technigas technology, or plane Invar for Gas Transport technology). Structural function (resistance and insulation) is ensured by the pre-stressed reinforced concrete secondary container.



1. Primary container (SS corrugated membrane)
2. Sidewalls (concrete)
3. Bottom insulation (load bearing PU)
4. Slab (concrete)
5. Slab Heating System
7. Insulated suspended deck (aluminium & fibreglass)
8. Hemispherical dome roof (concrete)
9. Wall insulation (load bearing PU)

Figure 13 – Example of membrane containment tank

An important difference between the two last technologies is that BOG is contained in the primary container for membrane containment (insulation under nitrogen atmosphere in order to stop any BOG leakage) whereas the second container (and its perlite insulation) is full of BOG.

The second difference is the insulation, PVC for membrane and perlite and foam-glass for full containment tanks, which do not have the same properties and ageing characteristics.

Another comparison can be made: for self-supporting tanks (single, double or full containment), the LNG hydrostatic head is first supported by the primary tank, which can transmit, in case of thermal expansion, the stresses to the insulation and then the secondary container. Membrane tanks' secondary containers are initially designed to accommodate stresses through the insulation, the membrane primary container is not designed for that.

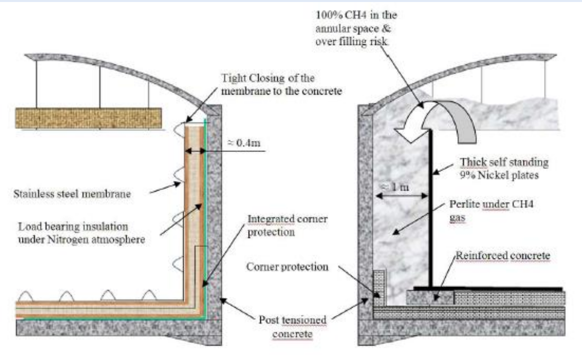


Figure 14 – Comparison between different tank design

2.3.3 Operating tanks during low or zero send-out periods

During low or zero send-out periods, if shippers do not supply sufficient LNG to the terminal, some operating problems can appear either because of tanks' low levels or because of the ageing of LNG.

Consequently, some precautions have to be reinforced during these periods to maintain good operating conditions.

2.3.3.1 Control of tanks minimum level

A minimum level has to be kept in the tanks for different considerations :

1. **Pumps start-up level.** This minimum level is necessary to ensure good conditions for the pumps start-up. This level is generally provided by the pumps manufacturer.

2. **Hydrostatic pressure** (for self-supporting tanks with communication between internal tank and inter-wall space). A minimum level has to be maintained in self-supporting tanks to maintain good hydrostatic pressure. If the level is too low, a small differential pressure between the internal tank and the inter-wall space (characterized by pressure drops in the perlite layer i.e. inertia in pressure equilibrium) could lead to the lifting of the bottom plates. This small differential pressure could be caused by BOG compressor start-up, pressure safety valve opening… This minimum level is provided by the tank manufacturer.

3. **Cold temperature**. Finally, a minimum level of heel ensures the maintenance of the inner tank at a proper temperature. Below a few decimeters during a long period, the risk of getting a significant temperature difference (up to 50°C) along the tank is high.

Depending on tank technologies and dimensions, the minimum heel value has to be checked with manufacturers.

2.3.3.2 Control of tanks wall temperature

Tank heel temperature is not generally a big concern during normal operation. In some terminals, temperature measurements can be

local only. Temperature alarms are generally not associated with any automatic actions.
However, if tanks levels are very low, it seems important to control regularly wall temperature at various levels to prevent any uncontrolled warming up of the tanks.
Furthermore, temperature shall be measured very carefully during warming up and cooling down sensitive operations.
Tank instrumentation (level control, temperature) has to be kept in good operating conditions and must be checked regularly if possible, as they are the guards of the tanks good operating conditions.

2.3.3.3 Preventing roll-over phenomena in tanks

The periods of low nomination do not necessarily result in maintaining a low level of LNG in the tanks with its associated problems. At the request of the customers, the terminal can be faced with situations where the tanks are maintained fully or partially filled for a long time. In this case the risk of rollover has to be tackled by the terminal. The rollover is briefly discussed in paragraph 2.1.4; a deeper analysis of the phenomenon is given in “Rollover in LNG storage tanks” released by GIIGNL in 2014.

2.3.4 Recommendation about tanks decommissioning or warming up

LNG tanks are not necessary designed to be regularly warmed up and cooled down. These operations can be long and risky for the facilities’ integrity.

However, during low nomination periods, if shippers do not supply sufficient GNL in the terminal, a tank may be warmed up.

Letting a tank warm up is a sensitive operation, which must not be carried out on all tanks in a terminal. For example, if there are three tanks in the terminal, the good option is to keep two tanks with LNG, in order to be able to continue to receive LNG tankers and to have better operating conditions during the third tank’s subsequent cooling.

Furthermore, LNG terminal tanks age and maintenance should be taken into account; all problems or significant events encountered (decommissioning for repairs or inspection, operational incidents,…) should be considered for the studies and to choose the warmed tank.

Finally, it is important to consider different technologies of the LNG terminal tanks. All technologies are not equal regarding the possibility to warm up a tank.

2.3.4.1 Membrane tanks

The recommendation is to give priority to membrane tanks as far as warming up or decommissioning is necessary, if this technology is available in the terminal.

Indeed, this technology provides several advantages :

- the membrane is not sensitive to thermal cycles, due to corrugations ; LNG tankers’ containers are regularly warmed up and cooled down in shipyards, without impacts on the cargo tanks; the membrane technology is successfully applied in very stringent conditions and approved by major classification societies,
- all the stress is supported by the pre-stressed reinforced concrete secondary container through the PVC insulation,
- membrane tanks are not self-supporting tanks, there is consequently no problems of hydrostatic pressure and no risk of primary container lifting,

- PVC has a slower ageing process than perlite,
- no BOG in insulation layer, i.e. gain in warming up and cooling down time and costs.

It does not seem necessary to completely decommission (meaning putting under nitrogen or atmosphere conditions) a membrane tank during a long low send-out period, as it would be more expensive and longer. The emptied tank could be kept under ambient temperature BOG atmosphere, as there is no need to maintain a minimum heel to have a good hydrostatic pressure to avoid bottom lifting.

But in any case, even if it seems easier to carry out such operations on a membrane tank, it is essential to scrupulously study them, under the control of a manufacturer, taking into account all the characteristics of the tank, and with appropriate instrumentation.

There have already been some successful experiences of warming up membrane tanks in Europe (for example, Elengy experience in Montoir-de-Bretagne).

2.3.4.2 Single and double containment self-supporting tanks

It is not recommended to regularly warm up single and double containment tanks, because of their age (usually more than 20 or 30 years), and because of the important thermal expansion of the internal tank (which can reach some decimeters per diameter for big tanks).

Insulation between primary and secondary tanks is composed of perlite in these technologies. Perlite is a very light product, which could compact at first cool down and over time against the outside tank.

The glass wool resilient blanket is designed to absorb stresses, but over the years, as perlite is gradually compacting, the size of resilient blanket thickness can decrease and become less effective. The resilient blanket could also be compressed during perlite initial installation and vibration, or during regular perlite lowering from the top reserve.

This could be an issue for the tank in case of significant dilatation of the internal container due to high temperature variations (which can reach some decimeters per diameter for big tanks). If the resilient blanket is not effective, the external steel container will have to support high stresses. This container is not necessarily built for this purpose and could be damaged. The inner tank could be also damaged by the same phenomenon.

A second point regarding these tank technologies is to keep stability of the internal tank when there is no minimum heel. The hydrostatic pressure would be no longer maintained by the heel, consequently a risk of lifting of the internal tanks in case of pressure differential between the internal tank and inter-wall space would exist. The inner tank pressure should be controlled very carefully, at a very low pressure (some mbar more than the atmospheric temperature), with addition of gas or nitrogen if necessary. It seems prudent to isolate the tank from the BOG compressors and to control the pressure though a valve on top of the tank (with gas sent to atmosphere resulting in impacts on environment).

In conclusion, warming up single and double containment tanks for low nominations reasons seems complicated. If it was unavoidable to carry out such operations on a single or double containment tank, it would be essential to very scrupulously study them, under the control of a manufacturer, taking into account all the characteristics of the tank, and with appropriate instrumentation. If these precautions were not taken, there would be a mechanical risk to the tanks.

2.3.4.3 Self-supporting full containment tanks

These tanks are more recent and the prestressed reinforced concrete secondary container is designed to withstand constraints.

However, this technology is affected by the same problems as the single and double containment tanks:
•compacting of perlite and resilient blanket, with transmission of the constraints to the external and internal containers. Even if warming up these tanks seems less complicated than single and double containment tanks in terms of safety, the concrete quality and resistance has to be studied very carefully with the manufacturers.
•in the absence of minimum LNG heel, risk of lifting of the internal tank, which has to be considered (refer to section 2.3.3.1).

If membrane tanks were not available in the terminal, it could be necessary to warm up a self-supporting full containment tank. But it would be essential to scrupulously study this operation, under the control of a manufacturer, taking into account all the characteristics of the internal and external tanks, and with an appropriate instrumentation.

2.3.5 Other solution: receiving fresh LNG cargoes

The best solution to maintain the tanks in good operating conditions during very long low send-out periods is to keep LNG inside in sufficient quantity. But it depends on shipper's strategy: some shippers are interested in storing LNG in western LNG terminal's tanks in case of need, this approach is particularly interesting to guarantee terminals' tanks integrity. If no fresh LNG cargo is provided by shippers, the first recommendation is to raise shipper's awareness of this issue. If shippers still do not provide LNG, the last solution can be to receive fresh small LNG cargoes (LNG bought by the terminal).

2.3.6 Environmental considerations

These operations can also have an environmental impact: BOG created from minimum tank heels (LNG that cannot be pumped) contains generally C3-C4 products in large quantities, which must be sent to flare (because C3-C4 products can damage BOG cryogenic compressors), and causes CO_2 emissions and rise terminal neighborhood and Administration concerns. Moreover, if tank pressure is controlled by venting during the last phase of tank emptying (isolation from BOG compressors is required to avoid internal tank lifting), non-negligible greenhouse gas quantities are sent to atmosphere.

2.3.7 Economic considerations and conclusion

The new LNG context has deeply changed some LNG terminals' operating models, and LNG operators have to tackle this new situation. Economic considerations are different for each operator, depending if he deals in a regulated market, if the shippers want to store LNG in LNG terminals, if the terminal equipment is recent or old.

Different costs have to be taken into account:
• LNG minimum heel cost (if it is bought to avoid tank warming up),

- warming up cost (instrumentation, operator and tank manufacturer workforce, gas sent to flare or atmosphere…),
- decommissioning cost if it was planned (nitrogen cost, duration of the operation…),
- cost and duration of the cooling down operation (instrumentation, operator and tank manufacturer workforce, ...)
- tank repairs and long outage in case of damage,
- as a last resort, tank loss economic impact should be considered for very risky operations.

The best option during low nominations periods is to keep the tanks cold with a sufficient heel, thanks to shipper's decisions. Tanks levels and temperature have to be controlled carefully. If they are empty, it can become necessary to consider warming up a tank (provided that the terminal is capable of keeping LNG in other tanks). It seems better to consider this operation on membrane tanks rather than self-supporting tanks. But for all operations, it is essential to include tank manufacturers and to scrupulously study them, in order to minimize risks.

2.4 Maintenance management

The considerations explained in the following chapter are of general applicability. However they are based mainly on the experience of National Grid. Thus, some of the examples given refer to their specific approach to the maintenance and might not be applicable everywhere in other LNG terminals. The approach adopted by National Grid for maintenance management is not the only model applicable and available in the industry. However, it is recognized to be a good and effective model, so in the frame of this work it is presented simply as it is: a valuable contribution to the discussion to be shared with other colleagues with constructive spirit.

2.4.1 General description and specific technical problem

During periods of low and zero send-out, utilization of certain process equipment will be significantly reduced whilst the usage of other equipment may increase. An example of this would be a reduction in recondenser utilization whilst refrigeration units (where available) may be used more often; this will be different for each terminal depending on their specific plant configuration.

In general there are several maintenance management approaches that allow a terminal to adapt more readily to low and zero send-out periods. The approach taken is often driven by the type of asset management in place, whose requirements should comply with international standards in order to be effective.

2.4.2 Maintenance and periodical tests on main items

There is a minimum level of maintenance work and inspections required every year to fulfill the legislative requirements of an LNG terminal. These constitute a certain proportion of maintenance work and subsequent costs which are unaffected by the level of plant utilization. An example of this are hazardous area equipment inspections, these typically require completing every 3 years regardless of current or forecast utilization levels.

Generally speaking, from a commercial point of view, terminals are required to be available to respond to high demand. Therefore it is necessary to ensure a maintenance regime that keeps process equipment in a suitable working

condition so they can be run in case of any sudden demand spikes.
During periods of low and zero send-out there are more opportunities for conducting specific outages to complete necessary maintenance work, crucial repairs and to design and implement value driving initiatives. An example of such initiatives is root cause analysis of plant equipment failure.

2.4.2.1 Root cause analysis of plant equipment failure

Low and zero send out periods enable in-depth assessments of the root causes behind the breakdown of plant equipment. It is important to understand that there can be a wide range of reasons for equipment failure. The following are a few examples of such reasons:

- Availability/quality of spares: there may be a lack of spares available on-site thus preventive maintenance may not be possible ahead of equipment failure. Also the quality of spares may not match that of the original.
- Workflow packages: ineffective utilization of workflow packages designed to manage maintenance regimes can lead to failure.
- Training: it is necessary to provide employees with the right level of training in order to be fully competent in carrying out their job roles and ensuring equipment is properly maintained.
- Budget constraints: the pressure to explain and justify budgets can lead to insufficient maintenance of crucial plant equipment.
- Key Performance Indicator's (KPI's): KPI's may be unrealistic leading to an overworked staff resulting in less attention to detail in the completion of work tasks.
- Priorities identification: it can become more difficult to establish correctly priorities among equipment maintenance when terminals are underutilized.

2.4.2.2 Maintenance management improvement processes

In general, in order to avoid issues such as the example given in the previous paragraphs, the following concepts can be applied:
- Establishment of base operating conditions: it is necessary to establish base case as a reference for operating conditions. From that it is possible to detail the asset life of a piece of equipment and its likelihood of failure.
- Asset performance assessment: an analysis involving an asset's availability and how it impacts the planning of maintenance work. It is also necessary to evaluate its impact on general plant operations.
- Condition assessments: these can be applied to a specific asset or asset group. It will involve looking at the defect analysis, failure rates, forensic analyses and condition assessments.

At Grain LNG, for example, a maintenance strategy has been developed and implemented with the aim of streamlining the maintenance management process and ensuring that a suitable level of maintenance is applied accordingly to each piece of equipment.
The strategy mainly comprises of a two part approach involving a revamp of the existing asset management system and a more optimized approach to maintenance management.
This strategy enables the operator to deliver improvements in the timing of inspections, and the development of 'smarter' maintenance technician workloads. Examples of expected benefits from this strategy are the reduction in the number of permits to work issued, a maintenance level balanced with the plant utilization level and optimization of technicians workloads.

It is important that plant technicians are involved in this strategy, especially by carrying out the following actions:
- identifying areas where the amount of maintenance being applied is not proportional to the level required
- identify any inappropriate tasks
- apply the change request system more effectively and ensure any gaps in the system are highlighted
- use tools from process improvement initiatives such as Performance Excellence (PEX)
- engage with the Asset Management team regarding any other issues.

In order to effectively optimize the asset management system and maintenance management in general it is necessary to find answers to the following questions:
- What are the functions required of the asset?
- In what ways can it fail?
- What are the causes of failure?
- What happens when each failure occurs?
- Does each failure matter?
- What can be done to prevent each failure?
- What should be done if a failure cannot be prevented through maintenance?

Taking as an example the experience of Grain LNG terminal, the low send out period has allowed for more time available to improve and develop a clear 'change request' process as outlined below:

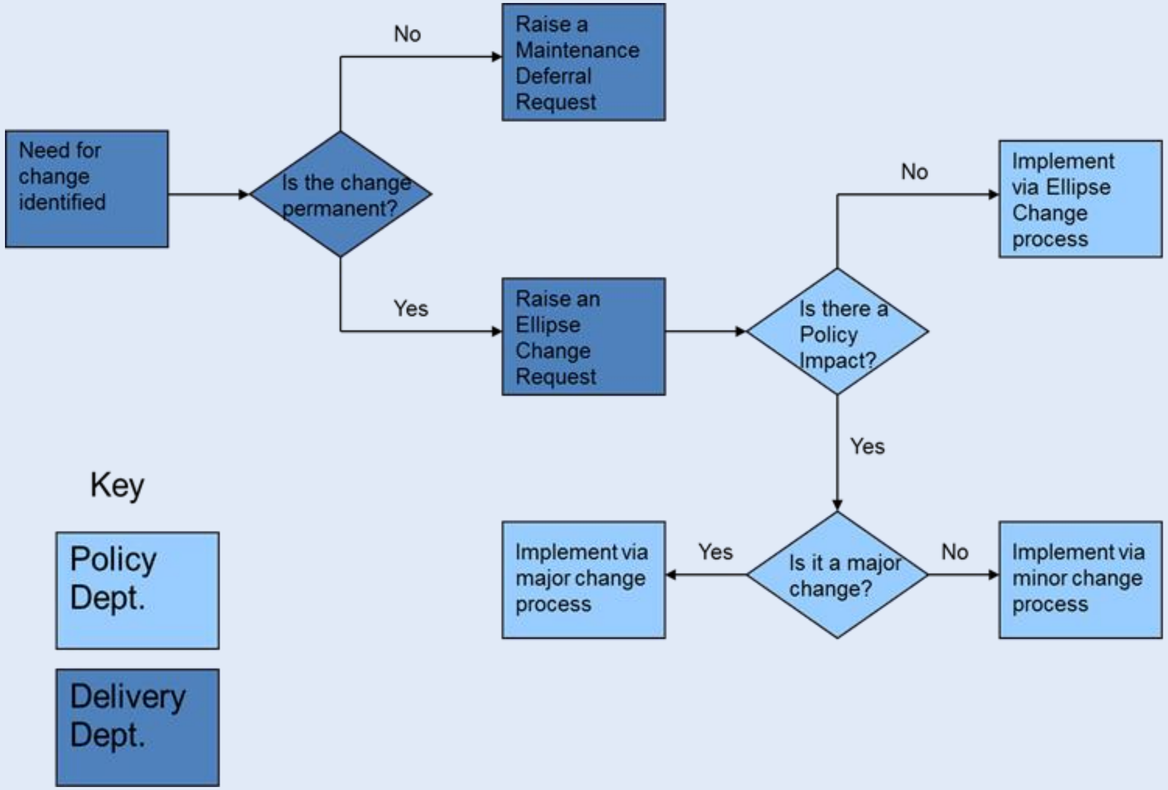


Figure 15 – Change Request Process Flowchart

2.4.2.3 Trending data

Common practice is to take prescribed maintenance actions after a certain amount of asset usage or a defined time period is elapsed. When the typical usage patterns of a specific process equipment changes, the timing or nature of the maintenance action required may no longer be suitable. In this context, using trending data to identify a developing problem can help to apply more effective maintenance regime of assets. A more precise assessment of plant equipment running hours is possible when plant historical records and data are taken into account in the process.

2.4.3 Focus on key elements

A few items among the whole play a crucial role in the process and thus deserve special attention also in the maintenance management system. Among them, pumps, vaporizers, loading arms and BOG compressors are potentially the most affected by change in hours of service and maintenance plan because of low and zero send-out periods.

2.4.3.1 Centrifugal pumps

Maintenance on centrifugal pumps is generally done according to a preventive maintenance plan. This can involve planned maintenance or condition based maintenance or some combination of the two dependent on terminal requirements.
Low send out periods generally do not affect this maintenance regime which is based on a combination of run hours and vibration analysis on newer pumps. Due to the redundancy of equipment, commercial availability is not affected when taking pumps out of service for maintenance.

2.4.3.2 Vaporizers

The existing regime is based on an annual maintenance routine, which can be more costly during periods of low send out; nevertheless this represents an opportunity to reduce costs. The Maintenance and Asset teams are actively collaborating to determine whether this frequency of maintenance is still required. This would involve a change of the existing policy which stipulates the need for a yearly service. However in the current market it is often necessary to seize the opportunity to review policies and determine whether they offer a suitable level of flexibility in maintenance management.

2.4.3.3 Loading arms

The maintenance regime around the loading arms is based on a vibration sensor system; in general no extra maintenance is applied to the loading arms during low send out periods, although the arms are frequently exercised.

2.4.3.4 BOG compressors

During periods of minimum delivery extra maintenance is carried out on the BOG compressors that export gas direct to the network because of the increased number of running hours. Maintenance on compressors is centered on hours run, but there is also some work ongoing to move to condition based monitoring plan. A target of 8000 run hours had previously been used for service but there are plans to push this to 10,000 in order to maximize equipment usage before they are taken out of service.

2.4.4 Economic considerations

There is always pressure to complete effective and safe maintenance with good value for money, which often results in staff distribution being optimized to meet that need.
With significant changes in maintenance schemes due to long term change in send-out, also staff distribution is likely to change. If the maintenance system is not capable of rapid adaptation to the low and zero send out scenario, variable costs could potentially increase above an adequate level for the changed scenario.

Another aspect to be considered in plans and budget adaptation is the reduction in asset expected life that could result from prolonged usage of some equipment designed to have a minor role for terminals in full operations.
When another year of low send out is expected, it is common to put reduction in yearly forecast maintenance budget. This applies further downwards pressure on management to find ways of achieving maintenance statutory requirements. Inevitably this can result in the need to reduce contractor or full-time equivalent (FTE) numbers and delay the replacement of permanent staff.

2.5 Human resources management

2.5.1 General considerations

The management of personnel in a changing environment is a constant issue for businesses around the world. The change from terminal's normal operation to low and zero send out is just one more changing factor to consider.
The main issue is how to manage staffing levels in such a way as to avoid holding on to excessive levels of employment during the low send out period whilst maintaining staff in key roles ready for better market conditions.
Anytime that someone leaves their role, management will generally consider if staff replacement is required or if tasks and responsibilities could be distributed and assigned to other members of staff without replacement. Performance reviews can be linked to the overall profitability of the plant, which will invariably be affected by a lower send out.

2.5.2 Know-how keeping and personnel training

There is a learning, development and competency procedure which applies to all staff including contract employees at Grain LNG. It incorporates a line manager conducting development discussions with employees and identifying any training needs required. A Safety and Technical Competency (STC's) framework is produced and reviewed bi-annually. Each individual is encouraged to take ownership of their development and commit to the closure of any identified training gaps. This is fundamental to producing a site training plan and then prioritizing training requirements throughout the year. Training needs typically come from three sources. Gaps identified following review against the STC's, performance reviews or development discussions and site or company initiatives or programmes including new equipment and processes. All employees need to complete site specific STC's to remain competent.

The guidelines provided in the National Grid Learning & Development Policy which outlines the ratio of different approaches to learning and development. Namely the 70:20:10 principle. The majority of development and gaining experience and knowledge should be achieved via on the job learning/hands on experience. A lesser amount is obtained via specific coaching, relationships or feedback. And the least amount through other training interventions i.e. attending courses, seminars etc. This final option should only be used where real benefit can be identified.

A training record is created for each individual who will demonstrate that staff are appropriately qualified and trained to undertake their roles.

During long periods of time with low send out there is the risk that skill levels amongst operational staff, especially those working in the control room, may decline. Therefore it is important to ensure an effective program of a plant simulator based training and general site process refresher training is implemented.

Periods of low send out are also ideal times for personnel to be developed via different initiatives such as technical training (formal qualifications such as City and Guilds NVQ training) and performance improvement programs i.e. Performance Excellence. Less experienced employees can also broaden their abilities in the completion of tasks which are considered more site critical, as there will be more time available for them to carry out the task.

Grain LNG is focused on developing a culture where safety is ingrained in the minds of our staff and each team is driven to ensure their work processes are as efficient as possible. To achieve these goals we have implemented both the behavioral safety and Performance Excellence initiatives.

Behavioral Safety

Behavioral safety is an innovative approach to changing the health and safety culture of an organization. The initiative places a continuous focus on the systems that are in place to ensure safety on site. This is achieved by adapting our culture and behaviors to a mindset where 'every injury is preventable'. To achieve this goal a combined approach of improving systems and people's behaviors is currently being implemented.

Performance Excellence

As a performance improvement programme, Grain LNG has adopted "Performance Excellence" to help meet our challenges and guarantee our future. To do this there is a need to improve customer satisfaction, find significant

efficiency improvements and step up engagement with our employees. This is all done in a sustainable manner which will help Grain LNG grow in an ever more competitive market. It is a way of working smarter, not harder, by making processes sleeker, cutting waste within a process and continually improving.
The programme is being implemented with help of Performance Excellence specialists to support individual teams in the adoption of this working model. This is all done in order to make our processes efficient, effective and elegant, cutting out waste and increasing integration across the breadth of work we carry out. Workshops to review the end to end processes at Grain LNG are underway.

2.5.3 Daily on shift work organization

During periods of low send out it is common for some operators to be employed in assisting the Permit to Work office in the completion of process isolations. The main shift in organization is that the operators for unutilized plant would assist the Permit to Work office in conducting isolations and the Jetty Engineer would spend more time in the Permit to work office. The other operators would then be in the main control room covering the control panels for in service and out of service equipment.

More incident management exercises are conducted during this period with the shift team actively engaged by the Production Manager to develop plant upset and emergency scenarios which can be used for incident management exercises.

The Permit to Work office has exploited the recent low send out period to review the risk assessment process for our permit system. This led to the issuance of a new set of 'Golden Rules' designed to ensure all aspects of safe working are considered before a work task is carried out. These rules are as follows:

- Permit to Work
- Operation of Vehicles
- High Pressure Systems & Stored Energy
- Ground Excavation/Disturbance
- Confined Space Entry
- Working at Height
- Lifting Operations

2.5.4 Personnel motivation

Employee motivation can be maintained by offering opportunities for mutually beneficial secondment across different parts of the business. This ensures the continuous development of personnel and helps drive productivity by reducing the likelihood of complacency and absenteeism. It also brings new ideas and fresh perspectives into different workplaces as well as knowledge sharing in terms of best practice.
Encouraging staff to participate in community involvement and social responsibility activities such as volunteering at Science, Technology, Engineering and Mathematics (STEM) events, is a useful way of boosting staff morale and also improving the reputation of the company. Grain LNG continues to be involved in several such events at schools across their local area. As well as providing assistance at local skills based employability events. This not only helps to improve an employee's sense of purpose and wellbeing but also improves the lives of local residents.

2.5.5 Economic considerations

Low periods of send out apply pressure on departmental budgets and force management to consider how best to achieve their targets with tighter financial constraints. One of the most obvious areas to target is staffing levels. Reducing headcount may reflect positively on the budget sheet in the short term, but in the long term it may prove costly to rehire staff or bring in new staff; as they may require further training and time for task familiarization.

In general it is more likely that vacancies may not be filled and the workload of departing employees may be distributed evenly across the rest of the team. It is also important to note that savings are achieved through less operational overtime payments and the Procurement department will be driven to achieve greater cost reduction targets. This can be done by engaging vendors contractually to apply stricter cost controls when carrying out projects.

It is important that customers are fully engaged and efforts are made to reduce costs with respect to low utilization operating modes. Grain LNG actively investigates and assesses different ways of reducing the site's costs to customers. Grain LNG is applying a sustained effort on reducing the minimum delivery send out. The aim is to be as efficient as possible during periods of low send out without compromising on the ability to respond quickly to customer nominations.

Alternative uses of LNG (with respect to regasification for network) are already available worldwide in several regions, while in other parts of the world there is an increasing interest in these businesses. They could represent an opportunity to increase terminals' utilization rates or simply to follow new market trends for terminals suffering low and zero send out condition. Here a few options are presented, together with considerations on main technical challenges, advantages and disadvantages.

3.1 Large scale Re-exporting LNG (Reloading)

3.1.1 General description and technical challenges

This option involves modifying an existing terminal so that it is capable of re-exporting cargoes of LNG which have been previously unloaded at the terminal. An under-utilized terminal may have large quantities of LNG stored in it that could be re-exported to higher value markets elsewhere.

In principle, the modification required for re-export capability to large scale carriers is relatively minor, as the major pieces of equipment should be suitably sized. However, while the physical modifications may be relatively small, detailed engineering and appropriate management of change is still required to ensure the terminal remains safe to operate. There are a number of technical aspects to consider before the modifications can go ahead, and hence, the engineering validation of this option could still take several months.

Considerations for the modification of the terminal to allow re-export of LNG include:

Ship Suitability

The ships used for the re-export could be standard LNG carriers of the type that would normally discharge imported LNG into the terminal, although there is the possibility that ships towards the smaller end of the range could be used for this operation due to availability.

Vessel Mooring

The jetty is designed to cater for LNG carriers, as these are the normal method of supply to the terminal. As such, all the mooring systems and the size of the loading arms should be appropriate for re-export to LNG carriers.

In-Tank Pump Capacity

The in-tank pumps at a typical existing import terminal are designed to send out LNG from tank to recondenser, rather than for re-export into a vessel. It would need to be confirmed that that the static head of the in-tank pumps is sufficient to transfer LNG to the vessel, as the LNG is loaded at quite a significant height relative to ground level. If the pump discharge pressure is sufficient to overcome this, it must also be noted that the flow rate would likely be much lower (typically around 2,000 – 4,000 m3/hr compared to approximately 12,000 m3/hr for a typical ship unloading operation) and consequently loading times much longer than discharge times. For example, loading of a ship with a capacity of 140,000 m3 could take 36 - 72 hours.

Loading Arms

Loading arms at import facilities are typically installed with check valves to prevent reverse flow of LNG back into the LNG carrier and of BOG back to the terminal. To allow LNG reloading these would need to be converted or removed in order to allow LNG to flow from tank to vessel and vapour to flow from vessel to tank.

Vapour Handling

As with tank filling, vapour must be handled to ensure both vessel and shore tank pressures are maintained within safe limits. If the check valves in the vapour return arm were converted/removed as mentioned above, vapour could flow from ship to tank. In order to prevent flaring, the loading process would need to be managed such that BOG can be recovered by the BOG compressors.

Control Systems & Operating Procedures

Introducing a new operation requires the control systems and operating procedures to be updated and operators to be re-trained such that loading operations are controlled and safe. The existing HAZOP is not likely to include a consideration of ship loading operations as this is not typically part of the original design intent for an import terminal. As such, a new or supplementary HAZOP would need to be completed.

Flare & Pressure Relief

Pressure relief requirements would need to be determined to confirm whether the existing provisions for pressure relief and the flare system are appropriately sized for the new operation.

Surge

When valves in the loading lines are closed suddenly, for instance during an emergency shutdown, a surge event could occur. The effect of surge during a reloading operation should be examined to ensure that the existing design system and any surge alleviation measures are adequate.

To summarize, it is likely that only a few minor modifications are required to make a terminal suitable for re-export via large scale carriers. The physical modifications to the terminal would likely only involve the conversion/removal of check valves in the loading line to allow flow from the on shore tank to the ship. However, any modifications will require engineering validation, a process that could take two to three months, in addition to regulatory approval.

3.1.2 Feasibility

As the modifications required for re-export are likely to be relatively minor, this option is very feasible from a technical perspective. This is shown by the number of import terminals that have re-exported large cargos, including, but not limited to, the following:

- Freeport, Texas
- Sabine Pass, Louisiana
- Cameron, Louisiana
- Zeebrugge, Belgium
- Cartagena, Spain
- Huelva, Spain
- Sines, Portugal

According to a GIIGNL report, 82 cargoes were re-exported in 2013, a further increase from 75 cargoes in 2012 and 44 in 2011. Of the 82, 78 were re-exported from Europe mostly to Asia and South America. Spain and Belgium were the largest re-exporters, accounting for 76% of global volumes re-exported in 2013.

For re-export to take place at a terminal, regulatory approval is likely to be required. This could be largely dependent on location but, as the numerous examples above demonstrate, approval for regular re-export may be expected in many regions around the world. In the United States, application for a two-year license of this kind typically takes around 90 days.

A period of a few months is likely to be required for engineering validation, after which the physical modifications to the terminal are usually minor enough that they could be completed within a small number of weeks. For instance, when Freeport LNG was granted approval for re-export, they expected the change to take a couple of days, and to be done by maintenance crew on-site. Thus the time span required for a terminal to become ready for re-export, from first application for approval through to complete readiness, is in the region of only a few months. In September 2010, Cameron terminal applied for approval before year-end, in order to have re-export facilities in place by February 2011.

Where authorization for regular re-export is not obtained, it may be possible to seek approval for a one-off re-export opportunity. For instance, Sempra Energy gained such an approval for its Costa Azul LNG import terminal in Baja California in January 2011. The BG Group's Methane Nile Eagle Tanker was loaded at the terminal and Costa Azul became the first Mexican LNG terminal to re-export. This re-export reportedly formed part of a swap for another cargo at its Cameron terminal. In this instance, re-export was a mitigation method to reduce the costs of running an under-utilised terminal elsewhere, rather than an opportunity for resale abroad.

3.1.3 Commercial

Benefits

A strong indicator of the potential benefits of LNG re-export is the number of terminals described above that have implemented it. LNG can be re-exported to other markets abroad where the demand is greater and consequently the value of LNG is greater. For instance, in 2011 the decision to re-export from Spain was a direct result of the Spanish LNG market being oversupplied. LNG demand had dropped significantly due to a rise in coal-powered generation and increased gas deliveries through the Medgaz pipeline from Algeria. Conversely,

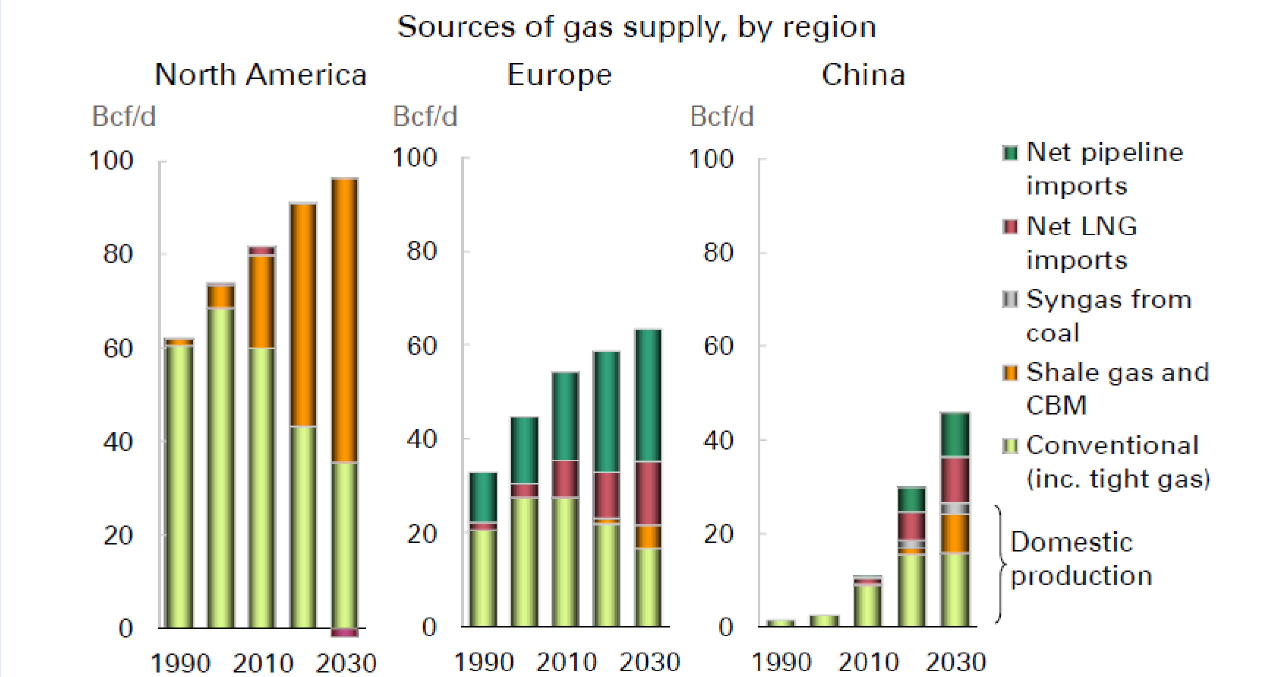


Figure 19 – Predicted sources of gas supply, from BP Energy Outlook 2030

Asian demand was growing rapidly, due in large part to the fall in Japan's nuclear power output after the Fukushima disaster.

Asian prices reached $17.50 per MMbtu while European prices were around $13 and consequently a number of cargoes were re-exported from Spanish terminals to Asia. As discussed above, a number of other US and European terminals took a similar decision to take advantage of this arbitrage at the time and offer reload services.

As the option to re-export abroad is somewhat opportunistic and relies on reacting to market changes, it is difficult to confidently predict exactly how extensive the benefit will be over the life of the facility or a capacity contract. According to BP's Energy Outlook 2030, unconventional gas sources such as shale gas and coal bed methane are predicted to account for 63% of production in North America by 2030. For existing import terminals, this suggests a continuation of under-utilization and the associated wastage in North America. Rather than import, export of LNG is expected, equivalent to an estimated 5 Bcf/day by 2030. Several of these projects are currently in development.

Elsewhere, gas production from unconventional sources is expected to rise but not enough to meet growing demands for gas, so in Europe and Asia there will be a rising need for LNG imports and potentially higher utilization of existing terminals. Figure 3.2 shows how the sources of gas supply are predicted to change. While the long term benefits of re-export capability are uncertain, it does provide a number of advantages in giving considerably more flexibility to importers and customers. With the capability to re-export comes an ability to respond to changing circumstances in the global LNG market. The terminal remains suitable for its original purpose of exporting to the local grid, but is also able to re-export entire cargoes to other markets. As such, the option is ranked 'Dark Green' for commercial benefits.

Costs

The capital expenditure of modifications is likely to be relatively low, as they are minor and can be completed in a short period of time. Some costs will also be incurred in the engineering validation and application for approval, over a period of a few months. The cost of the project is low, relative, to other options which involve the purchase of new equipment, so this option is ranked 'Green' for cost.

3.1.4 Safety & Operability

During ship loading, a new risk is introduced as there is extra potential for loss of containment. This risk is increased compared to the base case terminal because the loading time will be considerably longer than a typical ship unloading operation at the terminal.

The detailed engineering work discussed above should ensure that there are means of adequately managing this risk through measures such as ESD, relief valve sizing and operating procedures with validation by HAZOP. However, while these may mitigate the additional risk, they do not eliminate it completely, and as such the new ship loading operation still has some residual negative impact on safety at the terminal.

Additionally, due to extended loading times (around 36 - 72 hours), loaded ships may be ready to leave the terminal during hours of darkness. The safety implications of this and ways to manage the risk should be considered when evaluating the option in any further detail.

3.1.5 Other factors

Environment

As modifications are relatively minor, the modification project itself is not likely to have a significant impact on the environment. However, each of the re-export projects discussed above has been subject to environmental assessments before approval and met the standards required. This option is not a means of reducing boil-off, but purely a way to introduce an extra revenue stream. Boil-off would be significantly increased during ship loading and, once the loading operation was over, the terminal might continue to flare the boil-off caused by recirculation (where regulations allow).
The environmental impact of re-export depends largely on the handling of vapour and how much of it is flared. However, even with well managed vapour handling, ship loading would still be expected to results in more flaring or additional send out than the base case under-utilized terminal. The option is ranked 'Red' for environmental factors to account for the potential increase in flaring.

3.2 Small Scale re-export of LNG by sea - Bunkering

3.2.1 General description and technical challenges

To implement this option, the modifications may take one of two forms:
• Adjustment/modification of the existing jetty to cater for small ships or;
• The installation of additional purpose-built jetty.
As per the large scale re-exporting, described in section 3.1, the modifications required for re-export would be subject to detailed engineering work. A brief summary of the major design/operational considerations is given below.

Ship Suitability

For a small scale LNG distribution chain, smaller vessels than the typical large scale LNG carriers are used. There are many of these existing and under development as the LNG market focuses on increasing flexibility, new distribution channels and new markets. It is therefore reasonable to expect that suitably small LNG carriers would be available if required. However, the compatibility of the ships with existing large scale jetties may pose a problem.

Vessel Mooring

Typically, a conventional LNG import jetty is designed to cater for LNG tankers ranging from about 70000 to 175000 m3 in capacity and consequently there are a greater number of modifications required if the terminal is to be used for the loading of smaller vessels (approximately 1000 – 10000 m3 in size).
The existing unloading arms at an LNG import terminal are articulated arms which are designed for safe unloading from ship to tank. Smaller ships may not be tall enough to be reached by the loading arms, and as such they may need to be extended by the addition of a flexible hose or replaced with longer ones.
Additionally, an emergency decoupling system is usually in place to break away in the event of over-extension to prevent rupture of the arms. This system is typically activated by position sensors which detect if the ship is moving outside of the normal operating range for the arms. Initially an ESD will activate to stop cargo transfer, before a complete disconnection if excessive movement continues. This disconnect system must still be effective if the terminal is re-exporting to a small ship, so some

modification to the position sensors and control systems may be required.

One way around these issues is the use of purpose-built adaptable ships. Coral Methane, the world's first small-scale combined LNG/LPG/LEG was specially designed by Anthony Veder to be compatible with both large scale and small scale terminals. This was achieved by equipping the ship with both high and low level manifolds and flexible hoses . If such ships are readily available in the market, modification to the terminal itself could be relatively minor.

In-Tank Pump Capacity

As with large scale re-export, it should be confirmed that the pump static head is sufficient to deliver LNG to shore, as the LNG is transferred a considerable distance above ground level. The flow rate from the in-tank pumps is lower than it would be for a ship unloading operation, but this a less important factor for small ships, as 1500 – 4,000m3/hr can fill a small ship in only a few hours.

Loading Arms

Check valves in the loading lines would need to be converted or removed in order to allow LNG to flow from tank to vessel and vapour to flow from vessel to tank. Some modification may also be required to the knock-out drum on the jetty.

Vapour Handling

As per option 1a, the ship loading operation should be appropriately managed such that the BOG compressor is capable of recovering the BOG, to eliminate the need for flaring.

Control Systems & Operating Procedures

Introducing a new operation requires the control systems and operating procedures to be updated and operators to be re-trained such that loading operations can be conducted in a controlled and safe manner. The existing HAZOP is not likely to include a consideration of ship loading operations as this is not typically part of the original design intent for an import terminal. As such, a new or supplementary HAZOP would need to be completed.

Flare & Pressure Relief

Pressure relief requirements would need to be calculated to confirm whether the existing pressure relief system is appropriately sized for the new operation.

Surge

When valves in the loading lines are closed suddenly, for instance during an emergency shut down, a surge event could occur. The effect of surge during a reloading operation should be examined to ensure that the existing design system and any surge alleviation measures are adequate.

Even with the modifications described above, the minimum ship size may still be limited. As an alternative to these options, a purpose-built jetty for smaller ships may be built, as at the Zeebrugge terminal in Belgium. The second jetty is designed to take vessels as small as 3,500 m3 and is due for completion in 2014. However, this is a significant project of considerable size and expense, as discussed in the commercial section below.

3.2.2 Feasibility

The question of commercial feasibility of small scale LNG export is complex and goes beyond the capabilities of a single terminal, as the supply chain often requires an entirely new infrastructure. With the exception of Norway, there is currently no other established supply chain for LNG as a ship fuel, but increasingly stringent emissions regulations have led to growing interest in its potential elsewhere. On the whole the future of LNG bunkering looks positive, but its potential is best judged by the results of applicable regional studies.

From a technical perspective, the option to modify existing unloading systems is more complex than for re-export to larger LNG carriers as the terminal may not be designed to cater for small vessels. However, one possible solution is the use of specially designed ships which are compatible with both large and small scale terminals. The technology for this has been proven at Zeebrugge in Belgium where, in May 2010, a cargo was successfully loaded onto Coral Methane, a 7500 m3 LNG/Ethylene carrier. After being loaded, Coral Methane travelled to Norway, where its cargo was transferred to the Knudsen Pioneer, a 1100 m3 LNG carrier, and was subsequently distributed to GASNOR terminals.

The possibility of future similar operations is restricted by the availability of ships such as Coral Methane, which remains a relatively new and uncommon technology. At present, the loading of Coral Methane has been the only small-scale re-export at the terminal, or at any LNG import terminal around the world, that used existing large scale facilities.

A less restricted and more feasible approach may be the addition of a purpose-built jetty. Zeebrugge is currently undergoing an expansion project, part of which is a second jetty suitable for ships ranging in size from 3,500 to 217,000 m3. While a project such as this is technically feasible, it takes a considerable amount of time and expense and should be evaluated with these major factors and the wider market context in mind.

3.2.3 Commercial

Benefits

At the Zeebrugge terminal, the planned fee for small ships is around $136,000 per cargo, equivalent to a terminaling cost of $1.88/MMBtu for a small 3500m3 ship. This is in addition to the cost of the LNG. The new jetty will accommodate 70 loading slots per year, and consequently the terminaling charges could produce an income of up to $9.52 million per year.

The potential benefits of using import terminals for bunkering depend on the future of LNG as a ship fuel within different regions. The ranking given assumes that the modifications are made in a region where LNG bunkering is commercially viable, in which case the additional revenue stream is potentially quite large (as in the case of Zeebrugge). The benefit of small-scale versus large-scale export is that small-scale could be a more regular, predictable re-export business rather than occasional re- exports to markets abroad and as such would provide a much more reliable mitigation to issues caused low send-out to the network.

Costs

The option to modify an existing facility to accommodate smaller ships may not be viable for the some terminals, where this is the case it would remain restricted by the rarity of adaptable ships such as Coral Methane. As such, the cost evaluated here is that of a considerably larger jetty expansion project with a high CAPEX. OPEX may be increased by the need for tugs, as well as additional operators to manage the increased number of operations. Where jetty modification is possible, the required CAPEX will be substantially reduced. In some cases, where the potential for re-export is high, any expenditure could be outweighed by the benefits and the payback period may be short.

3.2.4 Safety & Operability

As described above, re-export to a ship introduces a new operation with the potential for loss of containment. In the case of small-scale re-export, there are potentially many more ships to load per year, as well as longer loading times. This could have an impact on safety of the shipping routes to the terminal, due to increased traffic flow and the potential for bottlenecks. The risks of this must be managed appropriately, as per the engineering validation discussed above, as well as management of ship traffic flows.

3.2.5 Other factors

Environment

Much of the interest in LNG as a marine fuel is driven by emissions targets set out by the International Maritime Organization, as shown in Table 3.1. These targets are stricter within the Environmental Control Areas (or ECAs) which include areas of the Baltic Sea, North Sea, North America and US Caribbean Sea.

Outside an ECA	Inside an ECA
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020 (depending on the outcome of a review in 2018, as to the availability of the required fuel oil, this could be deferred to 1 January 2025)	0.10% m/m on and after 1 January 2015

Table 12 – IMO SOx and particulate mater emisssion controls for ship fuels

According to DNV, LNG reduces NOx emissions by 92%, CO2 emissions by 23% and both SOx and particulate emissions by up to 100% compared to oil. Thus the use of LNG as a marine fuel is gathering momentum as a means of meeting environmental targets such as those shown above. Through its role in providing the necessary LNG infrastructure, a modified terminal could contribute to this long-term move towards more environmentally friendly ship fuels.

However, as above, this is not a means of reducing boil-off, but rather the emissions at the terminal could be increased due to increased boil-off during ship loading. As such, the option is ranked ‘Red’ for environmental factors. Where flaring is not permitted the additional environmental impact would be zero, however, this would require a period of send-out to the grid which may not be commercially attractive.

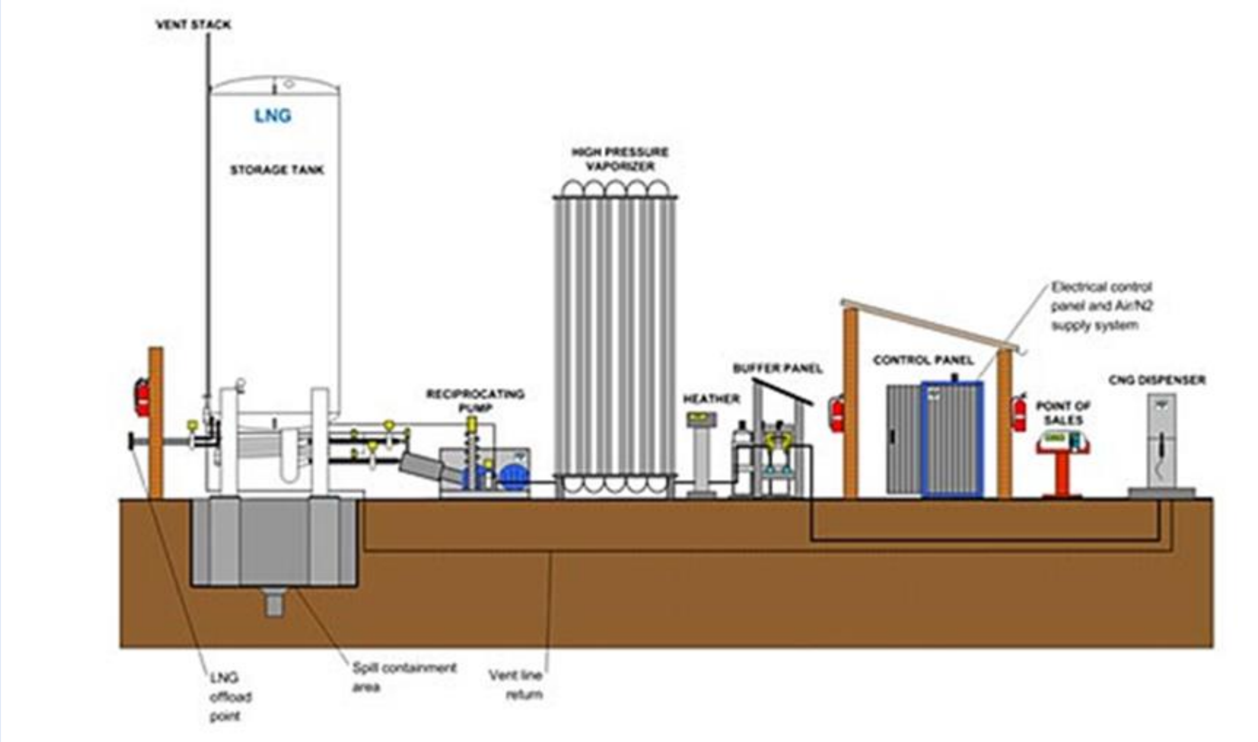
3.3 Small Scale re-export of LNG by road - Truck loading

3.3.1 General description and technical challenges

As an alternative to re-export by sea, the addition of truck loading facilities to the terminal could permit the re-export of LNG by road to bunkering facilities, LNG fuelling stations or off-grid industrial users. This would involve the addition of LNG piping, flow regulation and measurement, loading arms or flexible hoses, as well as drain systems and emergency shut down and disconnect capabilities. There must also be a vapour handling system, whether back into the terminal's BOG handling system or to a flare. Truck loading facilities such as these are available as a package, for instance the package provided by Tokyo Boeki Machinery, pictured in figure 20.

Figuree 20 – Truck Loading Package by Tokyo Boeki Macinery

Another possible alternative is to convert the LNG to CNG by the use of air panel vaporisers, another established technology, which is relatively straightforward to implement. The diagram below shows an LCNG station offered by Cryostar, consisting of pump, vaporizers and



Figuree 21 – Cryostar LCNG Refuelling Station control panel. This particular system has a fuelling pressure of up to 250 barg @ 15°C, and the capability to fuel up to 12 vehicles per hour. It requires around 30kW of power to operate. A similar package could be installed at the terminal to allow export as CNG, if the status of the natural gas vehicle market is such that CNG is more viable commercially.

3.3.2 Feasibility

The transport of LNG by road is well established around the world, and the technology has been proven over a number of years. A number of import terminals have been able to re-export LNG by road, including the BP joint venture terminal, Guangdong Dapeng, where truck loading facilities were installed as a brownfield project in 2007. Table 3.2 shows details of other regas terminals with truck loading capabilities.

As with small-scale transport by sea, there is a growing interest in this option as it may support the LNG bunkering infrastructure for ships, providing fuel for road vehicles or off-grid industrial users. According to NGVA Europe, the use of natural gas vehicles has seen an increase from 4 million to 14.5 million in seven years. However, the commercial viability of this option depends on the status of the LNG supply chain in

Terminal	Storage capacity (m3)	Truck loading capability (trucks per year)	Other details
Zeebrugge, Belgium	380 000	4000	Loading facility opened in 2010
Montoir-de-Bretagne	360 000	2200, (3300 from 2016)	Loading facility opened in 2013
Fos Tonkin, France	80 000	1100	Loading facility opened in 2014
Everett, Massachusetts	155 000	10000	
Barcelona, Spain	760 000	18250	
Cartagena, Spain	587 000	18250	
Huelva, Spain	610 000	18250	

Table 13 – Truck loading capabilities of LNG regas terminals

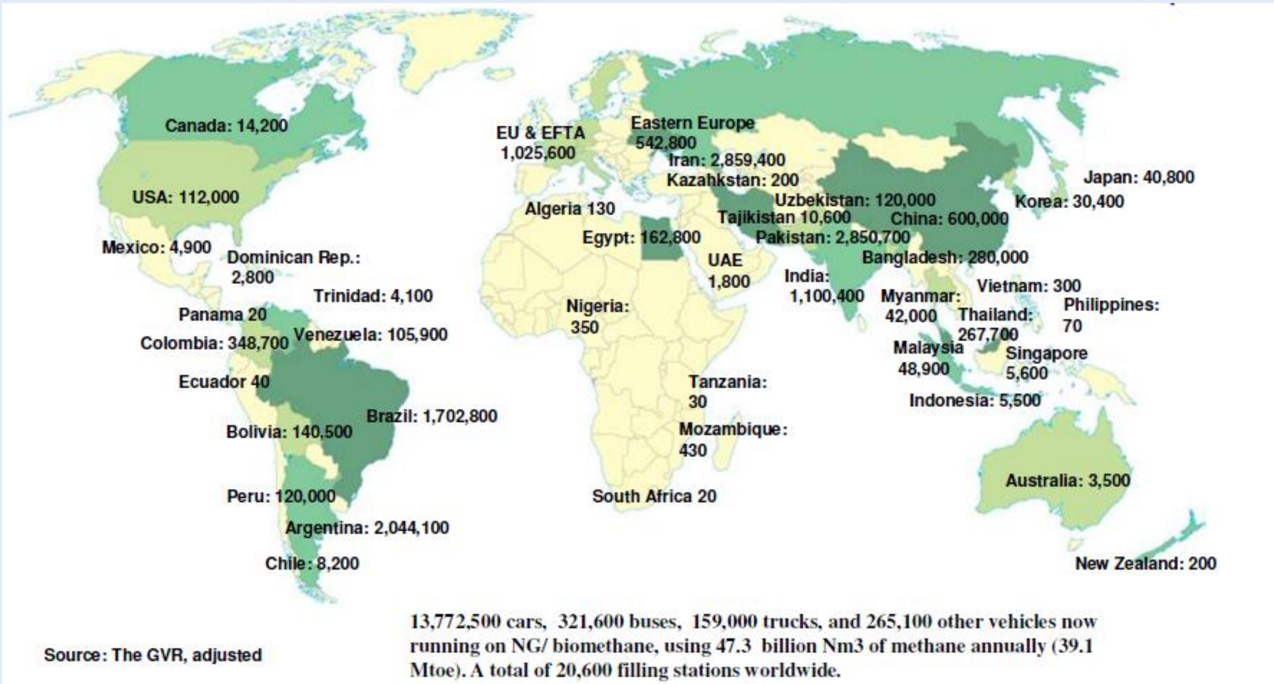


Figure 22 – Status of natural gas vehicles worldwide

the region. Figure 3.5 shows the number of natural gas vehicles, or NGVs, on the road at the end of 2011. The figures demonstrate there is a great deal of variation in uptake of NGVs from region to region. It should also be noted that not all of the natural gas fuelling stations are LNG based; in October 2012, only 60 of the 1500 natural gas fuelling stations in the United States were LNG based, the remainder being CNG based, thus LCNG appears to be a more favourable option in many regions. It has been also been suggested that CNG may be sourced from BOG.

While re-export by road is feasible from a technical perspective, region-specific studies on the status of LNG bunkering, LNG as a vehicle fuel or off-grid industrial fuel source should be considered to understand the commercial viability.

3.3.3 Commercial

Benefits

In addition to the revenue from re-exporting the LNG, some of the costs of truck loading may be recovered by charges to customers. For instance, the Zeebrugge terminal can currently export up to 4000 trailers of LNG per year. As of April 2014, the terminal was charging the following, in addition to the cost of the LNG itself:

A charge of €490 for each loading operation, equivalent to approximately $1.00 per MMBtu for a 36 m3 trailer.

a one-off fee of €3264 per trailer for inspection and approval

An optional €2176 if the trailer requires cool down prior to filling.

Loading up to 4000 trailers a year at a price of €490 each could potentially introduce an income of up to €2.0 million. In conjunction with the one-off and optional other fees, and savings due to the reduction of forced send-out, the benefits may be significant in regions where there is demand for the filling of LNG trucks.

Costs

This option would require only minor modification to the existing process and a suitable bay for the truck loading. There would be some CAPEX required but not to the extent that an expansion project, like that described in section 3.2, would require.

3.3.4 Safety & Operability

As with the re-export of LNG by sea, re-export by road introduces extra risk due to the potential for loss of containment during transfer from storage. For a terminal where there could be as many as 10,000 trucks loaded per year, it is vital that these risks are managed by detailed engineering and carefully managed operations.

Another important consideration for the option to re-export via road is the increase in off-site risk, as it introduces trucks of LNG onto roads used by the general public. LNG trucks are designed to high safety standards, but to fully understand the risk that the off-site population may be exposed to, a full Quantitative Risk Assessment (QRA) or similar study is advisable.

3.3.5 Other factors

As with the other re-export options, re-export into trucks does not act to reduce boil-off, but would increase boil-off due to loading operations. It would however increase the turn over of LNG in storage and reduce the risk of the cargo weathering beyond the acceptable network entry specification. As LNG is a vehicle fuel with low emissions, the terminal could be said to be playing a role in the reduction of emissions from road transport. While there may be further work required to understand the net benefit of increased boil-off versus the reduction in emissions due to natural gas vehicles, in this study the option is ranked 'Red' for environmental factors.

4.1 Benchmark methodology

A few questions regarding terminals characteristics and the problems discussed and analyzed in the report have been included in a questionnaire. The questionnaire refers to terminal activities after 1st January 2012, with the only exception of Hazira terminal, that experienced low send out condition earlier, in 2005, 2006 and 2010 during its first years of activity. The aim of the questionnaire was to collect information from participants in order to identify the problems experienced by the operators and the possible solutions adopted or considered to develop leading practices to improve terminals management.

This chapter summarizes the main findings and significant aspects for each topic. It is based on the contribution of Elengy, GNL Italia, GDF Suez N.A. , Southern LNG, National Grid PLC, Enagas, and Hazira LNG Private Ltd, referring to 9 terminals: Montoir-de-Bretagne, Panigaglia, Distrigas of Massachusetts, Elba Island, Grain LNG, Cartagena, Barcelona, Huelva and Hazira.

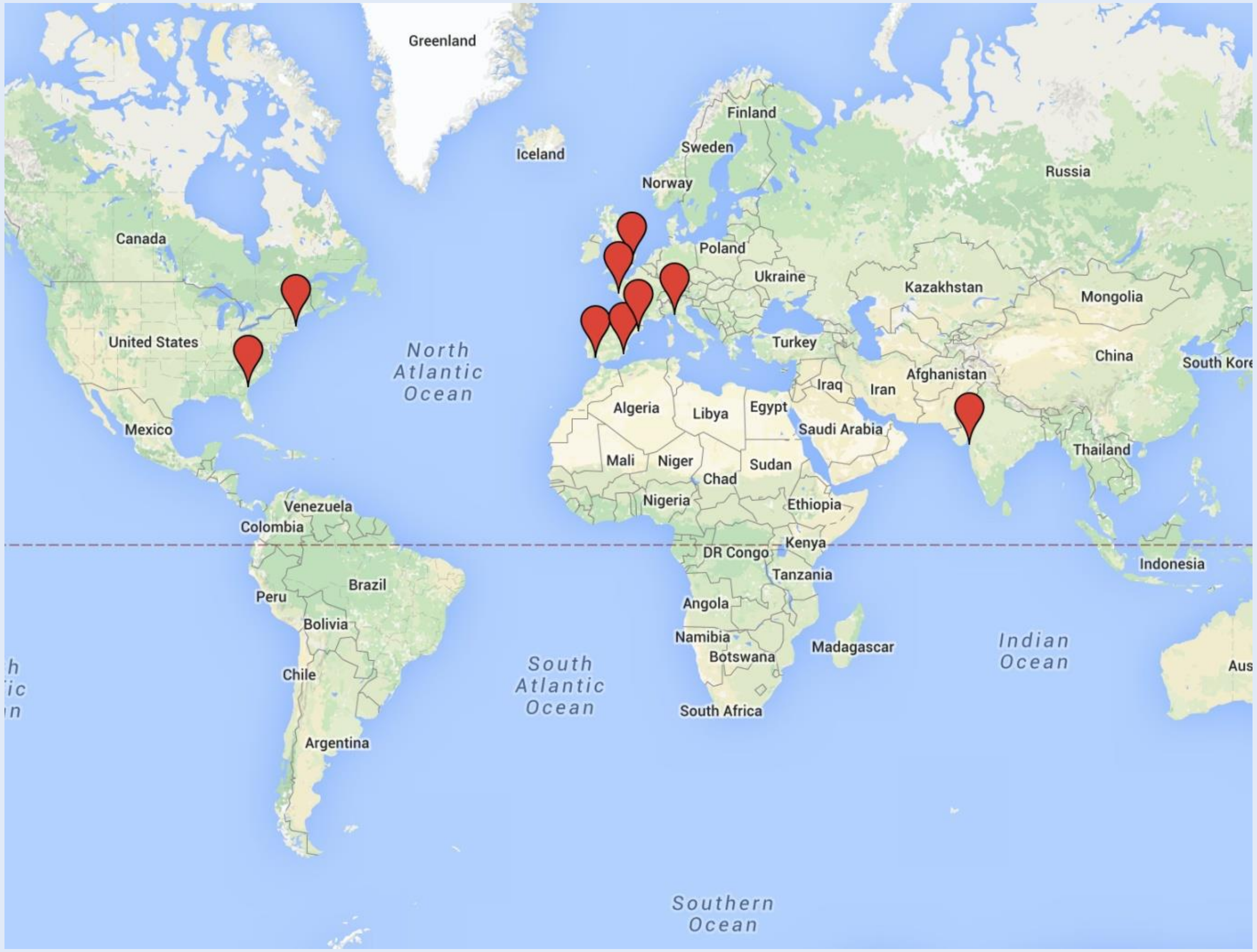


Figure 16 – Locations of terminals that partecipated to the poll. Maps © 2015 Google.

The following two tables summarize some of the main technical parameters of each terminal. Terminal characteristics are significantly different from case to case. Thus, it has been impossible to define a common ground to make clear comparisons among operators. Also environmental conditions that have a direct effect on BOG production are quite different from case to case. Slight differences on quality requirements on the gas sent to network are also present, but they do not imply huge differences among operators' strategies: everywhere the problem of gas interchangeability can arise and correction might be required.

In the end, although different environmental prescriptions are found among participants, venting and emissions are monitored and reported everywhere, even though sometimes only to internal organization. However, in spite of the different strengths of these constraints, the economic loss due to prolonged venting/flaring is a strong and common driver that leads operators' activity towards maximum recovery and operating cost minimization.

Terminal Name	Montoir-de-Bretagne	Panigaglia LNG Terminal	Distrigas of Massachusetts	Elba Island	Grain LNG	Cartagena	Barcelona	Huelva	Hazira LNG Private Ltd.
Operator	Elengy	GNL Italia	GDF Suez NA	Southern LNG	National Grid PLC	Enagas	Enagas	Enagas	Shell + Total
Place	Montoir-de-Bretagne, FRANCE	Fezzano di Porto Venere (SP), ITALY	Everett, Massachusetts U.S.A.	Savannah, Georgia U.S.A.	Isle of Grain Rochester, Kent UK	Cartagena, SPAIN	Barcelona, SPAIN	Huelva, SPAIN	Hazira, (Gujrat State) INDIA
Latitude	47°N	44°N	42°N	32°N	51°N	37°N	41°N	37°N	21°N
Daily production capacity									
Nominal Send Out [10^6 Sm^3/day]	28,9	10,5	20,5	49,7		34,5	49,5	34,2	18
Technical Min. Send Out Rate [10^6 Sm^3/day]	3,17 (2,2 from Dec 2014)	1,2	1,2	7,65		7,6	11,4	7,6	0,72
Min./Nom. Send Out Ratio	≈ 11,0% (7,6% from Dec 2014)	≈ 11,4%	≈ 5,8%	≈ 15,4%		≈ 22,0%	≈ 23,0%	≈ 22,2%	≈ 4%
Storage system main features									
n° tanks	3	2	2	5	8	5	6	5	
Max tank capacity [10^3 m^3]	3 x 120 TOT 360	2 x 45 TOT 90	1 x 58,75 1 x 94,07 TOT 152,82	3 x 63,59 1 x 159 1 x 200 TOT 549,78	4 x 47,7 4 x 204 TOT 1 006,8	1 x 55 1 x 105 1 x 127 2 x 150 TOT 587	2 x 80 4 x 150 TOT 760	1 x 65 1 x 105 3 x 150 TOT 620	2 x 166,5 TOT 333
Tanks Typology (containment)	1 x Full 2 x Membrane	2 x Double	Single	Single	Double Full	Full	Full	Full	Full
Tanks gauge pressure [mbarg]	180	35	86	114	90 - 180	220	70 - 100 - 220	220	100 - 180

Table 8 – Overview of locations and main technical features of the terminals object of the benchmark questionnaire.

4. Current challenges - Benchmark

Terminal Name	Montoir-de-Bretagne	Panigaglia LNG Terminal	Distrigas of Massachusetts	Elba Island	Grain LNG	Cartagena	Barcelona	Huelva	Hazira LNG Private Ltd.
Operator	Elengy	GNL Italia	GDF Suez NA	Southern LNG	National Grid PLC	Enagas	Enagas	Enagas	Shell + Total
Place	Montoir-de-Bretagne, FRANCE	Fezzano di Porto Venere (SP), ITALY	Everett, Massachusetts U.S.A.	Savannah, Georgia U.S.A.	Isle of Grain Rochester, Kent UK	Cartagena, SPAIN	Barcelona, SPAIN	Huelva, SPAIN	Hazira, (Gujrat State) INDIA
Latitude	47°N	44°N	42°N	32°N	51°N	37°N	41°N	37°N	21°N
Impact of low and zero send out conditions on terminals (updated at autumn 2014)									
Total duration low send out periods [days]	65 (+ 283 ***)	118	n.a.		0	670	387	363	240 + 120
Total duration zero send out periods [days]	286	364 + 165	176 *	498	0	111		3	
BOR [%] in low send out periods min - mean - max		0,2 - 0,3 - 0,4	0,05 - 0,075 - 0,075	0,29 - 0,35 - 0,54		0,14	0,14	0,15	0,045 - 0,05 - 0,06
BOR [%] in zero send out periods min - mean - max	0,1 - 0,1 - 0,06 (mean value for each tank)	0,08 - 0,13 - 0,2	0,05 - 0,075 - 0,075			0,14			0,045 - 0,05 - 0,06
Average BOG flow rate in zero send out [Sm^3/day]	150 000 - 230 000	35 000	106 200			415 528		415 000	84 000
Bog recovery solutions:									
Available	A B E	A B	A B	B	B	A C F	A C F	A F	A B C
Under construction			D						
In phase of study	B	D			C	B	B	B	
Additional services available	c d e		a** b** c g			b** c d f	a c d f	b** c d f	d

Table 9 – Overview of impact of low and zero send out operating conditions on terminals object of the benchmark questionnaire; BOG recovery solutions and additional services available at each terminal.
BOG recovery solutions: A = venting/flaring; B = Compression to network; C = thermal/electric power generation; D = Reliquefaction; E = LP BOG/HP LNG heat exchanger; F = Recondenser Optimization
Additional services available: a = supply to MP network; b = supply to LP network; c = Truck loading; d = LNG carrier reloading; e = LNG carriers transshipment; f = small scale ship/bunkering; g = power station supply;
* = the total duration of zero send out periods is the sum of very short and frequent zero send out periods (even less than 2 consecutive days)
**= not available during zero send out.
*** = during this period send-out was between Technical Minimum Send-Out rate (TMSOR) and TMSOR+25%

4.2 LNG Ageing

Regarding ageing, the main issues addressed by the questionnaire focused on gas quality evaluation in zero send-out periods, and operations like LNG transfer between storage tanks or fresh cargo unloading in order to avoid excessive weathering.

While there are not relevant issues in evaluating BOG quality (every operator is able to measure its composition), a few terminals, like Panigaglia, Montoir and Grain LNG cannot perform a complete characterization of LNG quality during zero send out periods. Density measurements are always available in tank at different levels, but the chemical composition of the LNG is estimated through numerical models of the tank evaporation or more complex overall plant process modeling tools.

LNG characterization is not a problem in other terminals where truck loading is in operation all year long. In fact, both ENAGAS and GDF Suez N.A. can sample LNG chemical composition straight from truck loading pipes and systems.

Most of the terminals did not transfer LNG between storage tanks. Panigaglia, Elba Island and Grain LNG terminals took this action as part of an overall plant strategy to balance tank levels, optimize recirculating cooling flows, control stratification and mitigate ageing. The excess of BOG produced during transfer prevents this solution from being considered as a single measure to mitigate LNG ageing. It must be coupled with effective BOG recovery or compression to network, to minimize losses and venting/flaring.

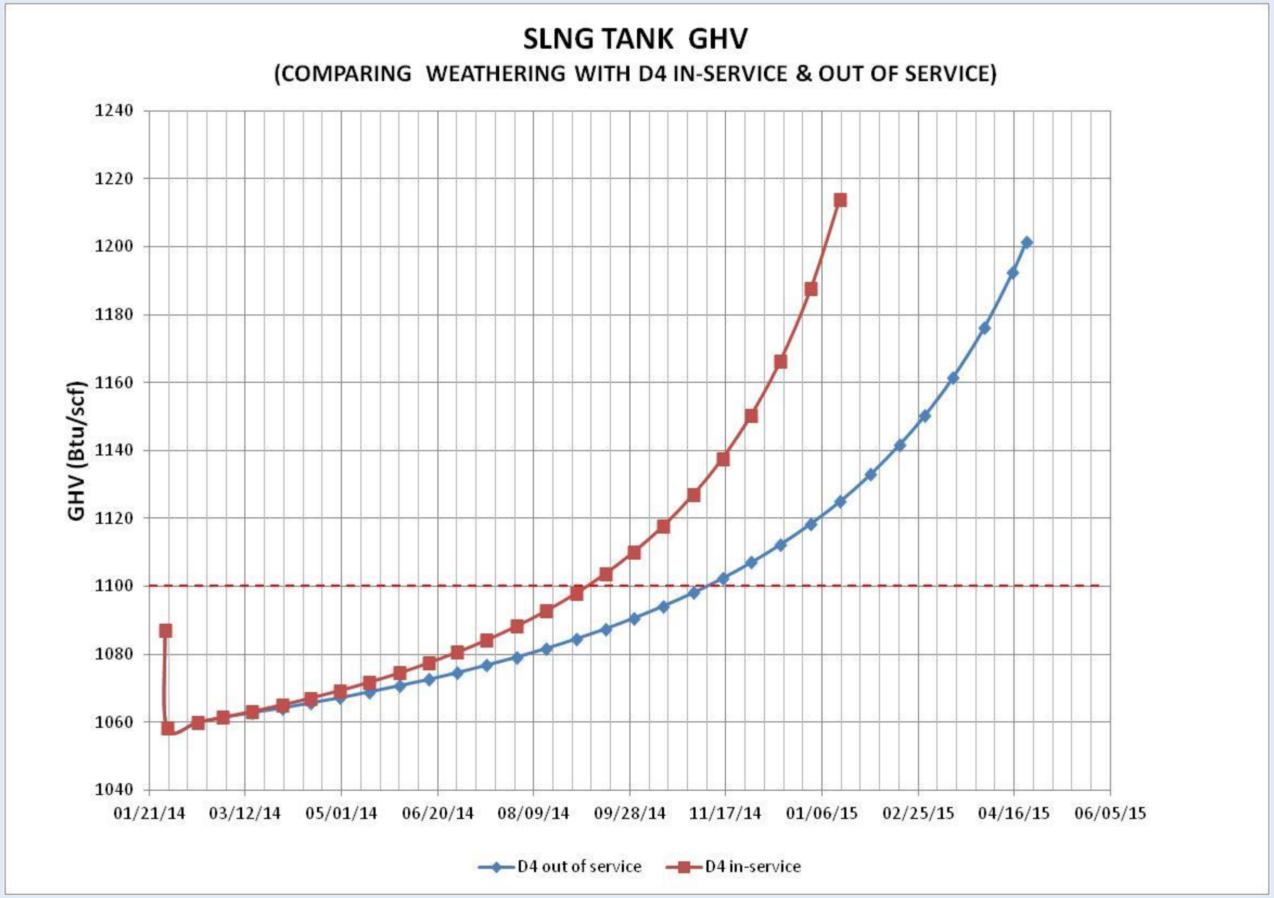


Figure 17 – Ageing prevision considering BOG reduction due to tank warming at Southern LNG terminal.

Since the discharge of fresh LNG significantly impacts on product ageing in tank, it is difficult to draw generic conclusion from comparison between terminals. However it appears clearly that so far just a few members experienced a critical situation due to LNG ageing and that in some cases the phenomenon has been mitigated thanks to the discharge of a couple of commercial carriers per year. Nevertheless, for Panigaglia terminal which experienced more than 500 days of zero send out, the prediction of excessive LNG ageing is one of the main driver which led to the decision to receive two "maintenance cargos" in 2014. Among other interviewed members only Southern LNG underlined that LNG weathering is an aspect which deserve adequate attention in zero send-out conditions. Among other measures, the operator has also warmed two tanks and has done some studies to determine if there were benefits in taking a tank out of service. Results confirmed that by doing so the boil-off reduction achieved allowed the LNG weathering limit to be extended by a few months. Accordingly, this measure seems to be beneficial only for medium/long term periods of decommissioning; reducing LNG weathering for just a few weeks might not be enough to compensate warming cost and issues.

4.3 BOG Recovery

The most common solutions for BOG recovery are gas compression to network and venting, with the exception of Enagas's terminals in Spain, which exploit the BOG for power generation. Due to more frequent zero send-out operating conditions, there is an increasing interest in compression to network. In fact, many terminals have been designed for continuous operation, therefore they lack low flow rate compression capacity. Enagas is studying solution to implement other compression equipment, and the problem of compressing low BOG flow rate was relevant also for GNL Italia and other members. At Panigaglia, a new compressor has recently been installed specifically dedicated to send the BOG generated in zero send-out conditions to the HP network. Other compressors available for the process were not designed to reach the nominal HP network pressure. Southern LNG also has recently installed a second send-out compressor, while BOG compression to HP network is implemented by Elengy at Montoir terminal. Also Hazira LNG, which experienced low send out during early years of operations, successfully installed a new minimum send out compressor in spite of all the problems related to the introduction of such items in brownfield environment.

Grain LNG terminal instead is able to send the minimum BOG flow to a 38 bar local distribution zone and the operator is now considering the possibility of using BOG for power generation. New applications involving re-liquefaction are being investigated by GNL Italia and GDF Suez NA while Southern LNG has already started a notable liquefaction project of about 10 million Sm3/day (350 mm scfd) which is expected to be in service in 2017.

On the side of preventing and minimizing BOG output, it is worth mentioning the recondenser optimization implemented by Enagas (see chapter 2.2.2) and the recent construction of a LP BOG/HP LNG heat exchanger at Montoir by Elengy in order to increase BOG recovery efficiency and plant overall flexibility.

4.4 Storage Tanks Management

Among the operators that answered the questionnaire, it is possible to find tanks of all types. The most common solution adopted is the full containment (23 out of 38), but it has to be noted that 16 of them are operated by the same operator (Enagas) in its Spanish terminals. After a rough overview of tanks typology, the questionnaire was intended aimed to poll the operators about the temperature monitoring in tanks and possible solutions to avoid tank warming.

Most of the terminals do not consider tank temperature as a critical aspect to be monitored except during warming and cooling operations. Temperatures are commonly measured by wall sensors or moving the LTD scanner along its span.

Except for keeping LNG inside tanks the questionnaire did not reveal evidence of any realistic strategy to keep tanks cold. Although the critical aspects involved in tank warming are detailed and explained in chapter 2.3, a successful experience of warming up and cooling down of a membrane tank has been done in Montoir by Elengy, in order to minimize BOG and reduce flaring.

At Elba Island, parts of the plant were warmed, including two single containment tanks. Tank warming has been successful; the only problem experienced was that apparently some water was drawn into the BOG system and reached the tanks, resulting in hydrates. It took a few months for the moist air to leave the system. Apart from this, there is no negative sign that could cast doubt on tanks' reliability and the intent of the operator is to remain in this partially warm state until the start-up of the liquefaction project.

At Panigaglia which has limited storage capacity, the operator wanted to guarantee plants full capacity and readiness to start, thus decided to receive two maintenance cargos to avoid tank warming. Three main aspects had been taken into account to define the strategy: prediction of LNG ageing, avoiding tank warming and LNG market opportunities. Apparently, except for these three cases, all the other interviewed operator did not face so far critical situations which involve tank warming. On the basis of the length of zero send-out periods, the second terminal after Panigaglia is Montoir de Bretagne then Cartagena. In terminals where there are still some commercial obligations, even though for just two or three commercial ship per year, the fresh arrival of LNG along with tank levels optimization mitigated ageing and tank warming risks. In other terminals the presence of multiple services such truck loading, gas supply for power station or other utilities in addition to regasification for NTS, or simply thanks to better commercial conditions the risk of tank warming did not arise yet. If is not possible to keep sufficient heel in tanks 2 options should be considered:

- tank warming up (with the essential advice of tanks manufacturers), taking into account that it seems easier to consider this operation on membrane tanks rather than self-supporting tanks;
- buy maintenance cargoes.

4.5 Operations management

This section of the questionnaire was aimed to get an overview of terminals' main equipment and verify if it is possible to identify different strategies adopted to optimize plant management in zero and low send-out conditions.

Also this answer is not straightforward because terminals are quite different and the duration and frequency of zero send-out periods change a lot from case to case. Thus it is not possible to identify clear strategies in such a multiform scenario. In low send out generally most of the equipment is kept cold with LNG, operating at minimum load or maintained in a ready-to-start condition. In zero send-out condition the quantity of warm equipment increases, depending on the overall number and the plant modularity. None of the operators considered it necessary to preserve warmed equipment in nitrogen atmosphere, but simply in BOG as it is required to be flared during cooldown operation. According to Hazira's Operator experience for zero send out periods, typically there is breakeven of 8 to 10 days if the process area and unloading line (considering length of unloading line to be 1000 meters) are heated up.

	Minimum Flow	Maximum Flow
Low Capacity Pump (Intank and High Pressure pump)	40 m^3/h (Equivalent to 0.2 MTPA) each pump	150 m^3/h (Equvivalent to 0.6 MTPA) each pump
High Capacity Pump (Intank and High Pressure pump)	150 m^3/h (Equvivalent to 0.6 MTPA) each pump	500 m^3/h (Equvivalent to 2.0 MTPA) each pump

Table 10 – Pumping system operating range. Example from Hazira LNG.

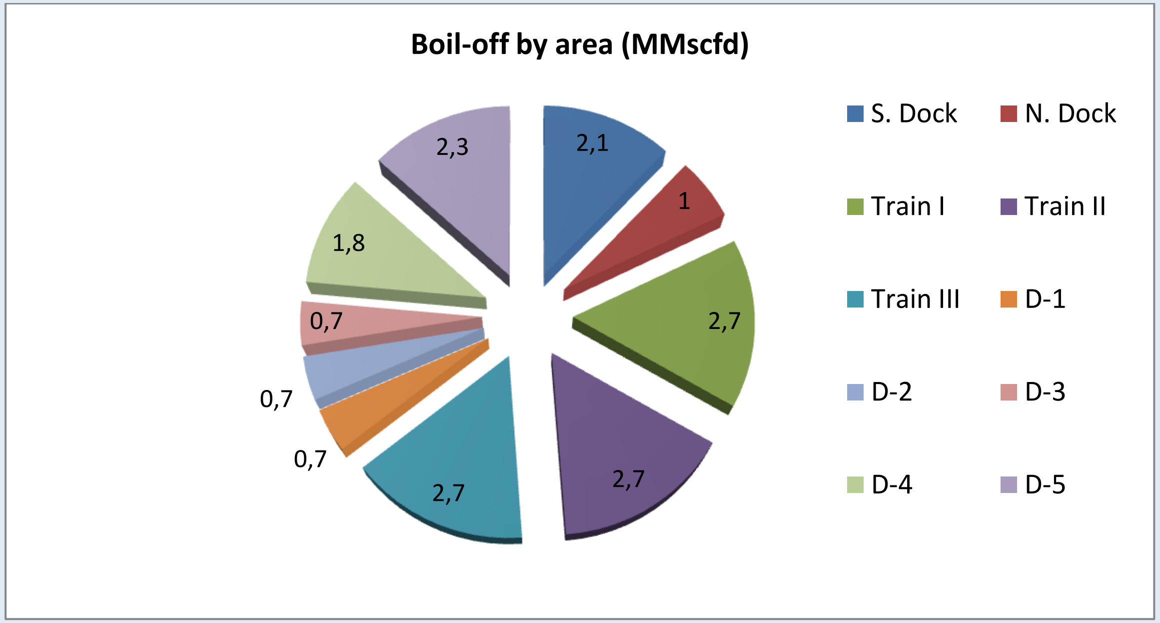


Figure 18 – Daily boil-off production per plant area.

Regarding terminal phasing and modularity, small capacity high pressure pumps and small capacity in tank pumps play a crucial role. At Hazira there are two types of pumps. High capacity (big pumps) and low capacity pumps (small pumps). The minimum capacity of big pumps is equivalent to maximum operating capacity of small pumps (please refer to table 10). Thus the pumping in the wide range (minimum to maximum) is possible. It helps in reducing the minimum theoretical send out with maximum flexibility". Also other terminals are designed with similar criteria.

At Elba Island the equipment warmed to reduce the daily BOG production included two tanks. The terminal operator monitored the BOG production before and after the cooling of plant section. Collected data for this terminal confirms that even though tank warming had a significant impact in terms of BOG reduction, the major contribution to BOG production comes from LNG recirculation while evaporation in tank has a minor effect. For such a plant, the estimated contribution to total boil-off rate by plant area is given in Figure 18.

It emerges that on the overall BOG production the contribution of the 5 tanks account for the 35,6% (average of 7% each), 3 trains accounted for the 46,6% (average of 15% each) and the 2 docks for the 17,8% (average of 8% each). Aggregating these numbers allow to say that the 64,4% of BOG production is due to pumps, pipelines and recirculation, while only the 35,6% is attributable to the storage section. The following table compares this result with Panigaglia terminal and Hazira LNG, whose plants have completely different sizing and configuration.

Other kind of problems experienced by terminal operators generally regards the matching of machinery and equipment because of the frequent running in off design conditions. At Hazira terminal, which experienced low and zero send out during its first years of operations, another problem arose. During that period only one tank was commissioned while the other was kept warm along with its riser line. Isolation valves on riser lines were available only at the top of tanks, and not at the point where the main line splits into two branches that rise up to tanks. Thus when recirculating flow was sent only to one tank, gas pockets developed in the warm riser were occasionally released in the flow causing a sudden increase of pressure in the cold tank. The operator then slightly changed its approach, introducing venting from top of the second riser, in order to keep it cold. Thus every terminal where such potential exist should consider installing additional isolation valves at branch points. Often BOG systems are designed to be fully connected which is an advantage for terminals in full operation. However, in the case of under-utilization of terminals, higher modularity and more sectioning points would allow the length of piping kept cold and the consequent BOG to be minimized, especially in case of tank warming.

	Elba Island	Panigaglia	Hazira LNG
% BOG attributed to tanks	36 %	48 %	61 %
% BOG attributed to recirculation in plant sections	64 %	52 %	39 %
n° tanks	5	2	2(*)
Nominal storage capacity [m^3]	550 000	90 000	330 000
n° jetty	2	1	1
n° vaporizers	11	4	5
Latitude	32°N	44°N	21°N

Table 11 – **Share of BOG production between tanks and rest of the plant. (*) 1 of the 2 was still decommissioned.**

4.6 Maintenance management

Regarding maintenance management the questionnaire focused on changes in maintenance plans and testing of new equipment in low and zero send-out operating conditions.

Generally maintenance plans have not been changed: mandatory interventions are performed regularly while running-hours based maintenance is reduced as a consequence of reduced equipment usage. Condition based monitoring has been increased for equipment that becomes more strategic in zero send-out periods, like BOG compressors and motor operated valves. In some cases this is not possible on warmed equipment and it may cast doubt on the reliability of such equipment. In order to guarantee equipment reliability at Panigaglia terminal, the maintenance plan has been slightly adapted, defining time based tests for valves, loading arms and vaporizers. Apart from this case and Montoir terminal that is reviewing its maintenance plan, no significant conclusion can be drawn from the questionnaire's answers. Without answers and evidence based on experience, the risk of failures increasing and further problems generated by a different type of service for pumps and other equipment (less continuous and more intermittent due to many start and stop cycles) is still a concern. The same holds for testing newly installed equipment: operators are aware of the problem, but if there are no alternative services running in terminals the only chance to test equipment is to wait until commercial conditions change and a cargo is available. In some cases where new compressors have been installed, plant redundancy has not been implemented yet, thus their maintenance can be problematic since their full availability is necessary in zero send-out periods.

4.7 Human resource management

The last part of the questionnaire tried to address if zero send-out condition had any impact on human resources in terms of workforce, and especially on strategy that could be adopted to keep the know-how and the motivation of the personnel during prolonged period of low activity.

None of the interviewed operators have reduced the personnel employed except for Montoir where a global process of reorganization is being implemented. None of the interviewed operators changed the workload distribution between maintenance operators and external contractors. In the frame of the ongoing reorganization process, Elengy is also evaluating which parts of the know-how have to be kept in-house and what is suitable for outsourcing. In general the global maintenance workload did not change; what has changed is its share between equipment according to the new operating condition (i.e. more focus on BOG compressors and less on warmed pumps).

In order to keep the personnel trained and motivated generally the standard training program and periodical meeting proposed by each operator have been maintained. The operator of Hazira terminal decided to send staff to other sites for temporary assignment and training. In the case of very flexible terminals like Everett that runs frequent start and stop cycle to feed a power station, there is absolutely no risk that the personnel loose its skills due to under-utilization of the terminal. Among innovative ideas to keep the personnel trained and involved, it is worth mentioning that Enagas implemented a process simulator and at Elba Island the personnel have been actively involved in the development of the liquefaction project at the terminal.

4.8 Summary of benchmark results

From an overall point of view, the questionnaire reveals that among the operators there is a wide variety of situations. While a few experienced very long periods of zero and low send-out, for others so far the situation not yet become so critical. In some cases zero send out periods are very short, having a very little impact on operations: items are kept cooled and the major challenges is represented by the change in the kind of services for pumps and main items: more intermittent and less continuous.

Where periods of low and zero send-out are longer, the priority goes to BOG reduction and recovery (warming part of the plant and improving compression and liquefaction capacity) in order to minimize operational cost and storage tank management, where issues due to LNG ageing and especially worries on tank warming become of primary importance.

The main solutions adopted so far are the enhancement of BOG compression capacity, and the optimization of the recondenser; there are also a couple of significant experiences of tank warming. When the implementation of these ideas is not feasible or has too little impact, the last option is to buy fresh LNG to guarantee terminal availability.

In terms of maintenance and human resources management, the operators interviewed focus on regular meetings to keep the know-how. There are also a few good examples of additional training through process simulators and involvement of personnel in other ongoing activities. The overall maintenance workload does not change significantly, often it is simply redistributed among the equipment, while additional monitoring and periodic testing of equipment has been introduced to guarantee reliability. Questions are still open on how to test newly installed or maintained equipment without LNG and other minor aspects.

It is interesting also to note that the presence of small scale services and commercial obligation that guarantees a minimum supply of LNG to terminals (even 2 or 3 carrier per year) minimize the effect of zero send-out periods, especially preventing LNG ageing and tank warming. Thus the opportunity to implement additional services and increase flexibility should be seen from a different perspective from terminal operators facing low send out period. Beside commercial and market-related considerations, it is clear that it helps to simplify the plant management in low production scenarios.

Terminal operators who have not yet faced prolonged periods of zero send out, but are expecting it soon based on market forecasts should take advantage of the questionnaire's findings to start working in advance on the implementation of the proposed solutions while continuing to look for others.

The recent market situation forced several operators to reduce significantly their terminals' production rate and to face periods of prolonged low and zero send out. This study tries to outline and discuss all the major issues encountered by the GIIGNL task force members. An attempt to make a benchmark among each members' terminal characteristic has been done, but due to the specific characteristics of each plant and different regional conditions it was not possible to make a clear comparison and identify global solutions. Each situation must be evaluated case by case, and every operator facing low production has to consider its own plant costs and benefits for every option. Accordingly this work must be seen as an overview of problems and challenges related to terminal under-utilization; the work tries to identify major issues and presents possible mitigating actions and solutions, starting from best practices and experience of task force participants. Even though some data are not fully comparable, and some examples might be specific enough to be considered a "lesson learnt", the value of this work is that it provides a global basis for approaching a problem that was quite unpredictable a few years ago. This work can be a valuable tool for terminal managers to better understand problems that can arise from market changes, and hopefully to help evaluations regarding plants improvements and transformations in order to increase terminals' capacity to respond to a more global and dynamic market.

From this report and discussion among task force members, it is possible to draw some conclusions about how to face terminals' under-utilization scenarios. These conclusions apply also for operators not affected by low demand: it is important for them to take advantage of this group's experience and to ask themselves what would be their terminal's weakness in such a scenario to be more conscious of the actions they could implement if market conditions would change.

When strong market conditions change and a terminal's perspective moves from high production to under-utilization, it is very important to observe the global scenario and especially long term forecasts. Obviously this approach suffers from high uncertainty that must be taken into account, but it shouldn't be underestimated. In fact, drastic and costly measures like liquefaction implementation or tank warm-up could have a technical and/or economical positive effect only if taken immediately and maintained for an enough long period. On the contrary, an excessive delay before taking similar decisions would diminish the time window available for savings and benefits associated to this strategy, and would increase risks and disadvantages that could outweigh any potential benefit associated with such strong measures. Apart from this macro-perspective and strategic approach, the first thing to put in place is an overall process analysis, to find margins for optimization, to minimize BOG production, and to diminish the minimum technical delivery. A few examples have been described and shared by task force group members in this document, but other solutions might be considered and included in future works. When there is no further margin for BOG production minimization, further (and more modular) compression capacity must be considered along with other measures such heat and electric generation to improve BOG recovery and plants' overall energy balances. Also re-liquefaction is considered a valuable option but, as already stated, it must be considered in the frame of an overall long term strategy of process change and improvement.

From the experience shared, it emerged clearly that decreasing the minimum technical delivery can provide many advantages and increase terminals' flexibility. Accordingly, in order to be better prepared to face low send-out and rapid market changes, new terminals' design criteria should consider also lower pump rates when designing technical minimum delivery. In fact the availability of low pumping rates is the first step to achieve low production rates and to have LNG flowing in small quantities for potentially handling any application, without an excessive BOG production.

Another important thing to do is to study historical BOG production data and to predict ageing in order to better understand the scenario and especially to forecast for how long and until when product ageing is acceptable without taking any countermeasure. While considering prolonged low and zero send-out perspective, terminal operators could take advantage of the problems highlighted in this work, and consider, depending on their applicability on the specific situation, to act immediately to minimize the related risk and problems. Future works should include feedback from other members on the problems presented here, and any other issues and solution, in order to broaden the overall understanding of this situation for the industry.

It might be also interesting, for future works, to address issues and opportunities from the commercial point of view for terminals that have to deal with aged product.

An effective measure to put in place with minor plant modifications is the possibility to reload LNG carriers, thus offering to customers an opportunity to exploit market price gaps. In fact, beside the commercial benefit, it helps the product turnover inside the tanks. Thus terminals that are not yet able to provide this service, should investigate the opportunity.

Similar considerations apply for small scale services: where there is the potential or a growing interest for such a market, terminal operators should investigate and consider this opportunity and the potential benefits that could be introduced when providing new services. However, if we focus on the implications of low and zero send-out problems, it is important to notice that for non-mature markets providing these services would potentially increase the challenges. In particular, the inventory turnover would probably be too low to avoid excessive ageing due to low demand of small volumes. Moreover, usually small scale customers arrive warm to terminals and require cooling, thus there is an increase in BOG generation that must be handled by the terminal. From the side of human resources, maintenance and loss of know-how, zero send-out periods introduce many concerns and inefficiencies difficult to be avoided. In this work a few examples of best practices have been presented to give a positive example of what can be done. Optimization of maintenance intervention according to the modified utilization rate of equipment, reallocation of human resources and the use of process simulators to train operators are just a few basic principles that operators follow to respond to the technical needs within more stringent budget limits. Once there is no more margin for resource optimization it is important to understand that under-utilization of a terminal can become a great opportunity to review procedures and to make more detailed analysis of some aspects like equipment failures, processes, safety and many aspects that cannot be investigated properly when terminals are kept busy for high market demand. Thus, staff cost that cannot be reduced and further compressed can be turned into a positive contribution to the overall know-how in a process of continuous improvement to become more effective and better prepared for future market opportunities.

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