INTEGRATION OF MAJOR LIQUEFACTION UNITS WITHIN EXISTING IMPORT TERMINALS

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ABSTRACT
As the global demand for natural gas increases and as energy companies continue to explore previously undeveloped North American gas reserves, the export of LNG from North America has become an attractive target for many developers and major investors, including owners of many existing LNG Import and Regasification Terminals, such as Freeport, Cheniere, Sempra, Dominion and Trunkline LNG, who are all well positioned to take advantage of their existing infrastructure, licenses, plant expertise and market contacts.

Integration of liquefaction equipment within an existing import terminal allows the project to benefit from the available equipment and infrastructure such as the LNG storage tanks, marine facilities and potentially some utility capacities. On the other hand, it poses challenges such as siting, seamless integration of the additional or replaced equipment, and ensuring that the bi-directional flow in major piping networks is achievable. Additionally, the design and modifications should be accomplished in a manner so as not to preclude the ability of the subject terminals from operating in import and regasification mode, should the market demand require it.

This paper outlines the major considerations that should be taken into account, from the initial planning through the design, engineering and operation of the facility. It also offers potential recommendations for management of operational variances between an import and an export terminal. As an example, options for Boiloff Gas reduction and handling within the design constraints are discussed and evaluated.

BACKGROUND AND OBJECTIVE
Aiming to realize potential benefits of the shifting LNG market demands, several North American LNG import and regasification terminals are evaluating their options of converting their existing facilities into a natural gas liquefaction and export or a bi-directional import/export facility.

The greatest advantage of such effort is the opportunity to utilize available equipment and infrastructure such as the LNG storage tanks, marine facilities and potentially some utility capacities, resulting in savings in capital investment and shortening the construction schedule. On the other hand, the design should overcome challenges such as regulatory compliant siting, seamless integration of the additional or replaced equipment, and ensuring that the bi-directional flow in major piping networks is achievable. Careful consideration should also be given to the isolation and long-term maintenance of existing equipment that will not be used during the liquefaction period.

This paper outlines major considerations in respect of the design, engineering and operation of the facility, along with potential solutions for management of operational variances between an import and an export terminal.

FACILITY INTEGRATION
As the project proceeds with the design of the liquefaction system and integration within the existing LNG import and regasification terminal, the following items should be identified as one of the first steps in the design:
• New equipment and units comprising the liquefaction train(s)\(^1\)
• Components requiring modification or replacement to enable liquefaction and export of LNG at acceptable rates
• Systems and Components that will not be used during the liquefaction phase.

As the design proceeds, the efforts should be focused to achieve the following:

• Maximize overall plant efficiency
• Maximize the use of existing equipment, utility and auxiliary systems
• Minimize modifications to the existing equipment, particularly if the facility intends to retain the capability of returning to import and regasification mode
• Minimizing vapor generation at the facility, particularly during loading of LNG carriers

While the above objectives are desirable, the long term operability and maintainability of the facility should also be taken into account.

ADDITION OF LIQUEFACTION TRAIN(S) AND ASSOCIATED HAZARDS

A typical natural gas liquefaction train is comprised of the following major systems:

• Feed gas booster compression
• Refrigerant compression
• Series of heat exchangers, air or water cooled, for process cooling, i.e., refrigerant cooling and condensation as well as, in certain processes, pre-cooling of feed gas
• Cryogenic heat exchanger
• LNG let-down system comprising of LNG expanders and/or J-T valves
• Natural Gas Liquid (NGL) extraction and potentially fractionation unit
• Emergency flare
• Auxiliary systems such as refrigerant storage and transfer systems, spill containment systems and oily/waste water collection systems
• Utility systems such as electrical power distribution system, service and instrument air, and service water systems, either by extending the existing terminal’s capacity or through standalone systems dedicated to liquefaction train(s)
• Expanding the firewater systems design and other hazard detection and mitigation systems
• Other elements such as nitrogen rejection unit may be required depending on facility’s specific requirements

When siting the proposed liquefaction facilities, it is important to take into account the fact that regulatory compliance will require significantly more real estate than that which is required for solely locating the equipment. The addition of liquefaction facilities to an LNG import terminal results in additional hazards that must be considered. The primary hazards associated with natural gas liquefaction and export facilities can be categorized as follows:

• Hazards associated with LNG

\(^1\) For the purpose of this article, the pretreatment of natural gas is assumed a standalone operation upstream of the liquefaction trains.
• Hazards associated with hydrocarbon refrigerants and Natural Gas Liquid (NGL) components removed prior to final liquefaction stage

• Hazards associated with storage of hydrocarbon refrigerant components on site

The hazards and related considerations associated with LNG are common to both LNG import and export facilities. These hazards are related to flow rates of LNG in transfer piping and the length of the LNG lines. The dominant flow rate of LNG in both import and export facilities is that of the transfer pipeline(s) designed for loading or unloading LNG carriers, which typically remains the same when converting an import terminal to a bi-directional facility. However, the LNG containment (impoundment) systems at the facility may need to be extended to include spill collection for the LNG rundown line from the liquefaction train to the storage tanks. New vapor dispersion analysis may need to be performed to ensure all siting requirements are met. The size of existing LNG spill containment sumps should be evaluated to ensure sufficient volume for containing a design spill from any single accidental leakage source. Provisions should be made to demonstrate compliance with flammable gas dispersion exclusion zones and to prevent thermal flux beyond allowable limits. The liquefaction process introduces new hydrocarbon refrigerants as well as NGLs to the facility and consequently the hazards associated with such components. The siting requirements for facilities handling such components require the following analyses:

• Vapor Dispersion Modeling, taking into account jetting and flashing scenarios from refrigerant and NGL single accidental leakage source

• Vapor Dispersion Modeling, taking into account possible liquid spills from refrigerant and NGL design spills

• Calculation of overpressure radii from ignition of the vapor clouds to demonstrate that the damaging effects of overpressure do not affect the public

• Design of trench, troughs and impoundment systems for NGL and refrigerant hydrocarbons; namely ethane, ethylene and propane

Due to expected depletion of refrigerants in the refrigeration loop, some refrigerant components such as ethane and propane are stored onsite to provide make-up to the system as needed. The size of the storage vessels is determined by leak rates through the system and the number of days the owner chooses to keep inventories on hand, based on facility’s proximity to refrigerant distribution sources and acceptable trucking traffic. An analysis to determine the potential for and consequences of a Boiling Liquid Expanding Vapor Explosion (BLEVE) associated with refrigerant storage vessels may be required to demonstrate that the proposed siting of the facility complies with the requirements of 49 CFR 193 and NFPA 59A. A BLEVE scenario can occur when a vessel is subject to sufficient heat to cause structural weakening of the walls. The liquid contents, which are stored under pressure, start to rapidly vaporize as the vessel temperature begins to rise. The liquid contents will boil off faster than the relief valves can release and the vessel wall will rupture. The resulting explosion will cause a pressure wave, potential pressure impulses and fire. If there is a potential for a BLEVE than thermal radiation and overpressure evaluations associated with catastrophic failure of the storage tanks should be performed to ensure required siting criteria are met.

Hazards associated with chemicals such as aqueous ammonia and glycol solutions are plant specific and not a discussed in this paper.

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2 For land-based projects located in the U.S.A, allowable limits are defined by 49 CFR Part 193 and NFPA 59A
3 Even though nitrogen expander cycles have developed significantly over the past few years, all major, world-class natural gas liquefaction facilities worldwide use a hydrocarbon-based refrigerant system.
4 A minimum 1 psi endpoint is generally required when performing consequence analysis, but due to rounding issues in some software an endpoint of ½ psi may be required.
Additionally, the hazard detection and mitigation systems for the facility will likely have to be extended to cover the liquefaction area and its components as required.

COMPONENTS REQUIRING MODIFICATION OR REPLACEMENT

In addition to installation of new components at the facility, several components of the existing LNG import terminal will likely require modification or replacement to enable safe production, storage and export of LNG at commercially acceptable rates. Major components that will likely require modification are as follows:

LNG In-Tank Pumps

Typically the in-tank LNG pumps in import terminals are designed to feed the high-pressure LNG pumps with low pressure LNG at sufficient flow to meet natural gas sendout requirements. However, in export facilities, the in-tank pumps are used to load the LNG onto LNG carriers. Accordingly, the in-tank pumps in export facilities need to deliver significantly higher flow rates than those in import terminals. Table 1 below shows general comparison between these two pump categories.

<table>
<thead>
<tr>
<th>Facility Type</th>
<th>In-Tank Pump Sendout Rate, (m³/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG Import Terminal, 1 to 2 Bscfd natural gas sendout</td>
<td>1,875 to 3,750</td>
</tr>
<tr>
<td>Natural Gas Liquefaction and LNG Export Facilities</td>
<td>10,000 to 12,000</td>
</tr>
</tbody>
</table>

The required head for the pumps in the export mode may also vary from that originally designed for the import terminal depending on the distance of LNG storage tank(s) from the jetty, length of the jetty, specific hydraulic arrangements, as well as the design of the existing high-pressure pumps.

Depending on the specification of the existing pumps at the import terminal, modifications to the pumps might be an option to expand their operating range to the point that they can deliver head and flow requirements to serve both import and export demands. Otherwise, replacing some or all of the in-tank pumps is the alternative option to achieve facility’s design export capability.

A potential limiting factor in converting an import terminal into an export facility is the number and design of in-tank pump columns. If the number (and size) of LNG pumps required to meet a desired LNG carrier loading rate cannot be installed in the existing tank columns, the facility’s export rate will be limited. The challenge becomes even greater when the existing terminal, due to factors such as contractual obligations, is required to maintain a minimum natural gas sendout capacity at all times or within a certain period of time following receipt of notice to revert operations. Since the number of in-tank pump columns is fixed for existing terminals, this can pose challenges on the design of the replacement in-tank pumps and may result in a potential limitation on LNG transfer rates to the LNG carrier.

LNG Unloading Arm System

To adapt to the new operation of regularly loading LNG carriers at high flow rates in order of 10,000 m³/hr, modifications may be required to the current design of the LNG “Unloading” Arm System. For example, the check valve which is typically located between the LNG transfer header and each LNG Arm may need to be replaced with a remotely operable butterfly valve in order to allow closing the valve in advance of ESD testing and re-opening to commence LNG transfer.
Vapor Handling System

Modifications to the vapor handling system at an existing import and regasification facility are one of the most important aspects of facility conversion. In import terminals, it is common practice to compress the generated Boiloff Gas (BOG) and direct it to the natural gas sendout pipeline. In liquefaction facilities on the other hand, the generated BOG is typically compressed and sent upstream of the liquefaction train or is used partially by the facility’s fuel gas system. Either way, vapor generation results in a decrease of process efficiency and decrease in the net exported LNG per input horsepower. Additionally, continuous introduction of BOG to the liquefaction system, with approximately 20 times higher nitrogen concentration than that of the LNG, may lead to a further drop in efficiency as well as process difficulties. Therefore, one of the most important efforts is to design and operate the liquefaction facility in a manner which reduces the BOG generation, in particular during LNG carrier loading operations. The two major factors determining the amount of BOG generation in a liquefaction and export facility are LNG conditions entering the LNG storage tanks and operating pressure of the tanks.

The liquefaction facility should be designed so that the LNG enters the LNG storage tanks at slightly subcooled conditions. This will avoid the thermodynamic flash of the produced LNG and limit the vapor generation to displaced vapor plus the BOG resulting from heat leaks through the tank.

To minimize BOG generation during LNG carrier loading periods, the operating pressure of LNG storage tanks should be maintained as low as possible to ensure the LNG in the tanks is at a lower saturation temperature than the LNG in the LNG carrier’s tanks. In other words, ideally, the saturated LNG in the storage tanks should be “cold” enough, that even after absorbing the LNG pumping heat and the heat leak through the transfer system, the LNG arrives at the ship flange at a lower temperature than that of LNG saturation temperature at the carrier’s tank pressure. This will avoid thermodynamic flash of the loaded LNG and limit the vapor return from the LNG carrier to displaced vapor and generated BOG resulting from heat leak through the LNG carrier’s tanks.

Since the vapor return lines are already constructed in an existing terminal, hydraulic calculations are required to determine if the discharge pressure of the ship blowers is sufficient to transport the BOG from the LNG carrier to the LNG storage tanks. Factors such as the vapor volume, vapor line dimension and routing, as well as the back pressure form the storage tank will determine if there is need for the addition of vapor blowers or compressors to ensure sufficient vapor return during design loading operations.

Modifications to parameters such as BOG compressor set points may be required to allow the LNG storage tank to operate at lower pressures, on the order of 0.5 psig versus the customary order of 2.5 psig (for full containment tanks) at import terminals.

LNG Storage Tank Vacuum Breakers

During periods of LNG carrier loading operations, significant volumes of LNG are withdrawn from the LNG storage tank, considerably larger than the volumes withdrawn in an import facility (see Table 1). This withdrawal rate directly impacts the design of tank vacuum breakers which are installed to protect the storage tanks against operating at pressures below allowable limits. Therefore the design of tank vacuum breakers should be analyzed to verify that their existing design is appropriate for the associated changes in operation of the LNG storage tank.

Flare System

The flare systems in import terminals are designed to safely dispose of vapors during process upsets or periods operating at significantly lower capacities than design. Any vapor generated during such scenarios, in excess of recondenser and pipeline compressor capacities will be flared. While import terminals are typically designed with one flare, it is customary for natural gas liquefaction and export facilities to segregate the flare into “warm” or “wet” and “cold” or “dry” flares. The “dry” flare is dedicated to relief systems containing light hydrocarbons. The “wet” flare is dedicated to relief systems containing heavier hydrocarbon
components, which could potentially cause hydrate formation and freezing if exposed to lower temperatures of the “dry” flare system components. In some export facilities, a third flare, commonly called “low pressure” or “dock” flare is included to dispose of any boiloff or other low pressure gases, not manageable by the facility due to unacceptable composition, warm temperatures or high flow rates, from gassing-in or cooling the LNG carriers.

While factors such as wind intensity and noise limitations can affect stack dimensions, the minimum height of the flare stack is dominantly defined by thermal radiation limits. In order to protect the operators and emergency crews during flaring periods, the maximum thermal radiation at grade should not exceed 1,500 BTU/hr-ft².

Traditionally, mostly driven by economics, elevated flares are installed in LNG export facilities, which are commonly designed to handle the release from blockage at the outlet of the largest capacity refrigerant compressor. However, in order to comply with the maximum allowable thermal flux requirement at grade, such a flare for a 4.5 million metric tonnes per annum (mtpa) train would have to be over 400 ft tall. The significant cost of such a flare structure along with its potential social and environmental impacts has driven owners and engineers to craft alternative solutions. The first objective, therefore, is to minimize the flare design load in order to reduce the thermal flux and allow use of shorter flare structures. The following design options can aid in achieving this target:

- Use of High-Integrity Pressure Protection System (HIPPS): In traditional systems, over-pressure is dealt with through relief systems. A relief system will open an alternative outlet for the fluids in the system once a set pressure is exceeded, to avoid further build-up of pressure in the protected system. This alternative outlet generally leads to a flare or venting system to safely dispose the excess fluids. HIPPS on the other hand is a type of Safety Instrumented System (SIS) designed to prevent over-pressurization of a plant. The HIPPS will shut off the source of the high pressure before the design pressure of the system is exceeded (Figure 1), thus preventing loss of containment through rupture of a line or vessel. Therefore, a HIPPS is considered as a barrier between a high-pressure and a low-pressure section of an installation. While a relief system aims at removing any excess inflow of fluids for safe disposal, a HIPPS aims at stopping the inflow of excess fluids and containing them in the system. Due to their simplicity, relatively low cost and wide availability, conventional relief systems are still often applied, however at times, minimizing the release flows is the only viable option for the project. HIPPS is widely used in chemical plants and oil refineries. In LNG facilities, the use of HIPPS systems has generally been restricted to protecting the natural gas sendout pipeline.

- Passive Fire Protection of Equipment: Following the refrigerant block-out scenario, the largest flare loads are from overpressure of large hydrocarbon vessels in the event of fire. Passive mitigation measures such as using adequate and appropriate insulation material on such equipment reduces
the heat absorption during a fire event and thus reducing the resulting flare load. Other solutions such as mounding of propane storage tanks are frequently used to minimize their impact on flare loads.

While minimizing flare loads is desirable, it is not always an option due to factors such as regulatory requirements and investor-specific demands. An alternative solution to the traditional elevated flare is installation of a ground flare with heat flux barrier walls installed to minimize thermal efflux during operation. Such a setup offers other benefits, including reducing the impact of flaring in terms of noise and flame visibility, in particular in congested populous areas. The main disadvantages of ground flares are large real estate requirements and higher capital cost. The size of a ground flare for a 4.5 mtpa liquefaction facility is on the order of 100,000 ft². Figure 2 shows the Darwin LNG ground flare system.

![Figure 2: Darwin LNG Ground Flare System](image)

**SYSTEMS AND COMPONENTS NOT USED DURING LIQUEFACTION PERIOD**

Certain systems and components will not be in service when the facility is operating in liquefaction mode. Such systems include:

- LNG regasification systems, including high-pressure booster LNG pumps, natural gas superheaters and if applicable, the heating fluid systems
- BOG condenser and LNG surge drum
- Any utility and auxiliary system that will not contribute capacity during liquefaction mode.

Typically the recondenser as well as LNG vaporizers and superheaters will be isolated and maintained under pressure. However, equipment specific requirements for maintenance while out of service for extended periods of time should be evaluated and appropriate procedures implemented.

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5 Image courtesy of Zeeco
OTHER CONSIDERATIONS

As a result of adding liquefaction train(s) to an existing import terminal, other elements such as the facility's electrical distribution systems will be impacted as well. The impact is even more significant if the liquefaction trains are designed to be electric-driven. The power requirement for a 4.5 mtpa liquefaction facility is on the order of 150 to 200 MW, requiring significant considerations in the design and integration of the new electrical distribution systems.

Process control systems will require significant modification during the integration of liquefaction facilities within an existing import and regasification terminal. Some owners have opted for adding and dedicating a second control system to the liquefaction trains. However, due to the shared major equipment such as LNG storage tanks and the in-tank LNG pumps, appropriate and sufficient communication should be ensured.

SUMMARY AND CONCLUSIONS

Any modification made to an existing facility carries certain advantages, disadvantages and challenges. The larger the magnitude of modification, the greater the amount of planning and design consideration required to drive the project to success. Adding liquefaction train(s) to an existing LNG import and regasification terminal and ensuring the plant's capability in exporting the LNG product at commercially acceptable rates is no exception. While taking advantage of the existing major components such as the LNG storage tanks and marine facilities, several modifications and other considerations need to be made to existing equipment and systems, and several major equipment and units are added to the terminal. Long-term maintenance plans should be put in place and implemented for equipment that will not be in service during the liquefaction period and revised operating parameters should be defined for the overall facility. Exceptional design considerations and developing innovative solutions are essential to the success of such projects, to provide safe and efficient engineering as well as to comply with all regulatory requirements.

It is worth mentioning that subsequent to weighing all pros, cons and challenges of converting an LNG import and regasification terminal to a bi-directional import/export facility by adding liquefaction train(s) and integrating it with the existing terminal, several owners and investors have found the effort economically feasible and are currently proceeding with developing such facilities. Presently Freeport LNG, Sempra, Dominion, Trunkline LNG and Cheniere are in different stages of design and construction of their existing LNG import and regasification facilities to include liquefaction to allow them to export LNG to worldwide markets.