ABSTRACT

With the booming interest for Natural Gas, many countries are looking to import LNG as an alternative energy source.

However, several 'newcomer' countries in the LNG chain are not interested in importing large quantities of LNG as their market simply cannot make use of it all.

Furthermore, the continuous trend to develop ever increasing capacity LNG carriers and equipment, does not support the development of small scale terminals with a capacity in the range of 0.5 mtpa.

The needs of such small scale terminals have already been addressed in various conferences and papers.

The investors and developers are, too often, considering these small scale LNG terminals in the same way as a typical large scale LNG terminal but with a reduced send-out.

Such an approach would not make the terminal economically profitable as only a portion of the CAPEX is driven by the send-out rate. The major element of the CAPEX is driven by parameters that are independent of the send-out rate such as jetty, tanks, utilities, etc.

The aim of this paper is to highlight the potential design alternatives that could be adopted to help develop profitable small scale LNG terminals.

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1. INTRODUCTION

While the LNG industry was looking for the past years for development of ever and ever increasing capacities, the outbreak of the oil products prices as well as the fact that natural gas could be seen as a cleaner fossil fuel than any oil product, has brought a large number of potential consumers to the same conclusion... Natural gas could be the next generation fuel. Around the world, Natural Gas is now seen as one major alternative fuel to the oil for many applications (Power Generation, Fuel for Transportation,...).

Since few years, these new applications have opened new horizons for the LNG, not only for gas transportation between points as illustrated on Figure 1 but rather as a tool to increase the flexibility and to reach new consumers. Figure 2 shows this new diversification.
In this new market approach, the small scale LNG terminal demand is growing up to deliver gas to new potential consumers and countries.

This booming need has already been developed in many papers.

Typically, the send-out rate of such small LNG terminals is ranging from 0.2 to 1 mtpa.

In the last years, Tractebel Engineering faced multiple requests to design small scale LNG receiving terminals dedicated to small power generation or consumers.

Quickly the traditional design approach, implemented in large scale LNG terminals since more than 30 years, showed its limits for these applications.

For this range of send-out rate, a simple downsacle of the large scale LNG receiving terminal design is not suitable and for most of the cases, acting as such will result in non sustainable business cases for the stakeholders. Cost reduction is a critical need to make the small scale LNG receiving terminals projects go ahead.
To try to solve this issue, Tractebel Engineering proposes an innovative approach for small scale LNG receiving terminals with customized solutions, both on technical and economical point of views.

Furthermore, TE recommends an accurate analysis of the LNG chain to appraise the main cost factors (CAPEX and OPEX wise) for global optimization.

The purpose of this paper is to present the potential design alternatives that could help the development of profitable small scale LNG receiving terminals.

Before presenting the potential design alternatives, the differences between large scale and small scale LNG receiving terminals are highlighted.

2. TERMINAL PERFORMANCES DEFINITION

To better understand the parameters which must be taken into account when designing a LNG receiving terminal, the basic functions are reminded.

- Unloading of LNG carriers
- Storage of LNG in tanks
- Send-out of gas and/or LNG to the consumers

The Figure 3 below is representing the 3 functions of a LNG receiving terminal.

![Figure 3: LNG receiving terminal main functions](image)

For each the 3 functions, major differences in term of performances requirements can be highlighted.

In these functions, it appears that only the vaporization part is directly related to send-out while unloading and storage are more impacted by the LNG carrier size.

Considering that 2 of the 3 functions of a LNG receiving terminal are not directly driven by the send-out rate, the accurate definition of the performances of each of these 3 functions is therefore critical for developing a profitable small scale LNG receiving terminal.

Moreover, even with an adequate definition of the performance of each function of the LNG receiving terminal, several investment costs could not be reduced in the same ratio than downscale ratio of the need.

By downscaling some parts of a LNG receiving terminal, some negative scale effects on the investment costs are observed. For instance, the price per cubic meter of a full containment LNG tank is rising when the capacity is decreasing.

The same is observed with the jetty infrastructure where the LNG carriers will berth. Reducing the carriers size in a certain ratio will not reduce the investment costs by the same ratio.
Others examples of non-proportionality can be listed, such as investment costs for cryogenic rotating equipment or even some utilities.

On the opposite, the requirement of a small scale LNG terminal could give some potential for deletion of the needs of some equipment or even part of the installation which are typically installed in a large scale LNG receiving terminal.

Again, this potential cost saving is directly linked to a correct definition of the performance of each function of the small scale LNG receiving terminal with regard to the whole LNG chain optimization.

The LNG carriers size being an important cost parameter for unloading and storage functions, smaller LNG carriers, typically in the range from 7 500 to 35 000 cubic meters, are to be considered.

The hundreds of thousands of cubic meters of LNG storage capacity in large scale LNG terminals, should be replaced by smaller tanks in the range of 20 000 to 50 000 cubic meters.

A major difference between large scale and small scale LNG terminals is obviously the reduced send-out rate, which is approximately (5) five to (20) twenty times lower than for a large scale terminal. Another major difference is the proximity and the number of customers to deserve. While a large scale terminal will be connected to a gas network with a lot of consumers, a small scale terminal could be dedicated to only one or a few consumers. This reduced number of consumers and the absence of buffer capacity created by the gas network will increase the required flexibility and availability of the send-out flowrate.

Furthermore, when a large scale terminal send-out pressure will be defined by the required downstream gas network pressure (i.e. typically from 55 to 90 barg), the small scale LNG terminal send-out pressure and characteristics should be customized to the specific consumers needs. It can ranges from few barg, when the small scale LNG terminal is dedicated to supply gas to a power plant generating electricity by the mean of Dual-Fuel Engines, up to 25 - 40 barg for Gas turbines or small gas grids.

The following table shows indicative send-out rates and amount of LNG shipment required with regard to the corresponding Power Plant Capacity:

<table>
<thead>
<tr>
<th>Terminal Functions</th>
<th>Small Scale LNG Receiving Terminal</th>
<th>Large Scale LNG Receiving Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unloading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LNG Carriers Size</td>
<td>From 7500 to 35 000 cubic meters</td>
<td>From 70 000 to 265 000 cubic meters</td>
</tr>
<tr>
<td>Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LNG Storage Tank Capacity</td>
<td>From 20 000 to 50 000 cubic meters</td>
<td>&gt;160 000 cubic meters (up to millions of cubic meters)</td>
</tr>
<tr>
<td>Send-out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Send-out Flowrate</td>
<td>From 0.2 mtpa to 1 mtpa</td>
<td>&gt; 2 mtpa</td>
</tr>
<tr>
<td>Send-out Pressure</td>
<td>From few barg to 25 - 40 barg</td>
<td>Gas Network Pipeline pressure (typically between 55 and 90 barg)</td>
</tr>
</tbody>
</table>
Table 2: Indicative Send out rates and required shipments for selected power plant capacities

<table>
<thead>
<tr>
<th>Power Plant Generation Capacity [MW]</th>
<th>Send-out Rate [mtpa](^1)</th>
<th>Amount of shipment/year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\eta = 0.35^2)</td>
<td>(\eta = 0.47^2)</td>
</tr>
<tr>
<td>100</td>
<td>0.190</td>
<td>0.141</td>
</tr>
<tr>
<td>200</td>
<td>0.379</td>
<td>0.283</td>
</tr>
<tr>
<td>300</td>
<td>0.569</td>
<td>0.424</td>
</tr>
<tr>
<td>400</td>
<td>0.759</td>
<td>0.565</td>
</tr>
</tbody>
</table>

Potential design optimizations are described in next section.

3. POTENTIAL DESIGN OPTIMIZATION

As introduced above, to have a profitable small scale LNG receiving terminal, a simple downscale of a large scale LNG terminal is not sufficient. An optimization of the design is required. Since the potential range of consumers of small scale LNG receiving terminal is very wide, this optimization shall be performed case by case.

Some of the potential design optimization that could help a small scale LNG terminal to be more profitable are hereafter listed.

Design optimization categories include

- Process Optimization
- Technology selection
- Layout optimization

First category of design optimization to investigate is the potential process design optimization. For small scale LNG terminal, depending on the required performances, one or several of the following process design optimizations may be implemented.

The first potential process design optimization is the cancellation of equipment or part of the system become unnecessary for the considered conditions:

- In the case of a small scale LNG terminal feeding gas to a power plant (typically up to 30-40 barg), the multiple level of pressure in the LNG send-out could be avoided. The required send-out pressure can be reached by pumping LNG directly from the LNG tank with In-Tank LNG pumps without the need of HP pumps. The cancellation of the second level of pumping allows to cancel the LNG buffer at HP pump suction, function typically ensured by the absorber.

\(^1\) GHV considered = 38 MJ/m\(^3\)(n)

\(^2\) Typical efficiency of open-cycle gas turbine

\(^3\) Typical efficiency of Dual Fuel Engine

\(^4\) Typical efficiency of combined cycle gas turbine
• The lower pressure send-out in case of Dual Fuel Engine gas supply allows using compressors to handle BOG directly to grid without any absorber. As a result of absorber deletion, the possible minimum send-out rate of the LNG terminal will be reduced thereby giving more flexibility to the LNG terminal operations.

• This potential design optimization will simplify the process of the small scale LNG receiving terminal, reduce the required footprint for installation, and consequently reduce the CAPEX.

• The removal of the vapour return line connection from the terminal to the unloading LNG carrier. The required vapour return quantities could be reduced in such an extent that the benefit of this return connection disappears 5.

• This potential design optimization will simplify the process of the small scale LNG receiving terminal, reduce the quantities of piping and equipment on the jetty head and consequently the required unloading platform area, reduce the size of the piping rack to the jetty head and the related infrastructure towards and cancelling the need of a desuperheater for gas returning to ship.

• Reducing the number of equipment will also have a positive impact on the operating costs (less maintenance, less power consumption, less consumables, less spare parts to store, etc.).

The Figure 3 is illustrating the typical process flow of a small scale LNG receiving terminal downscaled from a large scale LNG receiving terminal while Figure 4 is illustrating the typical process flow of a small scale LNG receiving terminal including potential optimization. The simplification can be clearly visualized.

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5 It has to be noted that the saved cost of the vapour line will have to be balanced with the potential (if any) additional investment cost required to handle the additional capacities by BOG/Pipeline Compressors as well as the related additional extra energy costs.
The second potential design optimization category is related to technology selection. Some alternative technologies to the ones installed in large scale LNG receiving terminal can be investigated for the small scale LNG receiving terminals:

- The LNG tanks full containment technology widely used in large scale LNG terminals can obviously be downscaled to be installed in a small scale LNG receiving terminal. However, since the storage cost per cubic meter will increase when the tank capacity decreases, the suitability of the full containment technology for LNG storage tank should be questioned. The potential alternatives could be either single containment API type metallic tank if spacing allows it or full containment tank with outer container in 9% Ni or Stainless Steel, or double membrane inner container with low temperature Carbon Steel outer tank.

- The vaporizer technology used in large scale LNG receiving terminal are mainly Submerged Combustion Vaporizers (SCV’s), Open Rack Vaporizers (ORV) or Shell and Tube Vaporizers STV (with various heat sources e.g. seawater or ambient air). In addition to the obvious balance between investment cost and operation cost, for small scale LNG receiving terminal, a key parameter for the vaporization technology selection is the required flexibility of operation. Efficiency of equipment will ever be better operating close to the design flowrate than at a reduced flowrate. For this reason, the typical capacity per unit of an ORV or SCV does not make those the most suitable equipment for a small scale LNG receiving terminal. A solution could be the selection of passive equipment like Ambient Air Vaporizer (AAV). This type of vaporizer allows a better matching of the installation capacity to the demand for small scale LNG receiving terminals. A major benefit of this type of installation is that it will reduce the energy costs to zero in most cases by using a free heat source. In most cases because, for some extreme conditions, a back up heater could be required to operate for a very limited duration and/or some fan could be required to optimize the heat exchange by dissipating the fog due to the air condensation.
The third category of potential design optimization is related to the layout. This optimization is obviously intrinsically linked to the process design optimization. Reducing the number of equipment will reduce the required footprint of the LNG receiving terminal. The lower inventories, the reduced quantities that could be released, the potential lower pressure of hazardous materials involved, will allow a more compact design of the LNG receiving terminal by reducing the required safety distances. On other side, some infrastructure like jetty have an important weight in the overall investment costs, it is very important to optimize the planned surface of such terminal parts to minimize the investment costs. Layout is also resulting from safety distances.

The fourth category of potential design optimization is related to the operation of the terminal and the potential synergies with the dedicated consumers. For a small scale LNG receiving terminal, the standard way to operate a large scale LNG receiving terminal shall be reconsidered. The typical extent of staff used in a large scale LNG terminal shall be questioned to avoid too expensive operation costs, minimum staff with outsourcing shall be considered. Synergies with consumers (power generation, etc) for maintenance and administrative activities could be considered if possible, the related buildings and resources could be shared.

<table>
<thead>
<tr>
<th>Terminal Function</th>
<th>Potential Optimization Considered</th>
<th>Impact on CAPEX</th>
<th>Impact on OPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unloading</td>
<td>Removal of vapour return line</td>
<td>Cancellation of equipment and piping (loading arms, desuperheater,...)</td>
<td>Additional energy consumption from BOG compressors (to inject the compressed BOG into send-out pipeline).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction of infrastructure size (unloading platform and trestle)</td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>Tank Technology Selection</td>
<td>Cost Reduction for low storage capacities</td>
<td>Potential additional BOG quantities to recover/compress</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase or reduction of plant footprint</td>
<td></td>
</tr>
<tr>
<td>Send-Out</td>
<td>Cancellation of second pressure level</td>
<td>Cancellation of equipment, piping and civil works (mainly HP pumps and absorber)</td>
<td>Energy savings by reduction of number of equipment$^6$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction of plant footprint</td>
<td>Potential increased flexibility (reduced minimum send-out)</td>
</tr>
<tr>
<td></td>
<td>Vaporizer technology</td>
<td>Depending on technologies compared</td>
<td>Optimization of flexibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Energy savings (in case of passive equipment selection)</td>
</tr>
<tr>
<td>All</td>
<td>Reduction of number of equipment</td>
<td>Reduction of plant footprint</td>
<td>Reduction of</td>
</tr>
</tbody>
</table>

$^6$ to be balanced by additional BOG quantities to be compressed.
<table>
<thead>
<tr>
<th>Terminal Function</th>
<th>Potential Optimization Considered</th>
<th>Impact on CAPEX</th>
<th>Impact on OPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>resulting in reduced hazardous material inventories, pressure, ...</td>
<td>maintenance costs</td>
<td></td>
</tr>
<tr>
<td>Operation resources</td>
<td>Reduction of plant footprint Cancellation of buildings</td>
<td>Reduction of operation costs (maintenance, staff,...)</td>
<td></td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

In order to develop profitable small scale LNG receiving terminals, simple downscale of large scale LNG receiving terminal is not efficient. Innovative solutions shall be implemented in the design.

To achieve this target, an adequate performance definition of each function of the LNG receiving terminal is critical. This evaluation shall be performed case by case. Potential design optimization includes process optimization (e.g. cancellation case by case of unnecessary equipment), technology selection (e.g. storage tank technology), layout optimization and operation resources.