Hybrid LNG & Ammonia Infrastructure: Key to a Green Economy

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Intro duction

As the world continues to shift towards decarbonization in chemical production, and strong market demand drives the transition to carbon-free energies, ammonia's role in the green energy economy continues to expand. Best known for its traditional role in fertilizer production, ammonia is gaining attention in other applications.

A gas at room temperature, ammonia is incredibly stable and can be easily liquified for storage and shipment around the globe in the same fashion as liquefied natural gas (LNG). It can be used across energy-intensive industries in several ways, helping to lower our carbon footprint.

- Made up of one nitrogen and three hydrogen atoms, ammonia can also be decomposed or "cracked" to produce hydrogen along with nitrogen, a non-toxic, non-greenhouse gas.
- Ammonia produced from renewable energy ("green ammonia") can serve as an energy storage medium, able to store electricity during high periods of production and transport that energy to parts of the globe with limited access to renewable energy sources.
- Ammonia can be burned directly as a carbon emissions-free energy source, thanks to the development of new technologies that produce ammonia from renewable energy or reforming of methane with CO2 capture.

Ammonia can also offer new possibilities when it comes to facilitating the use of hydrogen, which is emerging as a low-carbon breakthrough that promises to transform the power generation market.

Ammonia-ready storage and transportation infrastructure will be a catalyst for making ammonia a key player in the zero-carbon energy landscape.

An industry leader, Black & Veatch has more than 80 years of experience in the commercial ammonia and LNG infrastructure market, backed by a proven record of executing large-scale infrastructure projects safely, on time and on budget, and to the highest quality standards with minimal disruptions to operations.

Black & Veatch helps clients at every stage of the process de-risk investments and scale solutions that meet budget constraints, expectations for return on investments and navigate complex regulations.

Ammonia a Key Player in the Hydrogen Revolution

Backed by new advances in technology, hydrogen is expected to rise in prominence over the next decade.

However, fully integrating hydrogen into the energy mix will be a complicated endeavor, as the low volumetric energy density of hydrogen – and its extremely low boiling point – have made it challenging, both technically and economically, to develop infrastructure for the large-scale storage and transportation of hydrogen.

But ammonia offers several desirable characteristics as a hydrogen carrier:

First, ammonia can be liquefied under mild conditions. The boiling point of ammonia at atmospheric pressure is -33°C (-28°F), similar to propane. Ammonia has been produced for industrial and agricultural purposes, and proven methods of storing and transporting liquefied ammonia at scale are available.

Second, ammonia is more energy dense than hydrogen. The volumetric hydrogen density of liquid ammonia is about 45-percent higher than that of liquid hydrogen, which means that more hydrogen can be stored in liquid ammonia compared to liquid hydrogen with the same volume.

The supply chain for ammonia is currently underway, and now is the time to consider using the world's extensive LNG infrastructure – its existing LNG receiving terminals and storage facilities – to facilitate the safe, efficient transport of ammonia.

LNG Infrastructure Offers Opportunity

LNG has been used as an energy source for more than 50 years, due to its reputation as the cleanest fossil fuel as well as its ability to balance out the power generation mix. This has led to widespread investment in LNG storage and transportation infrastructure.

According to the *2020 International Gas Union (IGU) World LNG Report*, the global supply chain for LNG has matured with LNG receiving terminals (global nominal regasification capacity of 826 metric tons per annum [MTPA]), LNG liquefaction terminals (global liquefaction capacity of 430 MTPA), and LNG tankers (global fleet of 541 active vessels). As of February 2020, the worldwide storage tank capacity for LNG has grown to 65 million cubic meters (m^3), with nearly two-thirds of that capacity housed in Japan, Korea and China.

With this extensive global infrastructure in place, LNG receiving terminals and storage facilities can be modified to facilitate the safe, efficient transport of ammonia in the global energy trade. As such, LNG and gas power plant owners and developers would be well-served to begin preparing now for their LNG receiving terminals to become ammonia-ready, and to receive liquefied ammonia when needed as renewable energy production continues to increase.

This free download, Hybrid LNG & Ammonia Infrastructure Support a Green Economy, addresses how to convert LNG import terminals and storage tanks to handle ammonia, as well as how to design these facilities to be ammonia-ready.

Thank you,

Hoe Wai Cheong

President, Black & Veatch's Oil & Gas business

Converting LNG Import Terminals to Ammonia Import Terminals

By Mehran Ghasemi

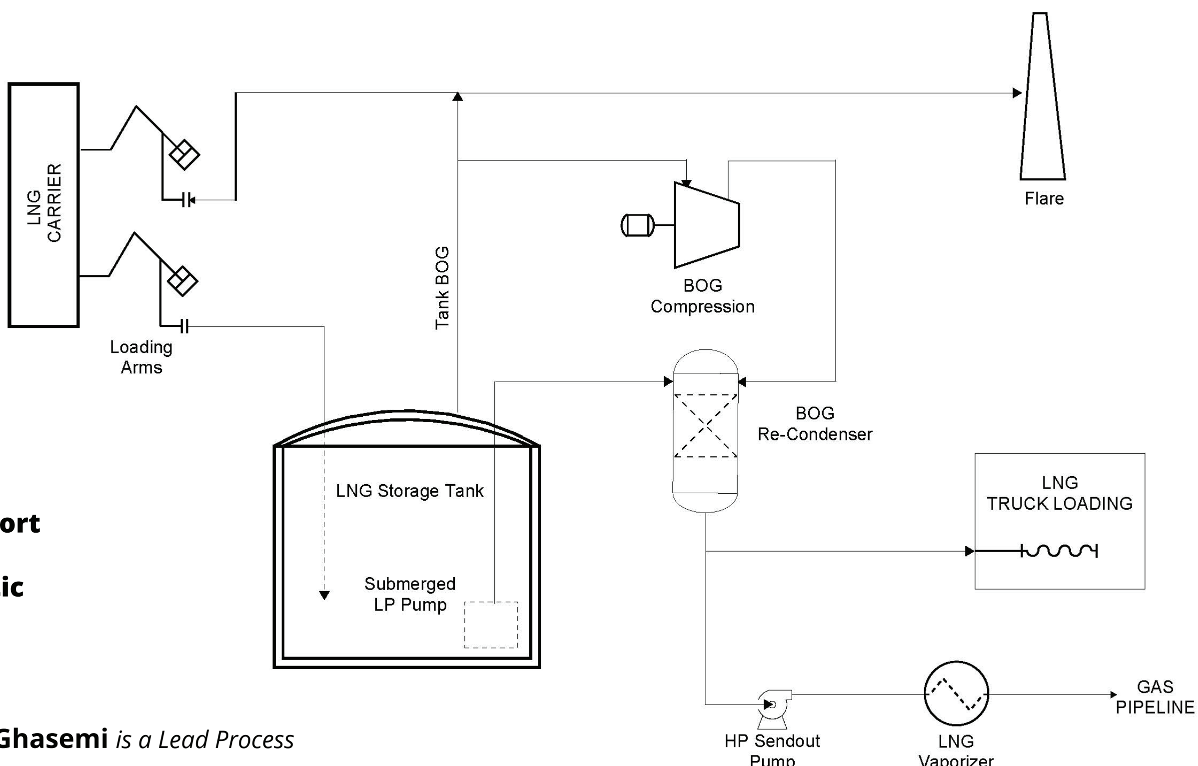


Fig. 1
LNG Import Facility Schematic

Mehran Ghasemi *is a Lead Process Engineer with Black & Veatch's Oil & Gas business. Ghasemi has more than 24 years of EPC experience in process design, simulation and operation support of upstream and midstream facilities. He is highly skilled in petrochemical and gas-to-liquid processes and technologies, gas processing facilities, onshore and offshore oil and gas production facilities, transportation pipeline design and utility systems design.*

This section discusses the design considerations for converting an LNG import facility to an ammonia storage and send-out facility with minimum required modification.

Design Parameters

Several LNG and ammonia governing design parameters need to be considered when identifying the impacted system that needs to be modified (Table 1).

Table 1. Properties of LNG and Anhydrous Ammonia

Property	LNG	Anhydrous Ammonia	Ammonia versus LNG
Boiling point at 1 atm (°F)	-259	-28	Higher cooling media temperature
Density (lb/ft^3)	26.4	42.1	Less liquid storage volume caused by heavier liquid, higher pressure drop, higher load on pipe support, structure and foundations
Heat of vaporization (Btu/lb)	220	598	Lower vaporization (boil-off gas) rate
Heating value (Btu/lb)	23,709	9,551	Lower flare radiation
°F – degrees Fahrenheit atm - atmospheric pressure lb/ft^3 – pounds per cubic foot Btu/lb – British thermal units per pound			

Design Impact

The required modification depends on the current design as the configuration of the LNG import facility could impact the systems. The individual impacted system configurations are discussed to determine the key items that need to be considered in the required modification design and overall cost impact.

The LNG import facility includes the following main systems:

- Storage tank
- Boil-off gas (BOG) system
- Liquid pumps and piping system
- LNG vaporizer/ammonia heater
- Flare System
- Instrument and control system

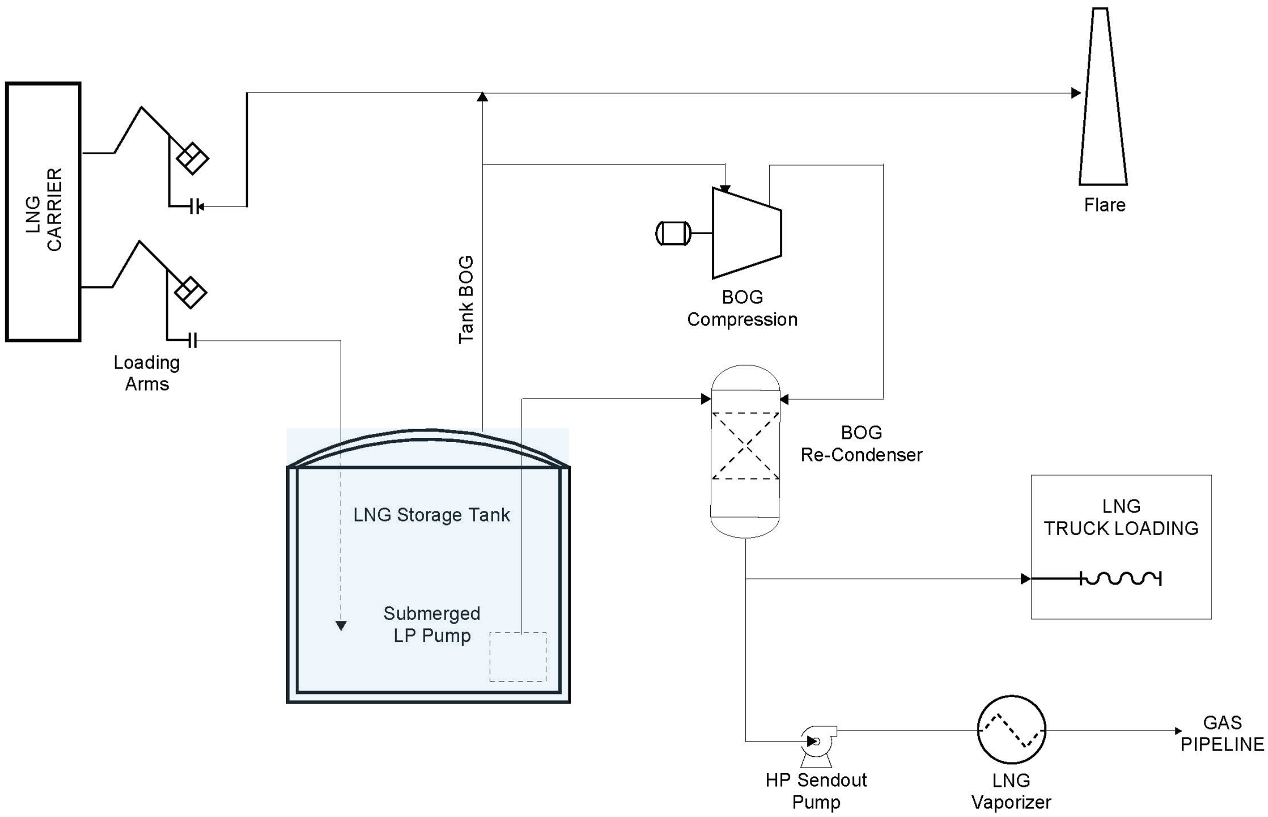


Fig. 1a
LNG Import Facility Schematic

Storage Tank

The LNG storage tank cannot be used at full capacity for ammonia due to ammonia higher density – these details are covered in *Converting LNG Storage Tanks to Ammonia Storage Tanks*.

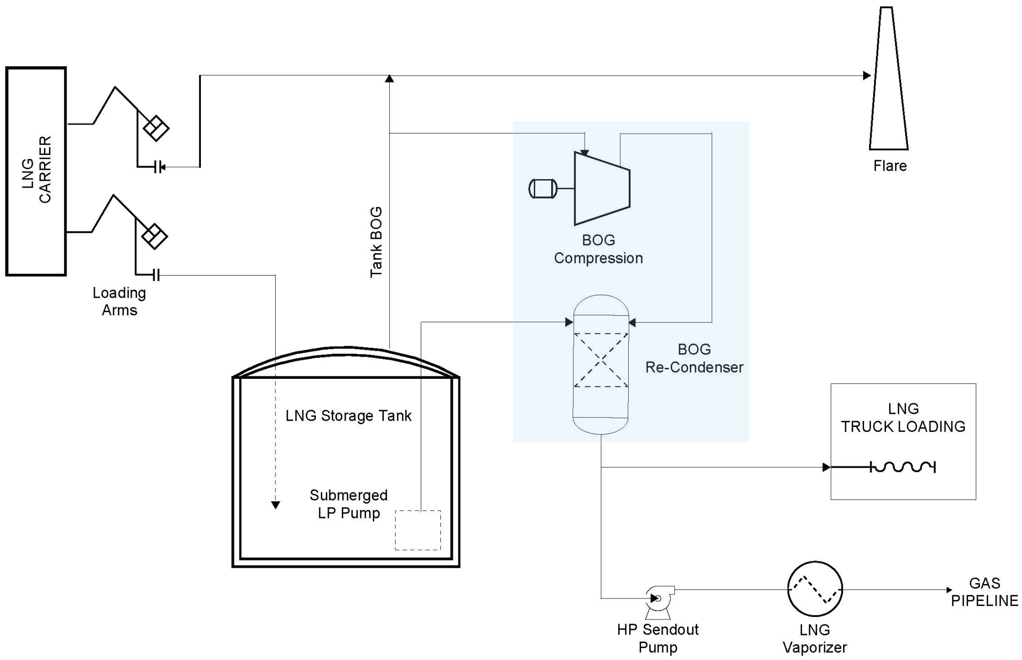


Fig. 1b LNG Import Facility Schematic

Boil-off Gas System

LNG import facilities are equipped with BOG compressor packages and a BOG recondenser. The BOG compressor configuration plays the main role in identifying the required modification to operate the facility with ammonia.

The BOG compressor typically operates at near LNG temperature at the suction. The higher ammonia boil-off temperature may inhibit compressor or downstream equipment re-use due to high discharge temperature. However, the compressors can potentially be re-used for ammonia service with upgrading such as seal gas system, if applicable, but needs to be evaluated in detail case by case.

In this paper, the cost impact is estimated based on replacing the BOG compressors.

It is estimated that the required BOG capacity for ammonia is about 60-percent of LNG in the design case. The following two possibilities are expected:

1 The current design includes one x 100-percent BOG compressors in operation; to avoid operation of compressors in non-efficient condition the compressors need to be replaced by the proper capacity.

2 The current design includes a greater number of compressors with lower capacity for operation flexibility in different operating mode and BOG rates (e.g., two x 50-percent or three x 33-percent for holding, loading modes).

Depending on the current LNG design configuration, the existing compressors can be used with different sparing philosophy. For example, the current three x 33-percent philosophy will be three x 50-percent in ammonia service. Two compressors will be operation and one as standby.

In case of a current LNG two x 50-percent design philosophy for ammonia service, BOG compressors sparing philosophy will be two x 60-percent for which both BOG compressors will be operating at 60-percent capacity in governing design case and the same for one compressor operating in low BOG rate case.

Depending on the actual BOG compressor specification and BOG rates at different cases, further study should be performed to identify the optimum facility configuration.

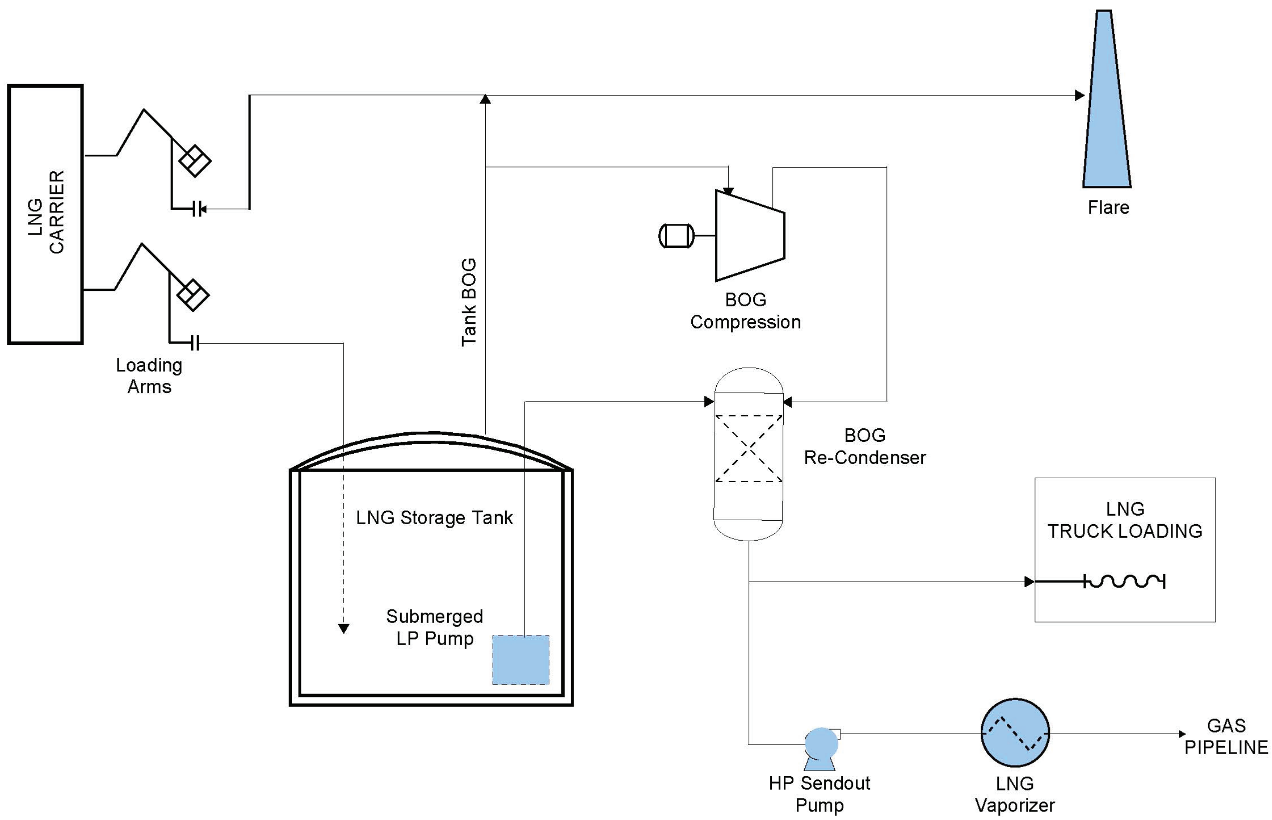


Fig. 1c LNG Import Facility Schematic

Liquid Pumps and Piping System

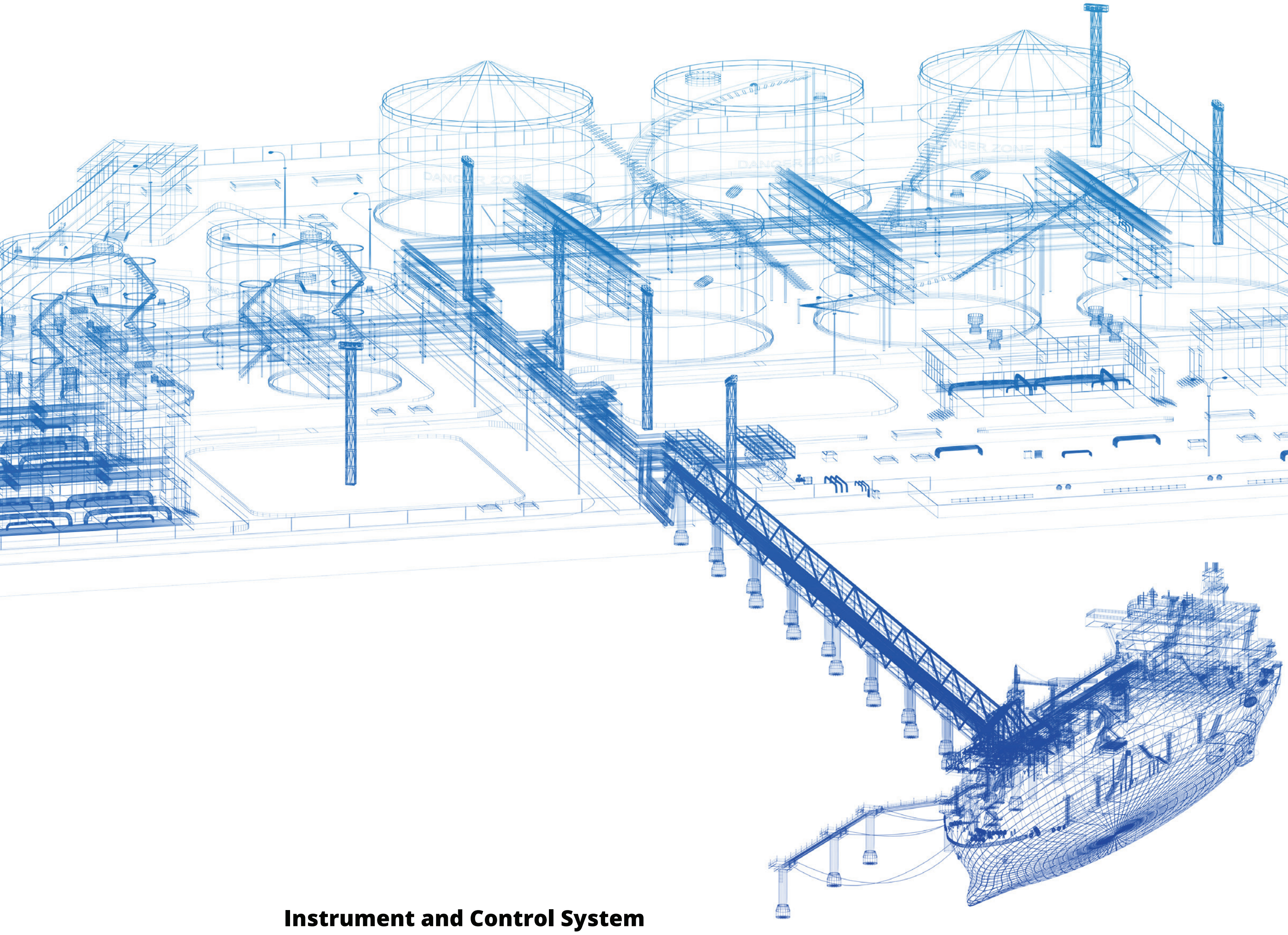
The LNG pumps cannot be used for ammonia service because of lower design temperature and sealing clearance. The pumps (submerged low-pressure [LP] and send-out high-pressure [HP]) need to be replaced for ammonia service. The associated piping and support modifications may be required because the ammonia density is much higher than the LNG, and the piping support needs to be enforced accordingly.

LNG Vaporizer/Ammonia Heater

Ammonia loading temperature might be higher than the storage temperature due to truck/pipeline material of construction design temperature limitation. The existing LNG vaporizer needs to be evaluated to verify the application of the LNG vaporizer as the ammonia heater.

Flare System

The LNG flare system is designed for higher relief load and greater heating value. The required flare system for ammonia with lower heating value and relief load requires detailed evaluation to identify the application of the existing flare system and any required modification.



Instrument and Control System

The LNG import facility control system consists of the following major items:

Control Valves – The actual pressure drop through the control valve will be increased due to higher density.

Pressure Safety Valves (PSVs) – The PSVs need to be evaluated in detail and to identify which PSVs need to be replaced.

Fire and Gas Detection System – The sensors of the fire and gas system layout and specification are designed for hydrocarbon, which is not applicable for ammonia service. A leak detection and dispersion study for ammonia toxicity should be performed to ensure a safe design.

Measuring Devices (e.g., flow, pressure, temperature, level) – The measuring devices need to be evaluated to identify the impacted devices that need to be replaced. The flow measurement and temperature devices are the most expected impacted devices.

Metering Package – It is expected that by updating metering package calibration, the package can be used for ammonia service.

Control Panels – The control panels need to be revisited to verify the ammonia system requirements.

Figures 1 and 2 show the import facility schematics for LNG and ammonia, respectively. The equipment that needs to be replaced or new equipment is shaded in Figure 2.

Fig. 1
LNG Import Facility Schematic

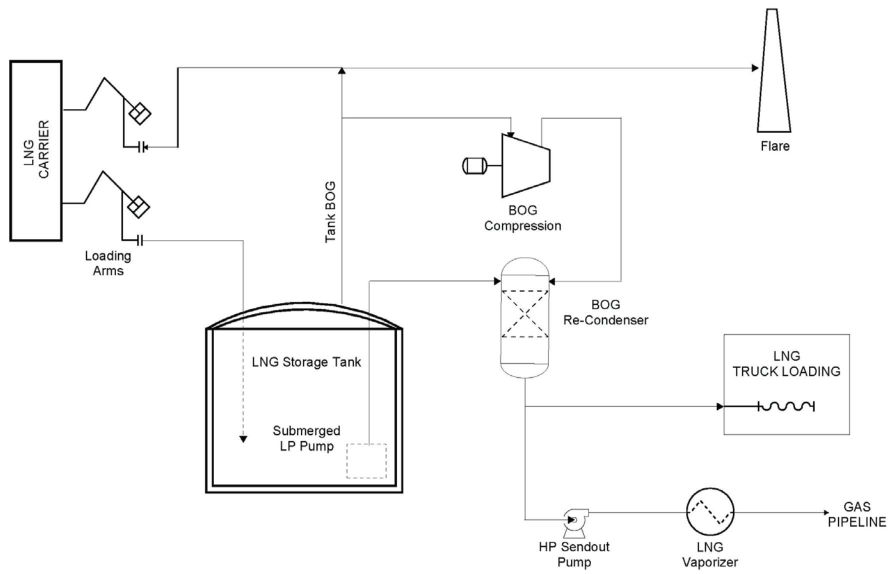
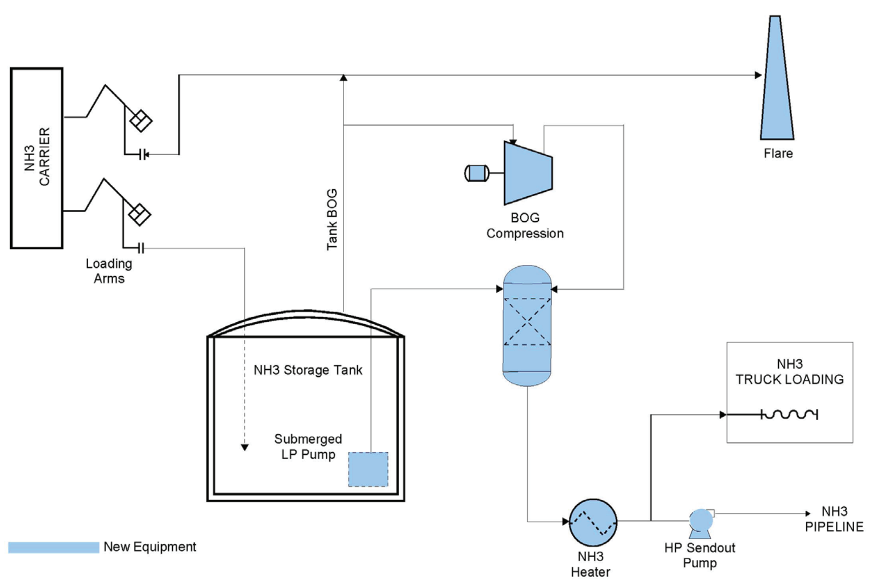


Fig. 2
Ammonia Import Facility Schematic



Modification CAPEX

The costs to modify an LNG import facility to satisfy ammonia requirements includes engineering, equipment, material and construction to dismantle and remove items and install new material and equipment.

Table 2 shows the installed equipment and material cost impact, including required engineering and items removal. The modification cost impact is estimated using the LNG import facility capital expenditure (CAPEX).

*Table 2. CAPEX Breakdown**

Impacted Systems	LNG Import CAPEX (%)	Modification Cost Impact (%) (1)	Total CAPEX Impact (%)	Remark
Storage tank	45 to 50	3	1.0 to 1.5	Full containment, 63-percent capacity
BOG system	10 to 15	5 to 8	5.0 to 8.0	Based on two x 50-percent compressors as current design. A new compressor package is required. The total CAPEX impact is the new compressor CAPEX.
LP/HP pump	3 to 5	1 to 3	1.0 to 3.0	As the pumps need to be replaced, the total CAPEX impact is the new pumps CAPEX.
Piping	5 to 10	40	2.0 to 4.0	Including pipe support and flare stack piping arrangement
Instrument and control system	3 to 5	70	2.0 to 3.5	Including control valves, fire & gas sensor, inline devices, etc.
Total			11.0 to 20.0	

** Based on LNG Facility CAPEX.*

Looking Ahead

The LNG import and storage facility can be converted to ammonia services with some modification on the storage tank but with lower working capacity. The BOG system needs to be evaluated in detail to identify the proper compressor configuration to avoid inefficient BOG compressor operation. The piping system and supports need to be enforced for ammonia service. The instrumentation and measuring devices need to be evaluated in detail to ensure their functionality with ammonia and identify the components which need to be replaced.

Converting LNG Storage Tanks to Ammonia Storage Tanks

By Hidemichi Iizuka

Hidemichi Iizuka *is an Engineering Manager with Black & Veatch's Oil & Gas business. He has more than 25 years of experience in large-scale cryogenic storage tank design for multiple international engineering, procurement and consulting (EPC) projects. Knowledgeable in international design codes, Iizuka specializes in the design of various types of storage tanks and field erected tanks. He is a member of the American Petroleum Institute (API) Refrigerated Tanks Task Group and Membrane Tanks Working Group.*

This section discusses the optimum conversion of existing LNG storage tanks to ammonia storage tanks.

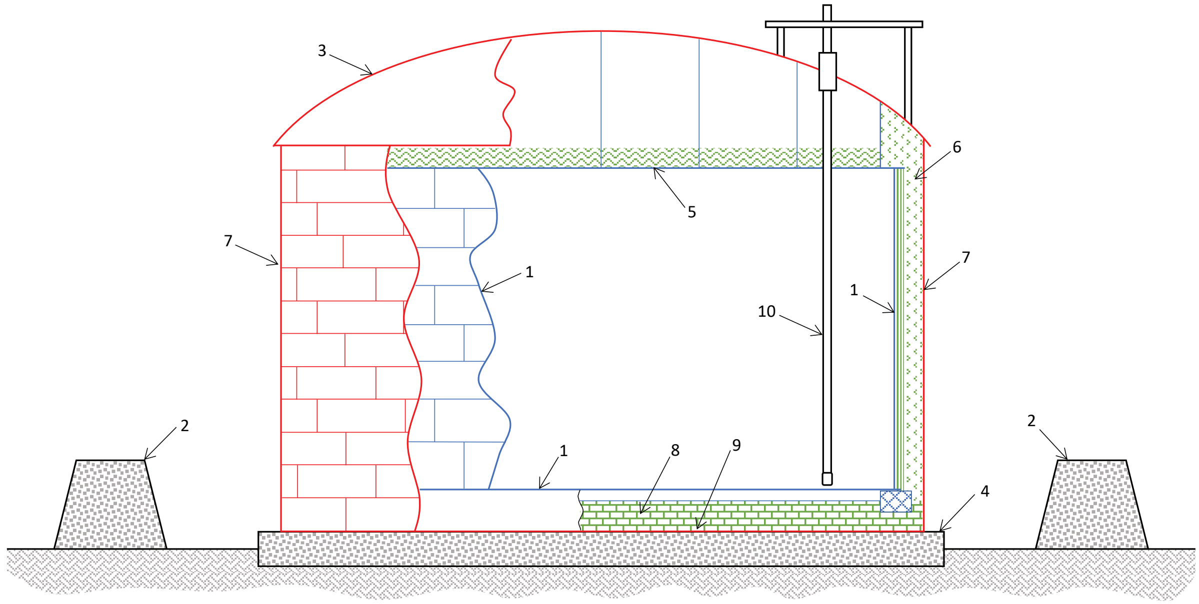
Design Parameters

The chemical properties of both LNG and anhydrous ammonia need to be considered when preparing to convert an LNG storage tank to an ammonia storage tank (Table 3).

Table 3. Properties of LNG and Anhydrous Ammonia

Property	LNG	Anhydrous Ammonia
Boiling point at 1 atm (°F)	-259	-28
Liquid density at 1 atm boiling point (kg/m^3)	423.54	673.59
Heat of vaporization at 1 atm boiling point (kJ/kg)	509.16	1376.8
°F – degrees Fahrenheit atm - atmospheric pressure kg/m^3 - kilograms per cubic meter kJ/kg – kilojoules per kilogram		

It is also critical to adhere to storage tank design codes including *LNG: National Fire Protection Association (NFPA) 59A, American Petroleum Institute (API) 625, API 620 Annex Q and Ammonia: American National Standards Institute (ANSI)/CGA G-2.1, API 625, API 620 Annex R.*



1. Primary liquid container (low temp steel)
2. Secondary liquid container (dike)
3. Warm vapor container (roof)
4. Concrete foundation
5. Suspended deck with insulation
6. Insulation (annular space)
7. Warm vapor container (outer shell)
8. Bottom insulation
9. Warm vapor container (outer bottom)
10. Pump column

Fig. 3 Single Containment Tank System (Double Wall)

Typical LNG Tank Configurations

Typical LNG tank types are double-wall, single-containment tank systems or full-containment tank systems. Membrane-containment tanks are currently used in Asia, notably Japan, Korea and Taiwan. Membrane-containment tank systems are typically built in-ground with the main body of the tank (except the roof) buried under ground level. The membrane-containment tank system is not considered in this paper because its design considerations are quite different from single- or full-containment tank systems. Figure 3 *(API 625: 2018)* shows the configuration of the double-wall, single-containment tank system.

The main materials for double-wall, single-containment LNG tanks are listed in Table 4.

Table 4. Main Material for Double Wall Single Containment LNG Tanks

Parts	Material
Primary liquid container	9-percent nickel (Ni) steel
Secondary liquid container	Dike
Suspended deck	Aluminum
Vapor container	Carbon steel
Bottom insulation	Cellular glass blocks
Side insulation	Resilient blanket and perlite powder
Suspended deck insulation	Fiberglass blanket
Pump well and internal piping	Stainless steel

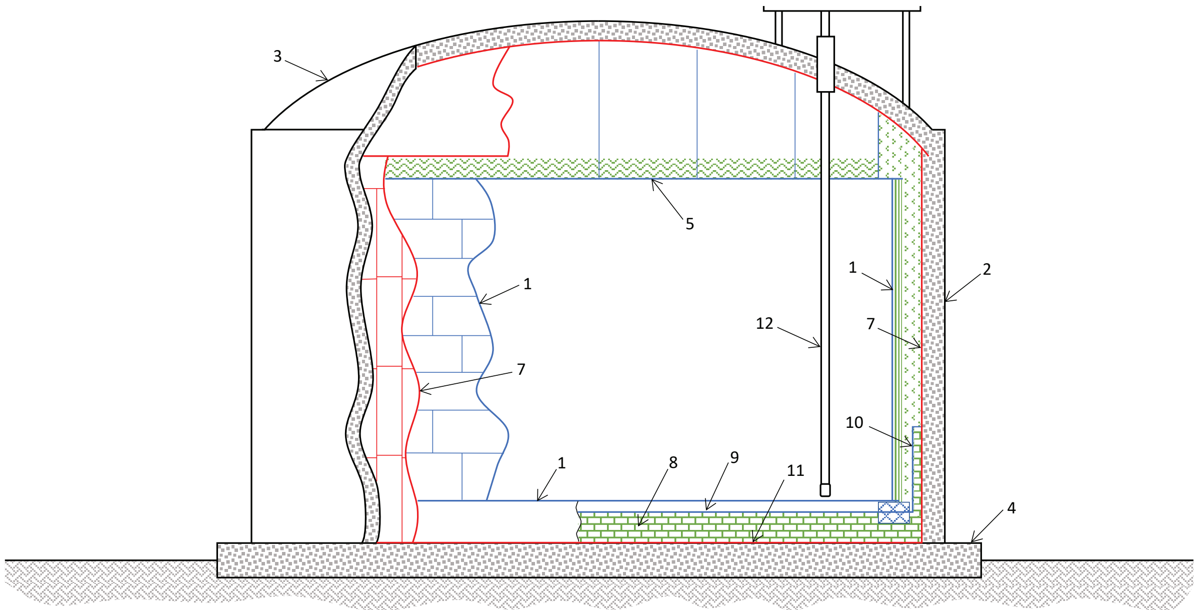


Fig. 4 Full Containment Tank System

Figure 4 *(API 625: 2018)* shows the configuration of the full-containment tank system.

The main materials for the full-containment LNG tanks are shown in Table 5.

Table 5. Main material for full containment tank system

Parts	Material
Primary liquid container	9-percent nickel (Ni) steel
Secondary liquid container	Prestressed concrete (wall) Reinforced concrete (bottom)
Thermal corner protection	9-percent nickel (Ni) steel
Suspended deck	Aluminum
Vapor container	Carbon steel
Bottom insulation	Cellular glass blocks
Side insulation	Resilient blanket and perlite powder
Suspended deck insulation	Fiberglass blanket
Pump well and internal piping	Stainless steel

Materials

The materials used for full-containment and single-containment LNG tanks are generally compatible with refrigerated ammonia tanks. However, under certain conditions, liquefied ammonia is known to cause stress corrosion cracking (SCC) in steel. Extensive research and investigations have been done on ammonia SCC, leading to preventative measures being adopted on low-temperature carbon steel used for refrigerated ammonia tanks. But to date, very little research has been done on ammonia SCC with 9-percent Ni steel – with this in mind, further research and investigation will be required to ensure that the structural integrity of the tank is maintained throughout the design life.

Structural Design of Tank

In the structural design of LNG tanks, design liquid level and liquid density are the necessary parameters used to calculate the static and dynamic liquid pressures acting on the wall and foundation. The structural integrity of the tank must be revalidated using the increased hydrostatic load.

Based on the ratio of LNG density versus liquid ammonia density, maximum liquid level allowed for ammonia storage is expected to be approximately two-thirds of the original design, hence the nominal tank capacity when used for ammonia will be approximately two-thirds of the original design.

Insulation System

Insulation system for a typical LNG tank between 100,000m^3 and 200,000m^3 capacity is designed to meet the BOG rate of less than 0.05 percent per day. Due to ammonia's higher boiling point and heat of vaporization, the BOG rate while storing ammonia will be significantly less than the rate while storing LNG.

Tank Accessories and Appurtenances

Tank accessories and appurtenances must be compatible for both LNG and ammonia and should be replaced when the stored liquid is changed.

- **In-Tank Pumps** – In-tank pumps will be required to be replaced when the stored fluid is changed from LNG to ammonia, or ammonia to LNG.
- **Tank Instrumentation** – Level gauges and density gauge require replacement or modification. Alarm settings for leak detection temperature gauges, etc., requires adjustment.
- **Pressure Relief Valve (PRV)** – PRVs equipped for LNG use are required to be replaced with PRVs sized for ammonia.

Decommissioning and Re-Commissioning

The LNG tank will need to be decommissioned before it is converted to an ammonia tank. The decommissioning process involves tank emptying, isolation, warmup and tank inerting (nitrogen purging), although detailed procedures should be established on a case-by-case basis.

Research on dismantled LNG tanks show no evidence of unsatisfactory structural or operational performance after 20+ years of operation. Depending on years of operation and the operational history of the tank, it should be evaluated whether tank entry and internal inspection or repair work would be required.

The procedure to re-commission the tank is similar to the initial commissioning of the tank. The re-commissioning process involves the testing of tank accessories, tank cooldown and initial filling.

Looking Ahead

Further study is required on the effect of SCC behavior of 9-percent Ni steel in ammonia. Once its effect and prevention methods are confirmed, double-wall, single-containment LNG tanks and full-containment LNG tanks can be converted to ammonia tanks as described above.

Designing Ammonia-Ready LNG Import Terminals

By Mehran Ghasemi

Mehran Ghasemi *is a Lead Process Engineer with Black & Veatch's Oil & Gas business. Ghasemi has more than 24 years of EPC experience in process design, simulation and operation support of upstream and midstream facilities. He is highly skilled in petrochemical and gas-to-liquid processes and technologies, gas processing facilities, onshore and offshore oil and gas production facilities, transportation pipeline design and utility systems design.*

This section discusses how the LNG import facility can be designed to be ammonia-ready with minimum required modification.

Design Parameters

Table 6 compares LNG and ammonia governing design parameters and their impact on the facility design.

Table 6. Properties of LNG and Anhydrous Ammonia

Property	LNG	Anhydrous Ammonia	Ammonia versus LNG
Boiling point at 1 atm (°F)	-259	-28	Higher cooling media temperature
Density (lb/ft^3)	26.4	42.1	Higher design load in piping and storage tank system[1] Control valves and measuring devices
Heat of vaporization (Btu/lb)	220	598	Lower vaporization rate (smaller boil-off gas [BOG] system)
Heating value (Btu/lb)	23,709	9,551	Lower radiation (shorter flare stack) Lower energy sStorage [2]
°F – degrees Fahrenheit atm - atmospheric pressure lb/ft^3 – pounds per cubic foot Btu/lb – British thermal unit per pound			

Note 1: The storage tank design details are covered in, *Converting LNG Storage Tanks to Ammonia Storage Tanks*

Note 2: The Energy storage with the same mass capacity with ammonia will be less than 50-percent of LNG energy storage. Energy storage with the same volume capacity with ammonia will be 65-percent of LNG energy storage.

Design Impact

The following items need to be addressed in the initial design of an LNG import facility in order to import and store ammonia in the future.

Storage Tank

The LNG storage tank requires additional design consideration to be used for ammonia which is discussed in [Designing Ammonia-Ready LNG Storage Tanks].

Boil-off Gas (BOG) System

The LNG regasification facility requires much higher BOG system capacity due to greater vaporization rate. The alternative design provides BOG system and refrigeration in greater number of trains with lower capacity for each which increase the flexibility of the facility in operation also operates the compressors on the best operating points. Greater BOG rate for LNG requires the LNG/ammonia design flare stack to operate at lower BOG rate as needed for ammonia import and storage facility.

Liquid Pumps

The liquid LNG transfer pumps (submerged pump and HP pumps) need to be replaced for ammonia service.

The LNG pumps are designed for very low temperature which are not suitable for ammonia. The proper piping and layout requirements for ammonia pump need to be considered for required future modification.

Piping Supports

Piping supports need to be designed based on ammonia due to higher density.

Instrument and Safety Devices

Instrument and safety devices need to be designed for the governing case for LNG and Ammonia services.

Pre-Investment Planning

The LNG import facility design consideration for ammonia application requires pre-investment to minimize the cost impact on the future to convert the facility to an ammonia import facility.

Table 7 shows an overall capital expenditure (CAPEX) and pre-investment breakdown.

Table 7. CAPEX and Pre-Investment Breakdown

Impacted Systems	LNG Import CAPEX (%)	Pre-Investment Cost Impact (%)	Total CAPEX Impact (%)	Remark
Storage tank	45 to 50	5	2.0 to 2.5	Full containment
BOG system	10 to 15	30 to 40	3.0 to 6.0	Based on three x 33-percent compressors instead of two x 50-percent
HP/Low-pressure pump	3 to 5	0	0	The pumps need to be replaced (no pre-investment)
Piping	5 to 10	10	0.5 to 1.0	Including pipe support and flare stack piping arrangement
Instrument and control system	2 to 4	50	1.0 to 2.0	Including control valves, fire & gas sensor, in-line devices, etc.
Total			6.5 to 11.5	

The pre-investment cost impact will vary based on the capacity of the facility.

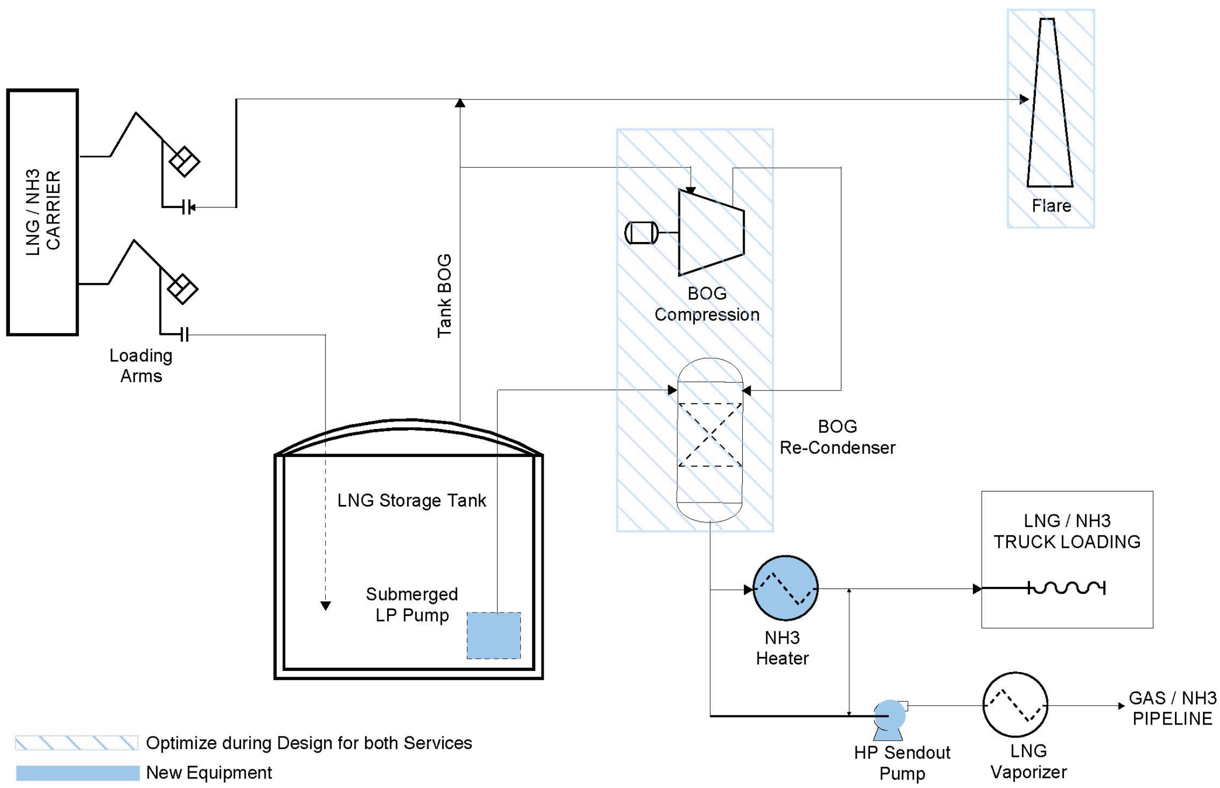


Fig. 5
Ammonia Ready LNG Import Facility Schematic

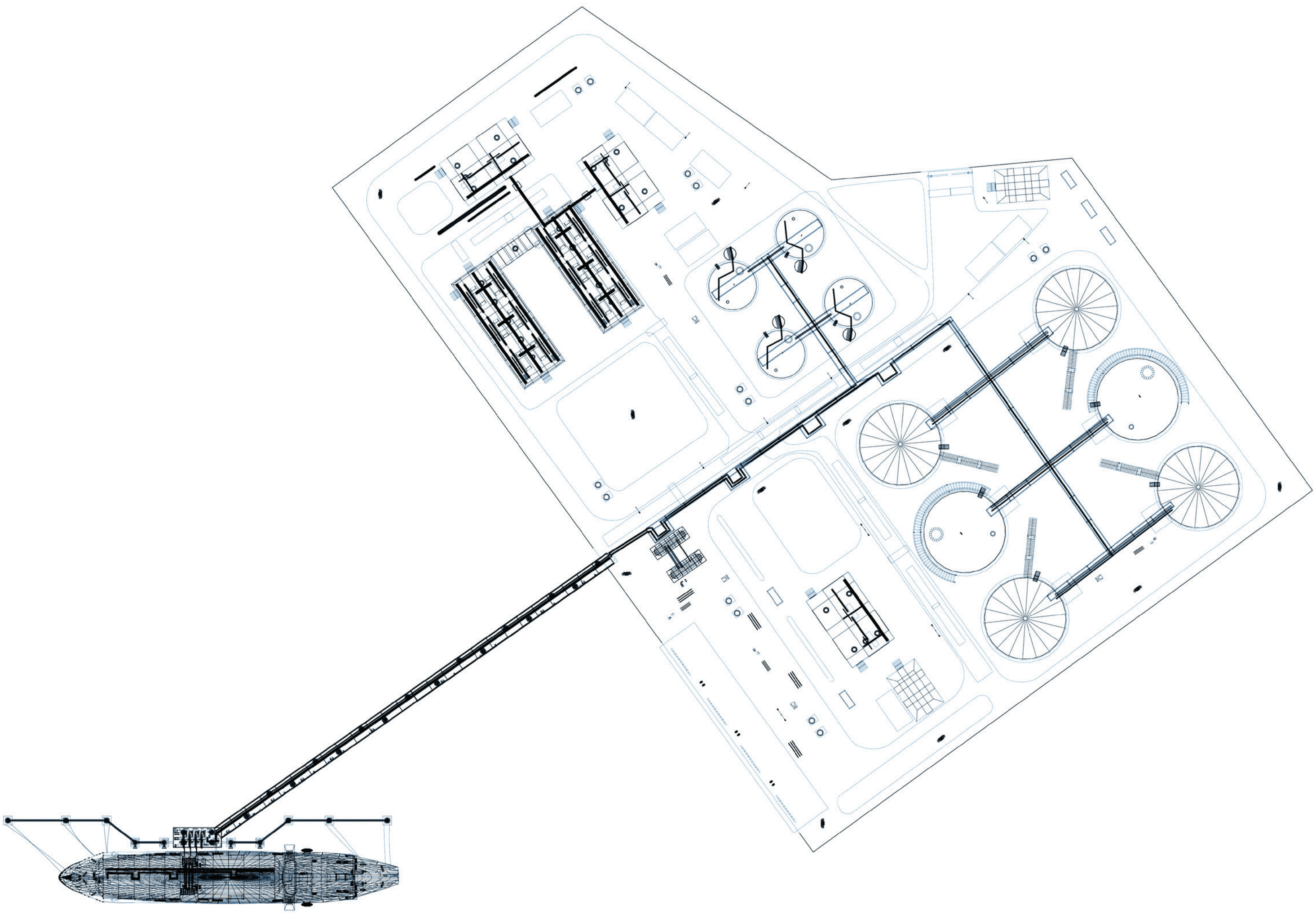
Looking Ahead

The import and storage facility can be designed for LNG and ammonia services without replacing the major equipment such as the storage tank and BOG compressors.

In comparison with the LNG import facility, additional investment is required to provide the alternative reception, storage and handling of ammonia. The areas of the pre-investment include the storage tank, BOG system, piping system and flare stacks, and instrument and safety devices.

Designing Ammonia-Ready LNG Storage Tanks

By Hidemichi Iizuka



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This section discusses the optimum design for ammonia-ready LNG storage tanks.

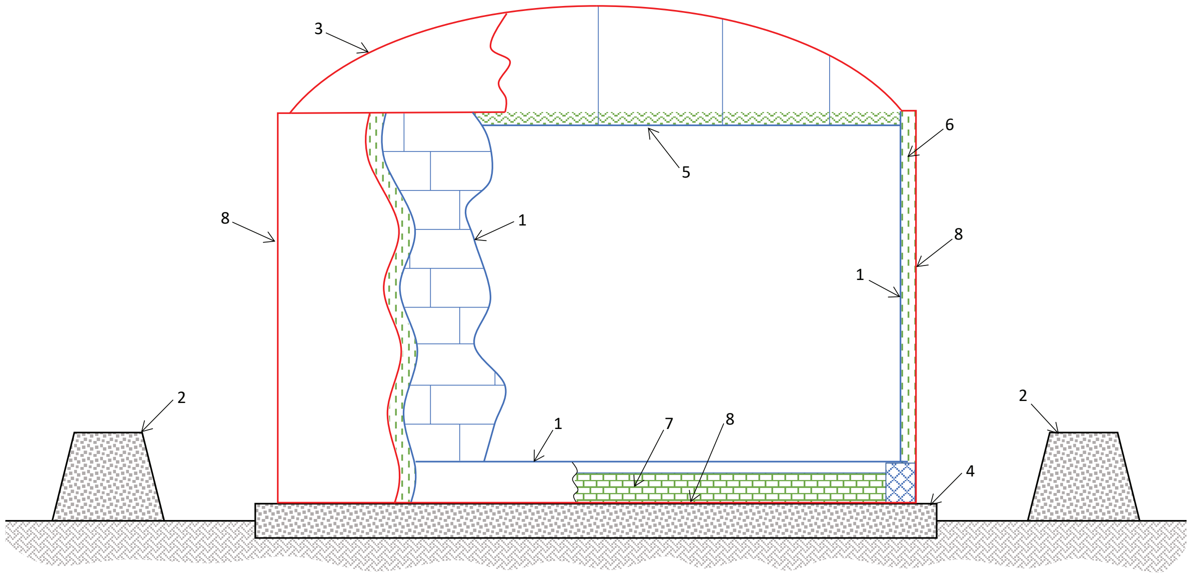
Design Parameters

Table 8 compares the properties of LNG and anhydrous ammonia, which will impact the design of ammonia-ready LNG storage tanks

Table 8. Properties of LNG and Anhydrous Ammonia

Property	LNG	Anhydrous Ammonia
Boiling point at 1 atm (°F)	-259	-28
Liquid density at 1 atm boiling point (kg/m³)	423.54	673.59
Heat of vaporization at 1 atm boiling point (kJ/kg)	509.16	1376.8
°F – degrees Fahrenheit atm - atmospheric pressure kg/m³ – kilograms per cubic meter kJ/kg – kilojoules per kilogram		

It is also critical to adhere to storage tank design codes including *National Fire Protection Association (NFPA) 59A, American Petroleum Institute (API) 625, API 620 Annex Q and Ammonia: American National Standards Institute (ANSI)/CGA G-2.1, API 625, API 620 Annex R.*



1. Primary liquid container (low temp steel)
2. Secondary liquid container (dike)
3. Warm vapor container (roof)
4. Concrete foundation
5. Suspended deck with insulation
6. Insulation (external)
7. Bottom insulation
8. Moisture vapor barrier

Fig. 6 Single-Containment Tank System (Single Wall)

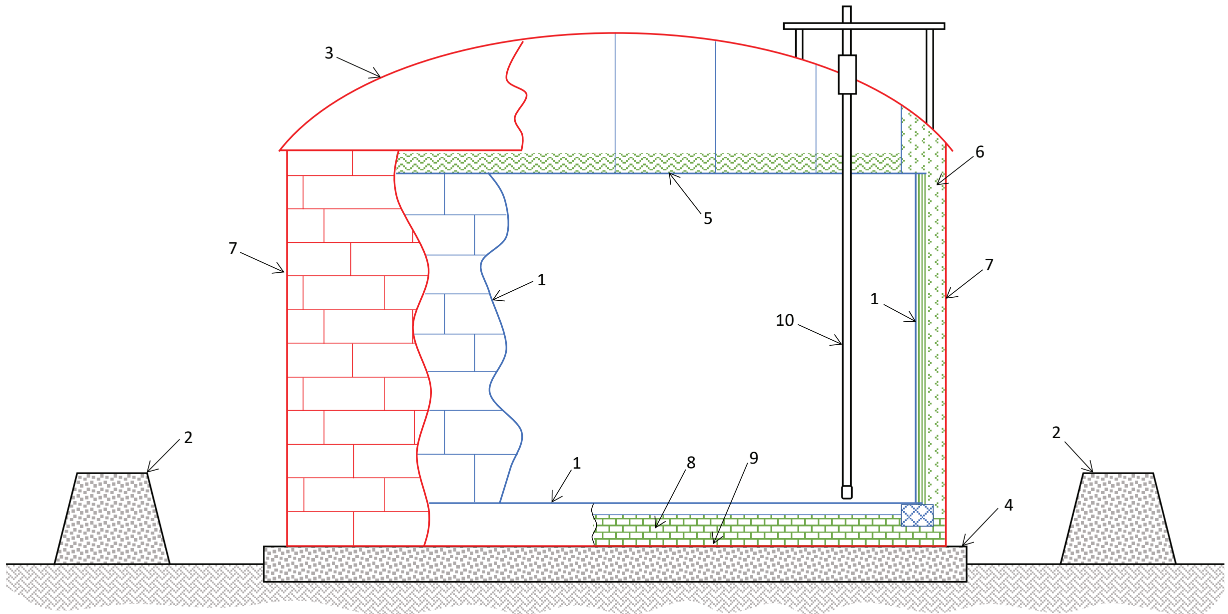
Tank Configurations

A single-wall, single-containment tank system can be used for refrigerated ammonia storage but is not used for LNG storage because of its limitation on insulation performance. This type is not suited for an ammonia-ready LNG storage tank. Figure 6 *(API 625: 2018)* shows a configuration of a single-wall, single-containment tank system.

Table 9 shows the main materials for single-wall, single containment tanks for refrigerated ammonia.

Table 9. Main Materials for Single-Wall, Single-Containment Tanks for Refrigerated Ammonia

Parts	Materials
Primary liquid container	Low temperature carbon steel
Secondary liquid container	Dike
Suspended deck	Low temperature carbon steel
Bottom insulation	Cellular glass blocks
Side insulation	Polyurethane foam
Moisture barrier	Cladding
Suspended deck insulation	Fiberglass blanket
Pump well and internal piping	Stainless steel or low temperature carbon steel



1. Primary liquid container (low temp steel)
2. Secondary liquid container (dike)
3. Warm vapor container (roof)
4. Concrete foundation
5. Suspended deck with insulation
6. Insulation (annular space)
7. Warm vapor container (outer shell)
8. Bottom insulation
9. Warm vapor container (outer bottom)
10. Pump column

Fig. 7 Single-Containment Tank System (Single Wall)

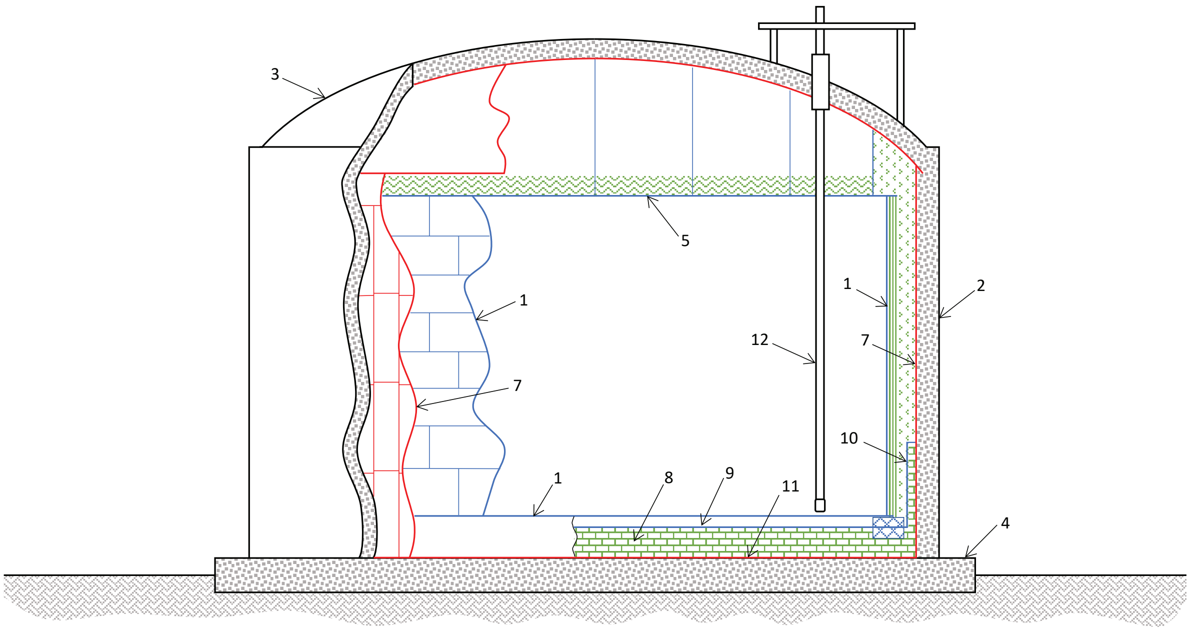
A double-wall, single-containment tank system can be used for both LNG and refrigerated ammonia storage. Figure 7 *(API 625: 2018)* shows a configuration of a double-wall, single-containment tank system.

Figure 7. Single-Containment Tank System (Double Wall)

Table 3 shows the main materials for double-wall, single-containment tanks for both LNG and refrigerated ammonia.

Table 3. Main Materials for Double-Wall, Single-Containment Tanks for LNG and Refrigerated Ammonia

Parts	LNG	Refrigerated Ammonia
Primary liquid container	9-percent nickel (Ni) steel	Low temperature carbon steel
Secondary liquid container	Dike	Dike
Suspended deck	Aluminum	Low temperature carbon steel
Vapor container	Carbon steel	Carbon steel
Bottom insulation	Cellular glass blocks	Cellular glass blocks
Side insulation	Resilient blanket and perlite powder	Resilient blanket and perlite powder
Suspended deck insulation	Fiberglass blanket	Fiberglass blanket
Pump well and internal piping	Stainless steel	Stainless steel or low temperature carbon steel



1. Primary liquid container (low temp steel)
2. Secondary liquid container (concrete)
3. Roof (concrete)
4. Concrete foundation
5. Suspended deck with insulation
6. Insulation (annular space)
7. Product vapor container (liner)
8. Bottom insulation
9. Secondary liquid container (low temp steel)
10. Thermal corner protection
11. Warm vapor container (outer bottom)
12. Pump column

Fig. 8 Full-Containment Tank System

The full-containment tank system can be used for both LNG and refrigerated ammonia storage. Figure 8 *(API 625: 2018)* shows the configuration of the full-containment tank system.

Table 4 shows the main materials for full-containment tanks for both LNG and refrigerated ammonia.

Table 4. Main Materials for Full-Containment Tanks for LNG and Refrigerated Ammonia

Parts	LNG	Refrigerated Ammonia
Primary liquid container	9-percent nickel (Ni) steel	Low temperature carbon steel
Secondary liquid container	Prestressed concrete (wall) Reinforced concrete (bottom)	Prestressed concrete (wall) Reinforced concrete (bottom)
Thermal corner protection	9-percent nickel (Ni) steel	Low temperature carbon steel (if provided)
Suspended deck	Aluminum	Low temperature carbon steel
Vapor container	Carbon steel	Carbon steel
Bottom insulation	Cellular glass blocks	Cellular glass blocks
Side insulation	Resilient blanket and perlite powder	Resilient blanket and perlite powder
Suspended deck insulation	Fiberglass blanket	Fiberglass blanket
Pump well and internal piping	Stainless steel	Stainless steel or low temperature carbon steel

Materials

The materials used for full-containment and single-containment LNG tanks are generally compatible with refrigerated ammonia tanks. However, under certain conditions, liquefied ammonia is known to cause stress corrosion cracking (SCC) in steel. Extensive research and investigations have been done on ammonia SCC, leading to preventative measures being adopted on low-temperature carbon steel used for refrigerated ammonia tanks. But to date, very little research has been done on ammonia SCC with 9-percent Ni steel – with this in mind, further research and investigation will be required to ensure that the structural integrity of the tank is maintained throughout the design life.

Structural Design of Tank

In the structural design of LNG tanks, design liquid level and liquid density are the parameters used to calculate the static and dynamic liquid pressures acting on the wall and foundation. Increased hydrostatic pressure must be considered to cope with the higher density of liquid ammonia compared to LNG. This may result in certain cost impacts because of changes that need to be made to the following tank components: inner tank (thickness of lower shell courses and annular plate); outer concrete wall (rebar and prestressing quantity); foundation (base slab and piles if pile foundation is selected); and bottom insulation (higher grade cellular glass blocks).

For single-containment tanks, the primary function of the steel outer tank is to contain the vapor gas and insulation; therefore, difference in the design temperature and the liquid density do not have any impact to the structural design.

Insultation System

The insulation system for a typical LNG tank between 100,000 m^3 and 200,000 m^3 capacity is designed to meet the BOG rate of less than 0.05 percent per day. Because of ammonia's higher boiling point and heat of vaporization, the BOG rate while storing ammonia will be significantly less than the rate while storing LNG.

Tank Accessories and Appurtenances

Tank accessories and appurtenances are required to be compatible for both LNG and ammonia; they should be replaced when the stored liquid is changed.

- **In-Tank Pumps** – In-tank pumps will be required to be replaced when the stored fluid is changed from LNG to ammonia (or vice-versa).
- **Tank Instrumentation** – Adjustments or modifications should be made for level gauges and density gauge, alarm settings for leak detection temperature gauges, etc.
- **Pressure Relief Valve (PRVs)** – PRVs equipped for LNG use are required to be replaced with PRVs sized for ammonia.

Looking Ahead

Further study is required on the effect of SCC behavior of 9-percent Ni steel in ammonia. Once its effect and prevention method are confirmed, double-wall, single-containment LNG tanks and full-containment LNG tanks can be designed as ammonia-ready LNG tanks with modifications described above.

Report References

IGU World LNG Report – 2020 Edition.

Statista.com: "Storage tank capacity for liquefied natural gas worldwide as of February 2020, by country," https://www.statista.com/statistics/723079/lng-global-storage-tank-capacity-by-country/.

Nickel Development Institute Technical Series No. 10067, "Evaluation of Decommissioned LNG Storage Tanks at Chula Vista, California."

LNG-17 paper, "Dismantling of Aboveground LNG Storage Tanks and Their Aging Research," Osaka Gas Co., Ltd., Hiroshi Nishigami, et.al.

API Standard 625 First Edition, Addendum 3, June 2018: Tank Systems for Refrigerated Liquefied Gas Storage.

Conclusion

Interest in ammonia will only grow as the world continues to march towards decarbonization. Backed by advances in emerging technologies, ammonia offers new opportunity to help accelerate the world's transition to a carbon-free society.

Proven methods of storing and transporting ammonia exist, and the supply chain of ammonia for CO2-free energy is developing. LNG terminals will play an integral role in the safe, efficient transport of liquid ammonia, helping to broaden the use of ammonia for cleaner, greener energy and accelerate our low-carbon future.

The company recently joined the Ammonia Energy Association (AEA) trade association, which advocates for responsible ammonia use in a sustainable energy economy and believes that decarbonized ammonia production will lead to new fuel and energy applications.

A champion of renewable energy and decarbonization, the company recently announced that it is strengthening its sustainability vision with new pledges that align with the United Nations' Sustainable Development Goals (SDGs) and address a range of environmental and business practices, including carbon neutrality by 2025, water usage, diversity and inclusion, anti-corruption and more.

The company earlier announced that it is ending its participation in new coal-based power design and construction to focus on clean energy technologies and help clients accelerate their path to net zero.

To learn more, please contact us at **www.BV.com/contact-us** or email Gary Martin, Vice President, Global Business Development Managing Director, Black & Veatch's Oil & Gas business, at **MartinG2@bv.com**.

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