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LNG VALUE CHAIN

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1. Introduction

Liquefied Natural Gas (LNG) has emerged as a transformative force in the global energy landscape, offering a cleaner and more sustainable alternative to conventional fossil fuels. This comprehensive paper delves into the intricate LNG value chain and explores the upstream processes of exploration, production and processing. Furthermore, it addresses the new trends and innovations that have revolutionized the industry. The midstream sector — encompassing liquefaction, transportation via pipelines, specialized LNG carriers and small-scale LNG distribution— plays a crucial role in ensuring the efficient and reliable movement of LNG from production centers to end-users across the globe. Downstream operations, including storage, regasification and distribution, facilitate the utilization of LNG in various sectors such as power generation, heating, chemical plants and gas-to-liquid (GTL) conversion. Moreover, this report delves into environmental aspects, regulatory frameworks and efforts to eliminate or mitigate methane emissions, thereby reducing the industry's environmental impact. Additionally, the market realities, with a growing LNG Carrier fleet, expanding orderbook and contracts shaping the market, are also analyzed. Finally, this report considers the societal perspective and acknowledges how the LNG value chain influences livelihoods and economies worldwide. As the report navigates this ever-evolving industry, exploring new technology trends and the "gray/blue/green" categorization of LNG, it aims to shed light on the significance of LNG as a vital pillar of the global energy transition.

This report is intended for stakeholders who are new to the LNG world. It reintroduces upstream, midstream and downstream operations and provides a comprehensive view of the LNG value chain, and it highlights actual and future environmental challenges in the eyes of world nations' energy security.

2. Upstream

2.1. Exploration & Production (Offshore and Onshore)

For centuries, oil and gas have stood as steadfast energy sources, with gas found as associated gas with oil, in independent gas reservoirs and even entwined with coal as coal seam gas. Unveiling these invaluable resources lies in the hands of geological experts as they decipher the intricate puzzle of subsurface pockets and reveal the treasure hidden beneath. Geological mapping, guided by sediment types and fault lines, serves as a compass in this endeavor, revealing promising locations for further data gathering. Understanding local reservoirs and sediment basins becomes paramount, providing valuable insights into the success rates and overall characteristics of a find, encompassing the rock and fluid properties, and offering estimations of total volumes and possible recovery.

Embracing the allure of promising geology, the exploration journey ventures further and sets the stage for gathering seismic data, initially on land. Early oil and gas exploration and production unfurled onshore, marking the advent of this industry's transformative impact. With the development of suitable offshore exploration and recovery technologies, promising geological formations on the seabed could also be identified and accessed for development of previously unknown and unrecoverable resources.

2.2. Fracking

Fracking, short for fracturing the reservoir, is a contemporary term that has sparked a revolution in shale gas exploration — witnessed in regions like North America, China and Argentina — and holds transformative power within its core.

Fracking combines technical prowess with geological insight. The process entails high-pressure injection of water, effectively breaking up the reservoir, carving new pathways for precious hydrocarbons to traverse through the intricate rock formations. To preserve these newfound fissures, proppants and delicate particles strategically introduced into the injection fluid, should maintain their resilience when the pressure subsides. The result is a web of pathways ensuring fluid migration, marking a revolutionary leap in hydrocarbon extraction.

As with any pioneering breakthrough, controversy inevitably follows. Given the substantial volumes required for fracturing reservoirs, water takes center stage. Environmental concerns arise and the quest for water reuse and effective management becomes paramount, which is a business endeavor in its own right. The dynamic interplay between energy exploration and responsible stewardship of natural resources remains a constant and vital pursuit.

2.3. Processing

Gas, often found intertwined with oil in the earth's depths, is referred to as associated gas when it accompanies crude oil. While gas from pure gas reservoirs necessitates less processing, historically, its value remained overshadowed by the significant revenues derived from oil and Liquified Petroleum Gas (LPG) products. The allure of the liquid riches compelled the flaring of gas, a practice that endured until recent times, and sought to prioritize oil over gas production.

The journey of processing the reservoir fluid commences with the meticulous removal of sand and sediments, followed by the critical task of bulk separation, parting oil, water and gas. This separation typically unfolds in two or three stages of flash separation and progressively lowers pressures to extract distinct components.

The gas extracted during the initial inlet gas separation demands further refinement through compression before it proceeds to liquefaction and it must be compressed to an optimal pressure to facilitate subsequent treatment.

In the quest for excellence in cryogenic processing, the focus turns to addressing mid-range hydrocarbons that might solidify during liquefaction. For this reason, it’s imperative to strive for the elimination of hydrocarbons that are heavier than butanes and most LPGs, therefore, aligning with the precise LNG heating value specifications. Additionally, acknowledging that there does not exist a “one-size-fits-all" global LNG specification will help with this quest, especially when considering that the quantity of LPG in the LNG varies slightly between lean (low in heavier hydrocarbons) and rich (higher in heavier hydrocarbons) LNG compositions.

Another facet of this meticulous process involves the removal of any contaminant present in the gas before it undergoes liquefaction. Certain gas fields harbor mercury, which poses corrosive threats to the aluminum components employed in cryogenic heat exchangers. Consequently, a guard bed is employed to effectively remove mercury from the gas, mitigating any potential hazards during subsequent cryogenic processing.

Steering away from undesired elements, the LNG preparation further necessitates the eradication of acid gas, sulfur compounds and carbon dioxide. The presence of these compounds can lead to solidification before reaching the methane liquefaction temperature. A proven method for eliminating acid gas involves passing the gas counter with an absorbing fluid such as amine, in a contactor, therefore, effectively capturing and removing acid gas from the liquefaction feed gas.

The absorbing fluid, amine, emerges as an aqueous solution and renders the gas that leaves the acid gas removal section of the plant water-saturated. Prior to liquefaction, it becomes imperative to eliminate all traces of water to evade ice formation and the dreaded occurrence of hydrates within the cryogenic plant's components. The most common technique for accomplishing this task involves leveraging molecular sieve absorber vessels, where several molecular sieve units play an essential role and must undergo sequential regeneration with hot gas to ensure operational efficiency and impeccable performance throughout the process.

2.4. New Trends – FLNG

Traditionally, LNG liquefaction plants have found their homes onshore, and while some of these facilities were situated in remote areas, they demanded the establishment of entire cities and intricate infrastructures to support the plant operations and personnel.

Pre-processing and bulk separation have conventionally been conducted at the primary production site, whether situated onshore or offshore. The feed gas destined for liquefaction would thus undergo the aforementioned processing steps before it could be transformed into LNG.

Venturing into the vast and remote offshore gas fields often posed significant challenges due to the substantial upstream costs, including the construction of extensive pipelines. The quest for a more cost-effective solution led to the concept of floating liquefaction facilities (FLNGs), where both liquefaction and necessary pre-processing occur on a floating structure that is positioned in proximity to the gas discovery site. The LNG, along with potential by-products like LPG and Condensate, could be directly offloaded onto product carriers, swiftly reaching the market from the floating LNG facility.

Three crucial factors initially held back the widespread adoption of floating liquefaction technology. These concerns revolved around uncertainties regarding the impact of motion on key process systems, the robustness of cargo containment systems, and most notably, the intricacies surrounding the offloading of LNG-to-LNG carriers.

The success of the pre-processing phase before liquefaction hinges on unwavering reliability. Ensuring the absence of heavier hydrocarbons, acid gas components and water is imperative to prevent any risks of impurity solidification within the cryogenic heat exchangers during liquefaction. Past experiences with distillation columns on floating production units yielded valuable lessons, necessitating the use of structured packing instead of trays or random packing. Applying sufficient design margins and considering motions and accelerations during column design and construction have been essential learnings applied to current operational units, significantly mitigating the challenges posed by predominant, mild metocean conditions.

Leveraging substantial experience gained from LNG tanks onshore and aboard ships, the transition to floating liquefaction presents a significant similarity to existing LNG ship technology. However, one critical difference arises. LNG carriers typically operate either at full or near-empty tank levels, while liquefaction units must contend with varying tank filling levels during LNG production until reaching capacity. For large-scale LNG carriers, membrane or type B tanks are predominantly employed, with the rising popularity of type A tanks and extensive use of Type C tanks in the small to mid-scale segment. Meticulous tank design and operational measures ensure the availability of reliable cargo containment systems for full offshore application of liquefaction. Strengthening and modification of systems, including the number and size of individual tanks, have been pursued to optimize the technology's performance.

The transfer of LNG from FLNG to the export carrier emerged as the primary uncertainty surrounding the first Financial Investment Decision (FID) for FLNG projects. While most onshore terminals employed LNG loading arms connected to the midship manifold of LNG carriers, the early days of Floating Storage and Regasification Units (FSRU) business primarily relied on hoses for LNG cargo transfer, managing return boil-off gas and displaced gas during loading. Emulating the successful deployment of floating hoses for offtake operations from FPSOs in benign locations and bow-loading systems in harsher conditions, the floating LNG concept sought to embrace similar methodologies. The commercial availability of floating hoses was not yet realized during the first FIDs, which necessitated alternatives. Current FLNG projects have adopted side-by-side ship-to-ship transfer systems, with larger FLNGs equipped with loading arms specifically designed to accommodate a floating structure. Smaller units, on the other hand, rely on transfer hoses in Ship-to-Ship (STS) mode. These arrangements mandate meticulous metocean conditions and mooring system configurations to enable LNG carriers to approach, load and depart in a side-by-side configuration. Until the feasibility of shuttle LNG carriers with bow loading and dynamic positioning during cargo filling operations is established, areas with excessively rough metocean conditions remain unsuitable for FLNG deployment.

3. Midstream

3.1. Liquefaction

Natural gas will undergo liquefaction by subjecting it to cooling at temperatures as low as -161°C, reducing its volume in its liquid state by approximately 600 times compared to its gaseous state. In the United States alone, there are over 100 patents related to the liquefaction of natural gas. However, the commercial use of liquefaction primarily relies on three main systems: cascade, mixed refrigerant (MR) and expansion cycles (EXP). Most available onshore or onboard liquefaction processes are based on these cycles or a combination thereof.

Prior to liquefaction, natural gas requires pretreatment to remove impurities such as mercury, sour gas (CO^2, H^2S), non-hydrocarbon (N^2) and water (drying).

A typical cascade refrigeration cycle involves three interconnected refrigeration cycles using different refrigerants, including methane, ethylene (or ethane) and propane. These cycles function in series, with the first stage — propane refrigeration cycle — providing cooling capacity for methane, ethylene (or ethane) and natural gas (NG). The second stage — ethylene or ethane refrigeration cycle — cools methane and NG, while the third stage —methane refrigeration cycle) — cools NG. Subsequently, as the NG is gradually cooled and liquefied, the transfer to an LNG storage tank takes place. It's worth noting that hydrocarbon-based pure refrigerants can also be utilized, but their flammability poses safety concerns, making them unsuitable for applications like FLNG where combustibles inventory must be minimized.

The expansion liquefaction process (EXP) for natural gas employs a reverse-Brayton cycle refrigeration using an expander, where the gas does work to achieve the cooling purpose. The output work of the expander is used to drive the compressor during the liquefaction process for energy-saving purposes. Nitrogen or NG is often used as the expansion working fluid and serves as the primary refrigerant for this cycle. The EXP process is simple and has a compact structure, making it easy to start and stop. However, it does incur higher energy consumption and is commonly used in small and medium-sized LNG plants.

On the other hand, the mixed refrigerant (MR) liquefaction process is a frequently utilized method for natural gas liquefaction. This process involves a multi-component mixed refrigerant that replaces multiple pure component refrigerants. MR offers advantages such as requiring less equipment, a simpler process and lower corresponding investment. The MR undergoes compression and cooling through compressors and air coolers before entering the heat exchanger for further cooling. Afterward, the MR is throttled for additional cooling via the Joule-Thomson valve, and then the vaporization heat of NG is utilized to evaporate in the heat exchanger to complete the cycle.

The choice of liquefaction processes largely depends on its intended application. For large-scale onshore projects with a capacity exceeding one million tons LNG per annum (MTPA), the cascade and mixed refrigerant processes prove more suitable. Conversely, for onshore, small-scale applications with a capacity below one MTPA, the single MR process is preferred, sometimes accompanied by the EXP process. The characteristics of offshore applications, such as footprint, ease of maintenance, sensitivity to motion and safety considerations, make the MR and EXP processes more appropriate than the cascade process.

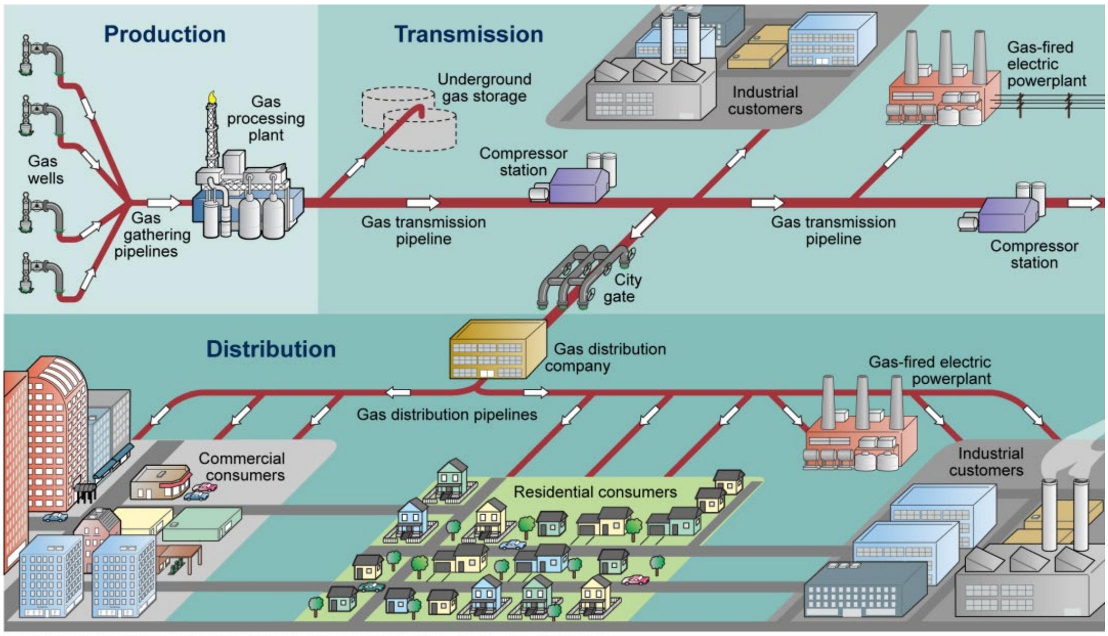
3.2. Transportation

3.2.1. Pipeline

The majority of the world's natural gas is transported through extensive pipeline networks, enabling swift delivery to processing facilities and to end consumers on land. This intricate network comprises three distinct types of pipelines along the transportation route:

1. *Gathering Pipeline System:* The gathering system consists of low-pressure, small pipelines responsible for transporting raw natural gas from the wellhead to the processing plant.
2. *Intrastate/Interstate Transmission Pipeline System:* These wide-diameter, long-distance pipelines convey natural gas from producing and processing areas to storage facilities and distribution centers. Along the transmission route, several compression or pumping stations are strategically placed. These stations house one or more compressor units that receive the transmission flow from a preceding station and enhance the rate and pressure of the gas to facilitate its movement along multiple pipelines, ultimately reaching various markets and consumers.
3. *Distribution Pipeline System:* The distribution pipeline system brings gas closer to cities and residential areas, where local distribution companies lower the gas pressure to a level suitable for residential and commercial establishments. Smaller service lines extend from the distribution system, supplying natural gas to homes, businesses, or industrial areas as needed as indicated in Figure 1.

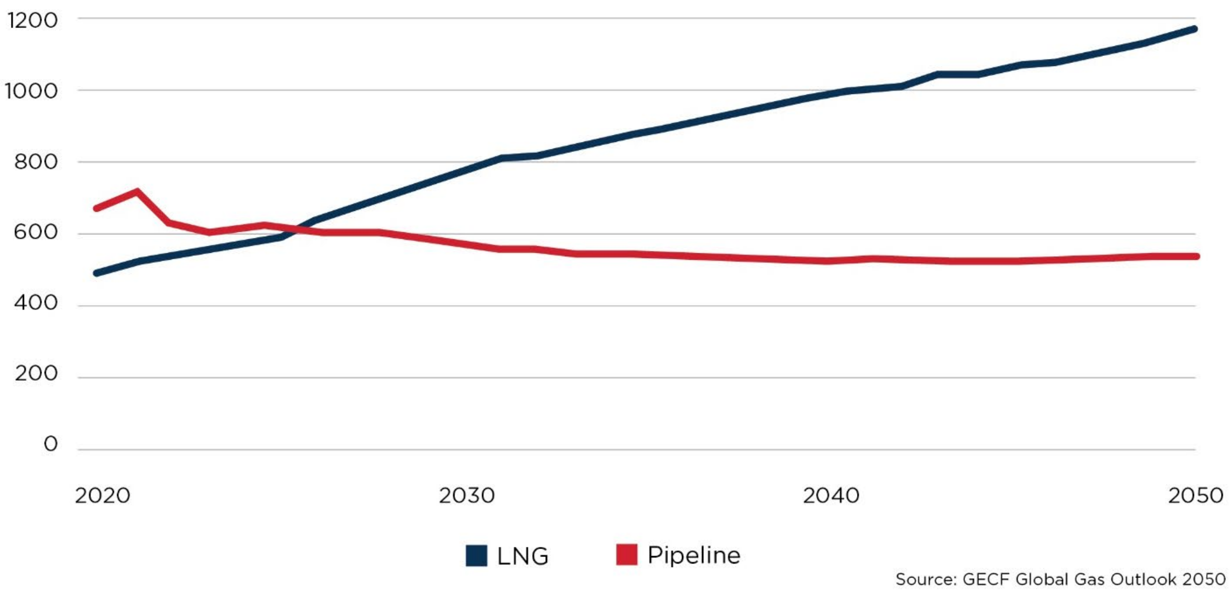
Figure 1: Distribution** Network **by Pipeline



Source: GAO analysis of Energy Information Administration and Natural Gas Council documents. | GAO-20-658

To enable the movement of natural gas along the pipeline, it must be maintained at high pressure. To ensure consistent pressure levels, compressor stations are strategically placed at intervals throughout the pipeline network. When the natural gas enters a compressor station, it undergoes compression through either a turbine, motor or engine. Metering stations are also installed at various points along the pipeline network to continuously monitor pressure, flow rates, and detect potential leaks.

Figure 2: Global Natural Gas Trade by Flow Type (bcm)



Offshore pipelines pose higher risks for leakage and environmental impacts compared to onshore pipelines. However, significant technological advancements in pipeline materials and monitoring systems have greatly improved pipeline safety and efficiency, mitigating potential risks.

While pipelines have long dominated international gas trade, the export of Liquefied Natural Gas (LNG) has experienced remarkable growth since the beginning of the century, more than tripling its volume. In their Global Gas Outlook 2050, the Gas Exporting Countries Forum (GECF) predicts that by 2026 the global LNG trade will overtake the pipeline trade. Considering in 2018, LNG exports accounted for just over half of the total international gas trade, underscoring its increasing significance in the global energy market.

3.2.2. Marine Transportation

When transporting natural gas by pipeline becomes unfeasible due to political, economic or environmental reasons, it is typically transported in its liquified state. This scenario often arises in regions located far from gas extraction sites without connecting pipelines but with favorable conditions for water transport. In such cases, cargo ships are used to deliver LNG efficiently at sea, as LNG exhibits excellent transport properties in its liquified form. Upon regasification, one cubic meter of LNG produces about 600 cubic meters of natural gas under normal conditions. The primary challenge lies in maintaining LNG's cryogenic condition at -161°C, for which various containment systems (CCS) have been employed and categorized in the International Code for the Construction and Equipment of Ships Carrying Liquefied Gas in Bulk (IGC CODE - IMO RESOLUTION MSC.370(93)).

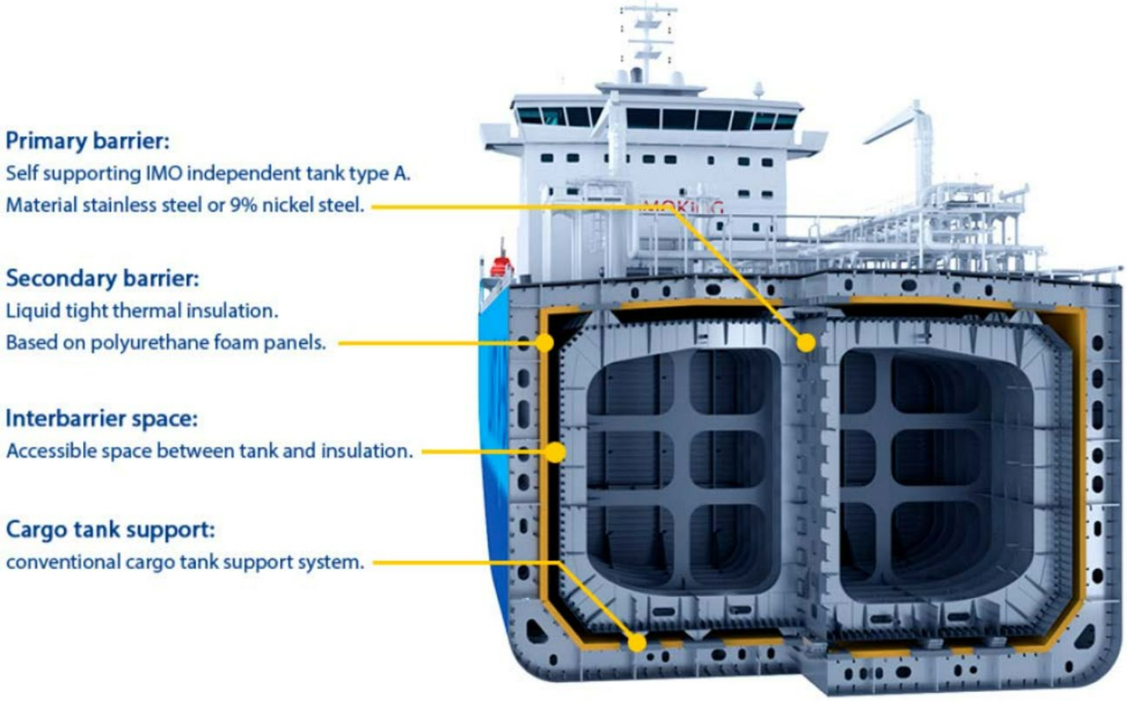
This resolution classifies CCS types into two main categories: Independent Tanks (Type A, B, and C), which are independent from the hull of the ship, and Integrated Tanks (Membrane Tanks), where the hull forms part of the tank.

Independent Tank Type A

These tanks are designed using the traditional method of ship structural design (prismatic shape) and are commonly used for LPG carriers. They can carry LPG at near-atmospheric conditions and can also carry LNG. The design pressure of Type A tanks is less than 700 mbar when constructed primarily of plane surfaces, with insulation provided on the outside. Additionally, potential leakage in the independent tank is mitigated by surrounding spaces designated as the secondary barrier which must hold the entire tank volume at a specified heel angle. For LNG carriers of this type, a full secondary barrier is required to prevent brittle fracture due to the cryogenic temperature of LNG. The space between the tank and the hull, known as the hold space, must be inerted when carrying flammable cargoes to prevent a flammable atmosphere from forming in case of a leakage in the primary barrier.

Over the years, the need for a full secondary barrier in LNG carriers with Type A tanks presented technical and economic challenges. The first type A tank LNG carriers were built in the 1960s, but likely due to high costs were not repeated. However, about a decade ago, LNT Marine introduced its LNT-A box system. This innovation involved fixing the insulation system to the ship's hull with a liquid-tight inner surface to contain any leaks from the cargo tank. Between the tank and the secondary barrier lies a "cold" inter-barrier space, providing direct access for visual inspections and maintenance of both barriers and tank supports. The tank itself is made of stainless steel (possibly nine percent nickel steel or aluminum) which slightly contracts under cryogenic conditions (3mm/m at -161°C) and its internal structure mitigates sloshing (swash bulkhead) while eliminating loading limitations.

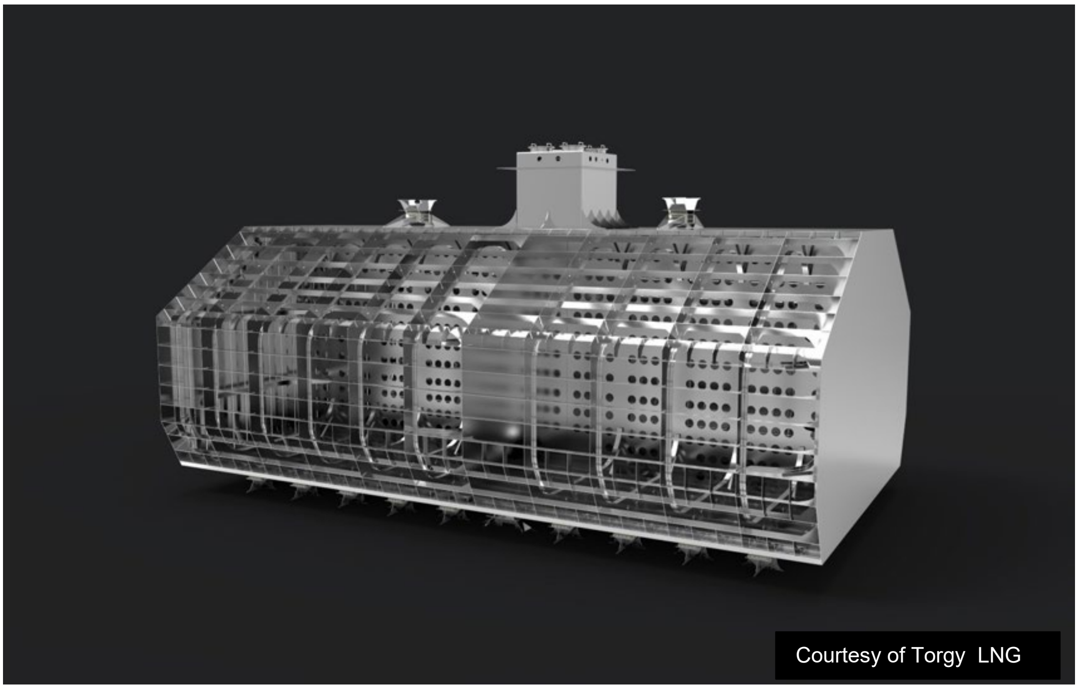
In 2015, the first LNG carriers using the LNT-A box system were signed with SAGA LNG Shipping, CMHI Shipyard and ABS Class (SAGA DAWN - 45km^3). Originally designed for small and middle-scale LNG carriers, LNT Marine's system has since gained approval in principle from ABS for a 175k m^3 design as well as for a LNT Fuel-box system, which will interest other types of ships looking to utilize LNG as a fuel.



Torgy's LNG A-Tank represents a significant advancement in type A tank systems, particularly concerning LNG usage requirements. Built upon the conventional type A tank design, commonly used for LPG, the Torgy LNG A-Tank incorporates an entire secondary barrier to meet the stringent demands of LNG applications. To achieve this, Torgy LNG utilizes a metallic barrier composed of thin plates made of stainless steel, carefully arranged to withstand the cryogenic environment and the challenging effects of cooldown during operation.

The innovative pattern developed by Torgy LNG, known as the "Fishbone pattern," is a patented design and layout that plays a crucial role in ensuring the system's efficiency and reliability. This pattern is specifically engineered to release stress in the membrane plates during cooldown, enhancing the tank's structural integrity and overall performance.

The Torgy LNG A-Tank's exceptional features make it particularly well-suited for small-scale LNG carriers and even more applicable for LNG fuel tanks. The system offers a compelling alternative to Type C tanks, offering greater space efficiency and enhanced functionality for LNG-fueled vessels. With its cutting-edge design and robust performance, Torgy's LNG A-Tank provides a valuable option for players in the LNG industry, further advancing the state-of-the-art in LNG containment technology.



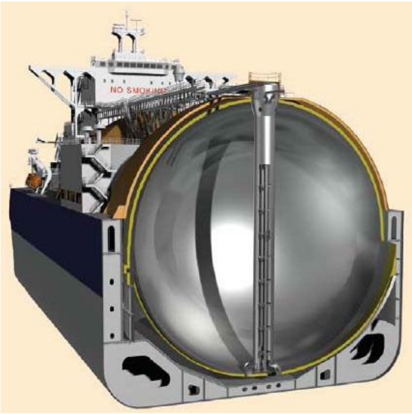
Independent Tank Type B

The design of these tanks prioritizes early crack detection to provide a time margin before potential failure occurs. To achieve this, various methods are employed, including first principle analysis to determine stress levels at different temperatures and pressures, evaluating the fatigue life of the tank structure and studying crack propagation characteristics. This enhanced tank design incorporates a partial secondary barrier, typically in the form of a drip pan beneath the tank bottom with insulation applied externally.

Type B spherical tanks, the most common in LNG ships, boast self-supporting spherical structures that eliminate sloshing concerns. These tanks are connected at the equator to a single cylindrical supporting skirt, which is welded to the ship structure. Made of aluminum alloy, these tanks have internal diameters above 40m and a shell thickness of up to 50mm. The outer surface of the tank and the upper part of the skirt are insulated with materials such as polyurethane, Styrofoam, or equivalent. Nitrogen atmosphere is used to check for leakages in a special thin layer called "tinfoil," which also keeps the insulation dry. The tanks' contraction and expansion during cool down and warm up, reaching up to 0.6m, are managed through flexible bellows connected to the ship's lines via bell-shaped structures on the bottom, absorbing variations.

The design allows higher pressures up to 2100 mbar, and net tonnage is determined solely by the ship's dimensions rather than its cargo capacity or load. Moss tanks LNG carriers, with half the spherical shape protruding above the deck, incur higher tolls and fees, such as when passing through the Suez Canal, due to the increased ship volume per cubic meter of LNG transported. Additionally, the design's protruding shape may impact the ship's aerodynamics, rendering it more susceptible to wind forces compared to membrane tanks.

Mitsubishi Heavy Industries, Ltd. (MHI) has introduced a next-generation spherical tank LNG carrier known as SAYAENDO, inspired by the term "peas in a pod." This innovative design, first introduced in 2012, features a continuous tank cover, integrating with the ship's primary strength members to house all tanks under one roof while maintaining necessary compartment divisions. This design contributes to the overall structural strength and enables hull weight reduction. By providing a continuous cover over the length of the ship, the SAYAENDO design optimizes the structural efficiency and performance of the LNG carrier.



Courtesy of MHI (Tech Review No.51 – March 2015)

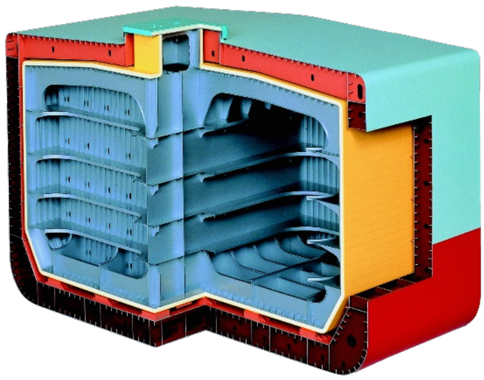
In 2017, Kawasaki Heavy Industries, Ltd. made a significant announcement regarding the approval in principle for a new Moss-type LNG storage tank. This innovative concept introduces a non-spherical tank design, aimed at maximizing space utilization on board LNG carriers. By adopting this non-spherical design approach, Panamax-size LNG carriers can significantly enhance their total carrying capacity, achieving a remarkable 15 percent increase in volume compared to traditional spherical tanks.

The implementation of non-spherical tanks represents a novel approach to optimize the available space on LNG carriers, enabling them to transport larger quantities of LNG without compromising safety or efficiency. This advancement in tank design opens new possibilities for the LNG industry, enhancing the transportation capacity of vessels and improving the overall economics of LNG shipping. The approval in principle for this cutting-edge technology marks a significant step towards enhancing the global LNG transportation infrastructure.

Courtesy of MHI (Tech Review No.51 – March 2015)

In 1985, the Japanese shipbuilder IHI developed the SPB Tank, a Type B cargo containment system featuring self-supporting prismatic tanks. This innovative design revolutionized LNG carriers by offering enhanced space efficiency and structural integrity. The first vessels equipped with IHI's SPB cargo containment system, built back in 1993, were *Polar Eagle* and *Arctic Sun* with both being LNG carriers with a capacity of 87,500 m^3.

Similar to the Moss Rosenberg tanks, the SPB tanks are prefabricated and installed inside the inner hull as complete units. These tanks have a rectangular shape and are constructed from aluminum plates with thicknesses ranging from 15 to 25mm and covered with heat-insulating material blocks. Supporting blocks made of reinforced plywood are fixed at the bottom and top of the tanks, mounted on steel supports on the double bottom structure to ensure the tanks' stable position in all directions, even in the event of flooding.



Each tank is equipped with an internal centerline bulkhead and a subdividing swash bulkhead, which effectively eliminate sloshing issues experienced in partially filled tanks. This design feature enhances the safety and stability of the vessel during transportation. Moreover, the SPB tank design facilitates practical access for inspection and maintenance to the inner hull, ensuring the continued integrity and reliability of the cargo containment system.

Furthermore, vessels equipped with the SPB cargo containment system boast a completely flat weather deck and a double hull, further contributing to the structural strength and overall safety of the LNG carriers. This unique design approach offers several advantages, including optimized space utilization, improved vessel stability and enhanced maintenance accessibility, making the SPB Tank a significant advancement in LNG carrier technology.

Independent Tanks Type C

Type C tanks are pressure vessels designed to operate at pressures higher than 2 bar and do not require a secondary barrier. They are primarily constructed with curved surfaces and can be cylindrical or spherical in design, mounted either vertically or horizontally. Some Type C tanks utilize bi-lobe or tri-lobe designs to optimize the hull geometry. When fitted on fully pressurized gas carriers, the typical design pressure ranges between 10 to 18 bar, with the ability to withstand approximately 50 percent vacuum.

Due to the high reliability of pressure vessel design, a secondary barrier is unnecessary. Type C tanks typically employ one of two types of insulation: double shell with vacuum and insulation in the annular space or single shell with spray insulation on the outer layer. These variations in design influence the level of the hazardous area adjacent to the tank, especially if enclosed.


Courtesy of Watts Energy and Engineering

One of the advantages of Type C tanks is the allowed pressure build-up, which proves beneficial for LNG containment. The pressure rise reduces boil-off, achieving vapor saturation where the quantity of liquid transforming to gas is in equilibrium with the quantity of gas turning back into the liquid state. This equilibrium results in an increased holding time compared to other tank concepts. Additionally, the pressurized boil-off gas can be directly utilized by consumers, like boilers, or serve as fuel gas for low-pressure engines.

Courtesy of Tradewinds

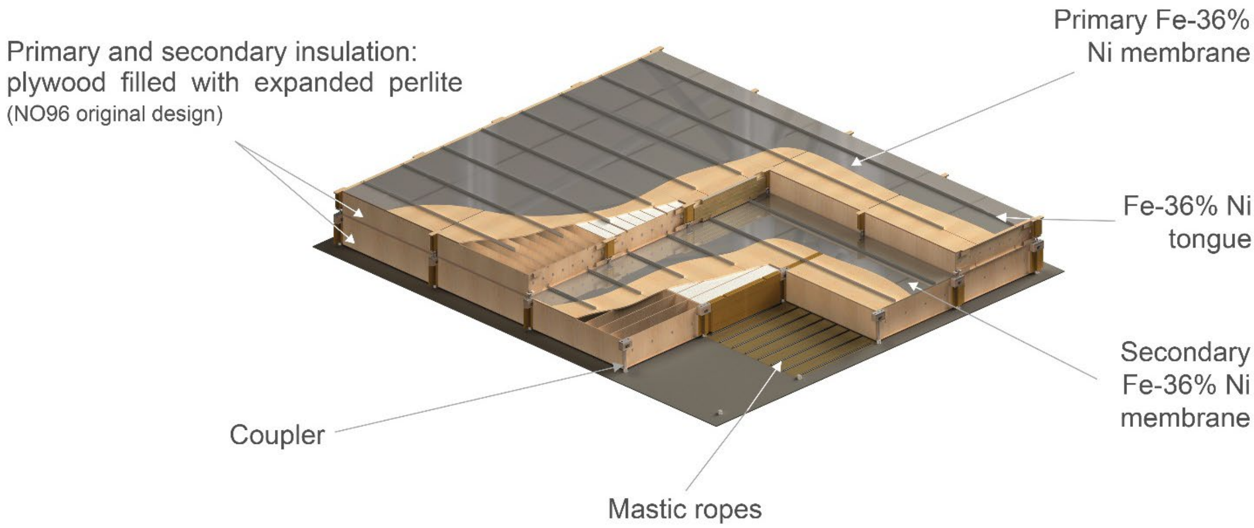
While Type C tanks are used in both LPG and LNG carriers, the tanks in the LNG trade are particularly dominant in mid-scale LNG carriers and with ships employing LNG as a fuel. The design's versatility and efficiency make it a popular choice for vessels in this capacity range, and it contributes to the continued growth and adoption of LNG as a viable fuel source in the maritime industry.

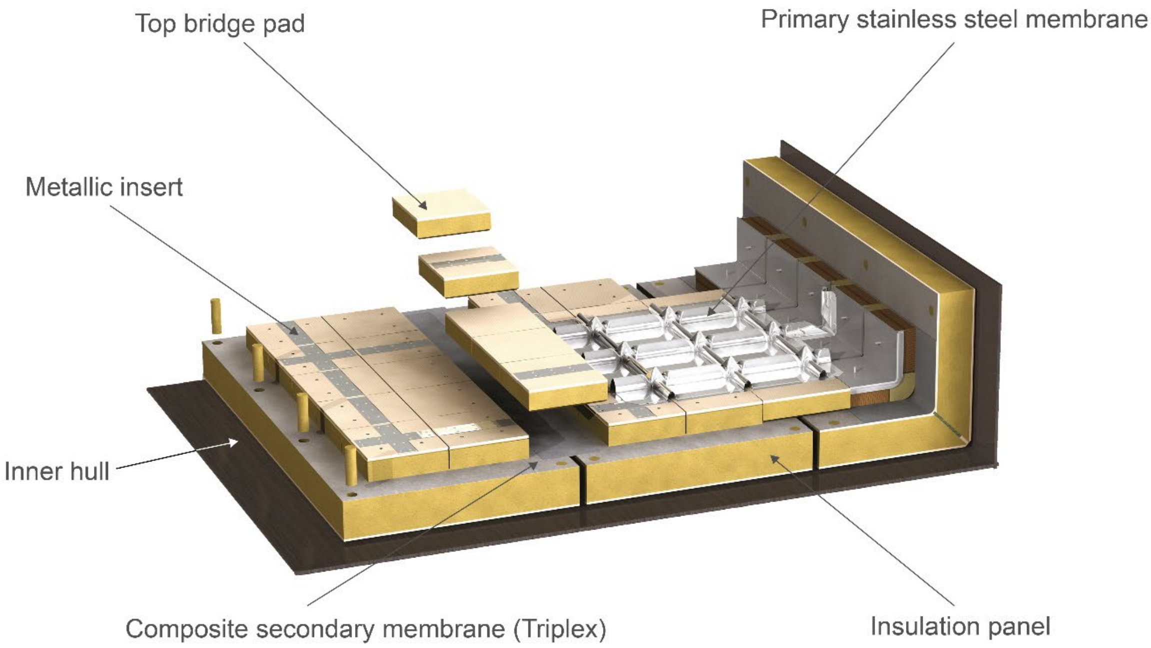
Membrane Tank

Membrane tanks are non-self-supporting tanks with the double hull being an integral part of the tank structure. These tanks utilize a primary membrane, which is a thin material supported by the adjacent hull structure (inner hull) through insulation. To ensure safety and redundancy, a complete secondary barrier is required. Originally designed with a maximum pressure of 250 mbar, membrane tanks may be designed with design pressure of up to 700 mbar. Recent developments in operational requirements have seen further incremental increases in the design pressures. Membrane tanks are commonly found on LNG carriers and are commercially available in two main systems: Gaztransport and Technigaz (GTT) NO96 and Mark III systems.

GTT was formed in 1994 through the merger of Gaztransport and Technigaz, bringing together two technologies with extensive experience in LNG bulk transportation – the NO82 and Mark I systems. These technologies have become dominant in standard to large-scale LNG carrier containment systems.

The NO96 concept is an evolution of the NO82 system and features primary and secondary membranes made of Invar®, a 36 percent nickel-steel alloy with a thickness of 0.7mm. The primary membrane contains the LNG cargo while the secondary membrane — identical to the primary — provides 100 percent redundancy in the event of a leak. The insulation, made of plywood boxes filled with Perlite, has been optimized by GTT to meet shipowner and shipyard requirements. Various modifications have been made to improve boil-off rates (BOR) —using glass-wool (NO96 GW) or foam (NO96 L03) instead of plywood insulation — while introducing a pillar structure and employing insulating Reinforced Polyurethane Foam (R-PUF) panels.





The Mark III concept is a containment and insulation system directly supported by the ship's hull structure. It consists of a primary corrugated stainless-steel membrane (1.2 mm thick) positioned on prefabricated polyurethane insulation panels. It includes a complete secondary membrane made of composite material (Triplex – 2 Glass clothes with an aluminum foil in between). Improvements to decrease BOR led to the development of Mark III Flex and Flex+ systems, with focus on enhancing insulation thickness.

The latest evolution, GTT Next1, features a 1.2 mm stainless steel primary membrane and a 0.7 mm Invar secondary membrane with Reinforced Polyurethane foam insulation. This design allows for potential optimization of tank arrangements by having three tanks instead of four, therefore, reducing costs and increasing overall efficiency.

LNG Propulsion

Due to the cleaner-burning properties of natural gas, using it as a propulsion system for ships has been an attractive option for companies looking to comply with IMO and MARPOL environmental regulations. For LNG carriers, utilizing their cargo for propulsion offers significant advantages, and various options are available.

Boil-off gas (BOG) is a natural occurrence in LNG carriers due to heat transfer and ship motion, and if not managed properly, it can increase the pressure inside the tanks to critical levels. Venting the BOG is not a viable solution as methane, being a greenhouse gas, has been forbidden except in emergencies. Additionally, it must be recorded in the ship's logbook. Approximately two decades ago, reliquefaction plants were expensive and complicated to operate, thus making the use of BOG for propulsion a viable alternative. Burning methane as a fuel in the propulsion system results in reduced emissions of sulphur oxides, nitrogen oxides and approximately 26 percent lower carbon dioxide emissions. If there is insufficient BOG for propulsion, it can be forced back into a gaseous state with compressors and heat exchangers. Another alternative to this is using Heavy Fuel Oil (HFO) to power the propulsion.

Initially, steam turbines (STPS) were the dominant propulsion machinery for LNG carriers due to their ability to burn BOG while at sea despite their relatively low efficiency. However, the low fuel efficiency of steam turbines led shipowners to explore other propulsion systems.

The Slow Speed Diesel with Reliquefaction Plant (SSDR) combines a single fuel diesel mechanical propulsion system with a re-liquefaction system. The entire BOG is liquefied and returned to the cargo tanks instead of being used as fuel. A Gas Combustion Unit (GCU) is typically fitted for Boil-off management and tank safety, and diesel or HFO is injected into the slow-speed diesel engines which are usually in a twin-screw configuration. Improvements and simplification of reliquefaction plants have contributed to the adoption of SSDR propulsion.

The Dual Fuel Diesel Electric Propulsion (DFDE) uses diesel engines designed to burn BOG as well as diesel fuel oil. Multiple diesel generators provide all the vessel's power requirements, including propulsion, and a GCU is typically present to manage BOG when the main propulsion system is not in use. DFDE engines offer increased fuel efficiency and cargo capacity, lower fuel consumption, higher flexibility in operation and lower emissions.

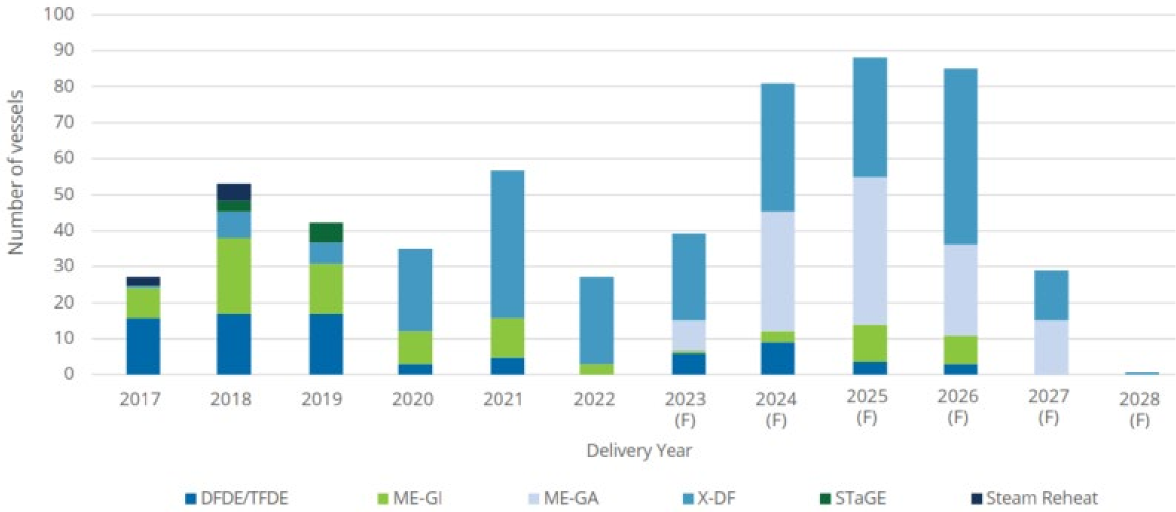
Around 2002, owners began building LNG carriers with dual-fuel diesel engines, accounting for the bulk of the modern LNG carrier fleet. These engines provide operational benefits and environmental advantages.

Since 2012, engine makers have offered engines with slow-speed, two-stroke engines known as MEGI (high pressure) or X-DF (low pressure). They were specifically designed for natural gas-propelled ships. The MEGI engine operates on a high-pressure natural gas (350 bars) and fuel, and it generates minimal methane slip during gas operation. On the other hand, the X-DF engine operates on the Otto cycle when running on gas, meeting IMO's Tier III NOx limits in Emission Control Areas (ECA) and significantly reducing particulate matter emissions. Both engines offer environmental benefits, though the MEGI system is more fuel-efficient than the X-DF.

Another player in the market is the Steam Turbine and Gas Engines (STaGE) propulsion system, which is a hybrid between the STPS and DFDE. This innovative configuration combines an ultra-steam turbine with a dual-fuel diesel electric system, with waste heat from exhaust gases used to improve efficiency. The Sayaringo STaGE, developed exclusively by Mitsubishi Heavy Industries (MHI), is an advanced version of the Sayaendo LNG carrier.

Overall, the LNG carrier propulsion options offer various benefits in terms of fuel efficiency, emissions reduction, and cargo capacity, allowing shipowners to choose the most suitable system for their operations.

Figure 3: ***Historical and future vessel deliveries by propulsion type, 2017-2028***



Source: *IGU 2023 World LNG Report*

3.2.3. Small Scall LNG Distribution

LNG carriers are primarily used to transport LNG from export terminals in one country to import terminals in another. Additionally, they are designed to handle large capacities to make the transfer economically viable. The standard capacity for LNG carriers is approximately 174,000 m^3 currently, although it can vary between 138,000 m^3 - 266,000 m^3.

In regions where LNG demand fluctuates significantly during the year — such as during peak shaving in winter or due to geopolitical tensions affecting demand — there is a need for supply flexibility. Additionally, there may be requirements to cover areas that are distant from existing LNG terminals, like remote islands or newly developed LNG bunkering facilities. To meet these smaller and specific LNG needs, the small-scale LNG carriers' market has emerged, catering to local trade or bunkering operations. The market for small LNG carriers received a boost from the IMO's Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) regulations, which gives a good opportunity to shipowners to turn to LNG to comply with environmental regulations. As a result, there has been an increase in the construction of small LNG carriers for bunkering purposes.

The bunkering vessels market, which involves refueling LNG-fueled vessels, has seen growth in recent years. Truck-to-ship transfer is currently the most common configuration at terminals and ports due to its low capital investment and minimal infrastructure requirements. However, ship-to-ship and shore-to-ship transfer methods are gaining popularity due to their ability to handle larger storage capacities and higher flow rates. Europe and Asia have been at the forefront of adopting these newer transfer methods.

Most LNG bunkering vessels use Type C tanks, but some newer vessels employ membrane tanks, specifically those with GTT Mark III Flex technology. These newer designs focus on improving the bunkering operation and fender installation. Pressure differences between bunkering vessels with Type C tanks and dual-fuel ships with membrane tanks can be an issue during the transfer of LNG, necessitating decompression.

Regulations for bunkering conventional fuels were already in place, but for LNG transfer, port authorities had to start from scratch. Establishing bunkering regulations involved creating working groups and gaining acceptance from local authorities, government officials and the public which led to a slower development process. Nevertheless, the number of ports worldwide offering LNG bunkering has been steadily increasing, with plans for more facilities in the future to meet the growing demand. According to Clarkson's research, there are 185 ports offering LNG bunkering, and this number is expected to reach 235 by 2025.

4. Downstream

4.1. Storage & Regasification Terminal

Traditionally, LNG has been re-gasified at its destination for utilization as natural gas, a predominant practice to this today. The exception lies in a portion of LNG used solely as transport fuel for road, rail or maritime transport.

Conventional regasification terminals are onshore facilities equipped with jetties to receive LNG carriers and large storage tanks for liquid LNG storage. Sufficient storage capacity is vital to maintain a steady market supply between incoming cargoes and to accommodate a full cargo with each ship arrival. The process involves pumping LNG through onshore regasification facilities before distributing it via pipelines or delivering it to end consumers.

4.2. FSRU

The emergence of Floating Storage and Regasification Units (FSRUs) occurred in the early 2000s, introducing a floating counterpart to the onshore regasification terminal. FSRUs are predominantly ships with added regasification capabilities, allowing them to serve as carriers or be anchored in specific locations to provide storage and regasification services. The inherent advantages of FSRUs include swift deployment, mobility to shift between locations, construction in a controlled shipyard environment and cost-effectiveness for entering new markets. Additionally, the risk associated with FSRU deployment is considerably lower compared to developing new land-based solutions, as the unit can be moved or traded in response to market changes.

4.3. Distribution

4.3.1. Power Generation

Regassified LNG is, most commonly, utilized for power generation. It is not unusual for the power plant and regasification unit to be situated adjacent to each other. Innovative applications of regasification cold energy have been employed in specific locations like Malta and the Netherlands. In Malta, the cold energy is harnessed to chill the inlet air to the gas turbines used in the power plant, effectively increasing the thermal efficiency of the facility. Conversely, in the Netherlands, where seawater temperatures are too cold for use as a heating medium during wintertime and freezing or clogging of the vaporizer heat exchangers must be avoided, the vaporizer circuit exchanges energy with onshore industrial waste heat to mitigate these challenges.

4.3.2. Heating

Regassified LNG, in its natural gas form, serves as an excellent medium for providing heat in both distributed and centralized systems. Often, steam or hot water is employed for heating and heat distribution purposes. Utilizing natural gas as a clean and efficient burning fuel supply renders it an ideal choice for such applications.

4.3.3. Chemical Plants

Natural gas serves a dual role in chemical plants, acting as both a valuable feedstock and a reliable fuel source. While providing an exhaustive list of the various chemical plant applications is impractical, it is noteworthy that natural gas can serve as the foundation for essential greener fuels in the energy transition like methanol, hydrogen and ammonia. The environmental attributes of these emerging fuels will be determined by the origin of the natural gas and the processing methods employed, including the management of waste streams.

4.3.4. GTL

Gas to Liquids (GTL) primarily involves the widely employed Fischer Tropsch reaction wherein natural gas serves as the feedstock for a catalytic conversion process, producing longer hydrocarbon chains that find application as transport fuel. Leading energy companies have devoted substantial resources to the development of GTL technologies and cutting-edge catalysts.

Additionally, methanol represents another form of gas to liquids conversion wherein gas acts as the feedstock, yielding methanol as the liquid product. In the past, methanol was predominantly produced as a feedstock material. However, with the ongoing energy transition, methanol has evolved into a preferred fuel choice, serving both as a standalone fuel and as an additive to enhance the oxygen content in transport fuels.

As the industry looks ahead, a surge in gas to liquids projects is anticipated, driven by the objective of creating cleaner fuels to support the energy transition. These projects may encompass diverse applications such as methanol, ammonia and other promising ventures. The level of environmental friendliness of these initiatives will hinge on multiple factors: the source of the feed gas, the processing techniques employed along the value chain, the management of fugitive emissions and the incorporation of mitigating technologies such as carbon capture and sequestration.

5. New Technology Trends

In recent times, there has been a notable inclination towards floating applications, primarily driven by the advantages they offer (e.g., rapid project development, ease of redeployment and the convenience of constructing in a controlled environment within shipyards).

Floating LNG (FLNG) made its first Financial Investment Decision (FID) in 2011, and the initial operational unit, the Golar Hilli conversion for Cameroon, commenced production in 2018. Subsequently, several more FLNG units have become operational, with many others progressing through the project execution phase.

The nature of wellstreams extracted from gas reservoirs can significantly vary. Consequently, feeding these wellstreams directly to the floater would entail distinct feed separation and clean-up requirements, depending on the characteristics of the field. To address this challenge and enhance the units' ability of redeployment, certain designs are tailored to handle pipeline quality gas. In such cases, a sweet gas stream can be directly fed to the FLNG unit, while bulk separation of liquids and/or acid gas treatment (for associated or sour gas) can be accommodated on another production unit or onshore, if necessary.

These considerations highlight that the entire processing chain may be distributed across one or more units. For instance, the Prelude FLNG, a sizable unit, performs all inlet processing, liquefaction and storage of condensate, LPG and LNG on the same floater. Conversely, the more generic floaters like Golar Hilli and Exmar Tango address bulk separation before reaching the FLNG, with onboard storage dedicated solely to LNG. In cases where Exmar Tango's feedstream contains LPG, it is commonly utilized as fuel for power generation. As Tango moves to its next assignment in Congo, it will require increased LNG storage capacity and will thus collaborate with an FSU to ensure seamless filling of an LNG carrier without excessive demurrage.

Innovative approaches, like combining Floating Storage Units (FSUs) with regasification on barges, have also been explored. This setup combines a suitable storage vessel with a regasification unit featuring some storage capacity. Notable instances include applications in Ghana and Eemshaven in the Netherlands. In Ghana, a regas barge with buffer storage complements an FSU while Eemshaven utilizes a full-scale FSRU alongside a barge FSRU. The latter configuration provides larger peak regasification capacity. Additionally, it provides the storage volume of the full-scale FSRU in combination with the 26,000 m^3 storage of the regasification barge. To maximize the utility of these assets throughout their lifespan, most FSUs intended for these purposes are either converted into permanently moored floating storage or serve intermittently in a storage function before resuming trading of commercial cargoes. This ensures their continued viability even if they no longer boast the most cutting-edge propulsion technology.

Furthermore, LNG storage and regasification technology have found synergy with floating power generation. While diesel-powered power barges have been operational for some time, gas-fueled power barges and power ships have recently entered service. In cases where these gas-fueled power generating units are not connected to a gas grid, they are typically equipped with a dedicated FSRU, either in the form of a ship-shaped unit or a barge. Kar-power, a significant player in the floating power arena, has established a gas-fueled power ship with a desiccated FSRU in Senegal, further exemplifying the diverse applications and innovative solutions in the domain of floating LNG and power generation.

6. Colors of LNG "Gray/Blue/Green"

6.1. Definition

Blue: Blue LNG refers to conventional LNG produced using the traditional method of extracting natural gas from underground reserves, liquefying it and transporting it via LNG carriers. In this context, the term "blue" represents the efforts to reduce or offset carbon emissions through carbon capture and storage (CCS) technologies. These technologies capture the carbon dioxide emissions generated during the LNG production process and store them in geological formations deep underground, preventing them from being released into the atmosphere. By doing so, blue LNG aims to reduce the overall carbon footprint and environmental impact associated with traditional fossil fuel-based LNG production and transportation. However, the environmental impact of blue LNG is still a point of concern as it involves the release of carbon dioxide and other greenhouse gases (GHG) during the extraction and liquefaction processes.

Green: Green is often used to symbolize environmentally friendly or sustainable practices. In the context of LNG, green LNG refers to liquefied natural gas that has been produced using low-carbon or zero-carbon sources. This might include LNG derived from renewable energy sources like biomethane or synthetic methane (e-methane) produced using a low emission hydrogen and carbon component from CCS technologies. Green LNG is seen as a cleaner alternative to traditional LNG as it has a reduced carbon footprint.

Gray: Gray LNG is not a type of LNG with environmental benefits. Instead, it refers to conventional LNG produced from fossil fuels without any efforts to reduce GHG emissions or carbon footprint. Gray LNG is the most polluting and environmentally detrimental type as it releases significant amounts of carbon dioxide and other GHGs during its entire production and transportation process. For this reason, it lacks the efforts towards sustainability and emission reduction found in green LNG options which prioritize renewable and low-carbon sources. It also lacks efforts found in conventional blue LNG which often implements carbon capture and storage technologies to mitigate environmental impact.

However, it's important to note that the specific meanings associated with colors in the LNG industry may vary depending on industry practices, regulations or specific initiatives.

6.2. Incentives

Green and blue LNG are terms often used to describe more environmentally friendly options in the liquefied natural gas industry. However, there are several potential incentives for using green or blue LNG:

Regulatory Incentives:

1. **European Union (EU):** The EU has been actively promoting the use of cleaner and more sustainable energy sources, including LNG. It has implemented regulations and initiatives such as the European Green Deal and the EU Gas Market Directive which is aimed at decarbonizing the energy sector and reducing greenhouse gas emissions (GHG). These policies provide incentives and support for the development and utilization of blue and green LNG, encouraging investments and regulatory backing for environmentally friendly projects.

   The EU recognizes the important role that LNG plays in its energy security, especially after recent geopolitical events led to a shortage of gas supply followed by volatile LNG prices globally. Furthermore, the EU parlement amended regulations EU 2017/1938 and EC No. 715/2009 in 2022 regarding gas storage imposing on member state. Effective on 1st November 2023, a minimum filling limit of 90 percent will be enforced each year. The regulation also addresses the sharing of storage between member states, the advantages of pool ordering and the certification of underground storage sites.

   The EU recognizes that the importance of LNG is the transport, heat and power sectors. Using LNG in lorries and shipping can reduce emissions of various pollutants, offering a pathway for ships to meet decreasing sulfur and nitrogen content targets in marine fuels used in the Emission Control Areas. When blended with liquid biomethane, the use of LNG can have significant GHG emissions reductions, particularly for heat and power. In line with its sustainability goals, it's expected that the EU will continue supporting the growth of LNG as an alternative fuel as part of its future energy mix, especialy where LNG replaces more polluting conventional fuels and does not compete with renewable energy sources.

   In 2023, the EU has adopted, as part of the Fit for 55 package, the deployment of the Alternative Fuels Infrastructure Directive (AFID). It requires EU countries to develop national policy frameworks (NPFs), aiming to put in place enough refueling and recharging facilities for certain alternative fuel vehicles and vessels.

   For natural gas supply, the AFID requires Member States to ensure that, by the end of 2025, an appropriate number of compressed natural gas (CNG) refueling stations are available for CNG motor vehicles along the core network of the trans-European transport network (TEN-T). The directive recommends that the distance between these stations shouldn't exceed 150km. To allow the free circulation of LNG heavy-duty motor throughout the EU, the directive suggests keeping the maximum distance between refueling stations to 400km. The AFID also requires Member States to ensure that an appropriate number of refueling points for LNG are put in place at maritime ports by 2025 and inland ports by 2030. This can help enable LNG inland waterway vessels or seagoing ships to circulate throughout the TEN-T core network.

2. **United States:** In the United States, regulatory incentives for blue and green LNG vary at federal, state and local levels. While the federal government provides oversight and regulations for LNG exports, states like California have implemented policies and incentives to promote cleaner and lower-carbon energy sources. Additionally, incentives such as tax credits and grants for clean energy projects may indirectly support blue and green LNG development.

   The below list contains highlights of some Federal laws and incentives related to natural gas.

Incentives	Highlights
Advanced Biofuel Feedstock Incentives (Reference Public Law 113-79 and 7 U.S. Code 8111)	- Qualified feedstock producers are eligible for a reimbursement of 50 percent of the cost of establishing a biomass feedstock crop. - Matching payments for the collection, harvest, storage and transportation of their crops to advanced biofuel production facilities for up to two years.
Alternative Fuel Corridor (AFC) Grants (Reference Public Law 117-58 and 23 U.S. Code 151)	Provide funding for designated **Corridor-Pending** AFCs to install infrastructure to convert to **Corridor-Ready** AFCs, and for **Corridor-Ready** AFCs to install alternative fuel infrastructure to provide station redundancy and meet higher demand.
Alternative Fuel Excise Tax Credit (Reference 26 U.S. Code 6426 and Public Law 117-169)	- For alternative fuel sold to operate a motor vehicle. - $0.50 tax credit per gallon
Alternative Fuel Infrastructure Tax Credit (Reference 26 U.S. Code 30C, 30D, and 38 and Public Law 117-169)	Fueling equipment is eligible for a tax credit of 30 percent of the cost or six percent in the case of property subject to depreciation (Max $100,000).
Alternative Fuel Tax Exemption (Reference 26 U.S. Code 4041)	- Are exempted motor vehicle used: on a farm for farming purposes; in certain intercity and local buses; in a school bus; for exclusive use by a non-profit educational organization; for exclusive use by a state, political subdivision of a state, or the District of Columbia.

3. **Japan:** Given Japan's heavy reliance on imported LNG, there is a strong incentive to promote the use of cleaner and more sustainable LNG. The Japanese government has implemented various policies and regulations to support green and blue LNG, including financial incentives and subsidies for low-carbon projects. Japanese institutions like the Japanese Bank for International Cooperation (JBIC) and Nippon Export and Investment

Insurance also play a significant role in providing financial support to LNG projects.

Financial Incentives:

1. **Green Financing:** Financing institutions are increasingly interested in supporting environmentally sustainable projects, including green and blue LNG. They provide financial incentives in the form of green bonds, green loans or sustainability-linked loans. These financial products offer favorable terms, lower interest rates, or longer repayment periods to projects that meet specific environmental criteria, encouraging the development of green and blue infrastructure.
2. **International Financial Institutions:** Development banks like the World Bank, European Bank for Reconstruction and Development and Asian Development Bank, actively support sustainable energy projects, including blue and green LNG. They provide funding, grants or guarantees to mitigate risks and incentivize investments in environmentally friendly initiatives.
3. **Export Credit Agencies (ECAs) and Export-Import Banks:** ECAs, such as the Export-Import Bank of China (China Exim) and Japan Bank for International Cooperation (JBIC), can provide financial support to LNG projects. They offer loans, credit guarantees and insurance to mitigate financial risks and promote investment in clean energy projects.

While the specific incentives and involvement of financial institutions may vary by region, the overall trend is toward supporting and incentivizing blue and green LNG through regulations, policies, green financing options, and involvement from international financial institutions.

7. Environmental Aspect

7.1. Regulatory Framework

The regulatory framework for environmental considerations of LNG encompasses various aspects, including the transportation of LNG for large vessels and small-scale vessels, regulations related to LNG bunkering and LNG as fuel and industry standards set forth by organizations like the Society for Gas as a Marine Fuel (SGMF) and the Society of International Gas Tanker and Terminal Operators (SIGTTO).

Regulatory framework for the transportation of LNG: The transportation of LNG involves adherence to specific regulations to ensure safety and environmental protection. For large vessels, the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC code) sets out the design, construction and operational requirements for LNG carriers. It covers aspects such as materials, insulation, containment systems, ship structure and safety systems, to name a few. The IGC code aims to prevent accidents and minimize the release of gas or vapors during transportation.

When it comes to small-scale LNG vessels, regulations may vary depending on the jurisdiction. In the United States, for example, the U.S. Coast Guard and the Department of Transportation have established regulations such as Title 46 Code of Federal Regulations, Subchapter D - Tank Vessels, which provides requirements for the safe transportation of LNG on small-scale vessels.

Regulations related to LNG bunkering and LNG as fuel: The bunkering of LNG refers to the process of supplying LNG to ships or other vessels for use as fuel. The International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF code) regulates the safe use of gases or low-flashpoint fuels as ship fuels. The IGF code provides guidelines for the design, construction and operation of ships using LNG as fuel, as well as fire safety measures and training requirements for crews.

Additionally, several countries and regions have developed their own regulations specific to LNG bunkering operations. For instance, the European Union has instruments like the Alternative Fuels Infrastructure Directive (AFID) and the standard EN 1474, which establish requirements for the design and operation of LNG bunkering facilities in Europe.

Industry standards by SGMF and SIGTTO: The Society for Gas as a Marine Fuel (SGMF) and the Society of International Gas Tanker and Terminal Operators (SIGTTO) are industry organizations that contribute to the development and promotion of best practices and standards for the safe and environmentally responsible use of LNG.

SGMF develops guidelines, recommendations and industry best practices for the safe and sustainable use of gas as marine fuel. They cover areas such as bunkering operations, storage and handling of LNG, risk assessments and emergency response procedures.

SIGTTO focuses on the safe and efficient operation of gas tankers and terminals. They provide guidance and standards related to LNG carriers, terminals and utilization of LNG as fuel for marine applications.

These industry standards developed by SGMF and SIGTTO complement existing regulatory frameworks and help ensure consistent practices and high safety standards in the LNG industry.

To conclude, the regulatory framework for environmental considerations of LNG encompasses regulations for transportation, bunkering and the use of LNG as fuel. It is guided by international codes such as the IGC code, the IGF code and regional regulations. Additionally, industry organizations like SGMF and SIGTTO play a critical role in developing industry standards and best practices for the safe and environmentally responsible use of LNG in various applications.

7.2. Methane Slip

Methane slips in the LNG value chain refer to the unintentional release of methane during the production, transportation, storage and use of LNG. Fugitive emissions are a significant contributor to methane slips and can occur from various sources such as processing equipment, pipelines, storage tanks, valves and compressors. These emissions should be measured and mitigated to minimize their impact on the environment.

The greenhouse gas (GHG) impact of methane slip is of particular concern due to the potent warming effect of methane compared to carbon dioxide. Methane has a much higher global warming potential (GWP) over a 20-year timeframe (84-86 times that of CO^2). Therefore, even small leaks or slips of methane can have a significant impact on climate change. It is crucial to address methane slips to ensure that the use of natural gas and LNG remains environmentally sustainable.

While the International Maritime Organization (IMO) does not have specific regulations for methane slips yet, efforts to develop such a regulatory framework show that such regulations might be enforced by EEDI phase 4. During MEPC 80, IMO has adopted the "Guidelines on Life Cycle GHG Intensity of Marine Fuels" (LCA Guidelines) which will address Well-to-Tank (WtT), Tank-to Wake (TtW) and Well-to-Wake (WtW) GHG intensity, including methane emissions. Under MARPOL Annex VI, ships will be required to control and minimize methane emissions during operation.

In the European Union (EU), regulations for methane slip are incorporated into the broader framework of reducing GHG emissions Fit for 55. As methane slip is considered as a percentage of the fuel mass used by the engine, the EU has set targets for reducing methane emissions from various sectors, including the maritime industry. The EU's Monitoring, Reporting and Verification (MRV) regulation requires ships to report their CO^2 emissions and provides a framework that indirectly addresses methane slips. In 2025, the FuelEU for Maritime regulation plans to limit CO^2-eq emissions from ships on a well-to-wake basis.

In the U.S., regulations related to methane slip from LNG operations have evolved over time. The Environmental Protection Agency (EPA) has implemented several initiatives to address methane emissions, including from the oil and gas sector. Although there is no specific regulation solely focused on methane slips in the LNG industry, existing regulations and initiatives — such as the EPA's New Source Performance Standards (NSPS) for the oil and gas industry — indirectly contribute to reducing methane slips.

It is worth noting that regulations related to methane slips from LNG operations are continually evolving as policymakers, and governing bodies become more aware of the environmental impact. The focus on reducing methane emissions and addressing methane slips aligns with the global commitment of combating climate change and achieving GHG reduction targets. As a result, it is essential for the industry to maintain compliance with current regulations and stay informed about any future regulatory developments regarding methane slips.

8. Market Realities

8.1. Global Energy Demand

The global demand for liquefied natural gas (LNG) has witnessed a significant increase over the past decade and is expected to continue growing rapidly in the future. This surge in demand can be attributed to the increased interest in cleaner energy sources to fuel economic growth to replace coal and traditional oil-based fossil fuels. LNG, which is produced through the liquefaction of natural gas, has emerged as a crucial component in meeting the energy requirements of various regions across the globe. One of the key factors driving the development of gas resources in developing countries is the promotion of domestic access to energy resources and the growth of the electricity and industrial sectors.

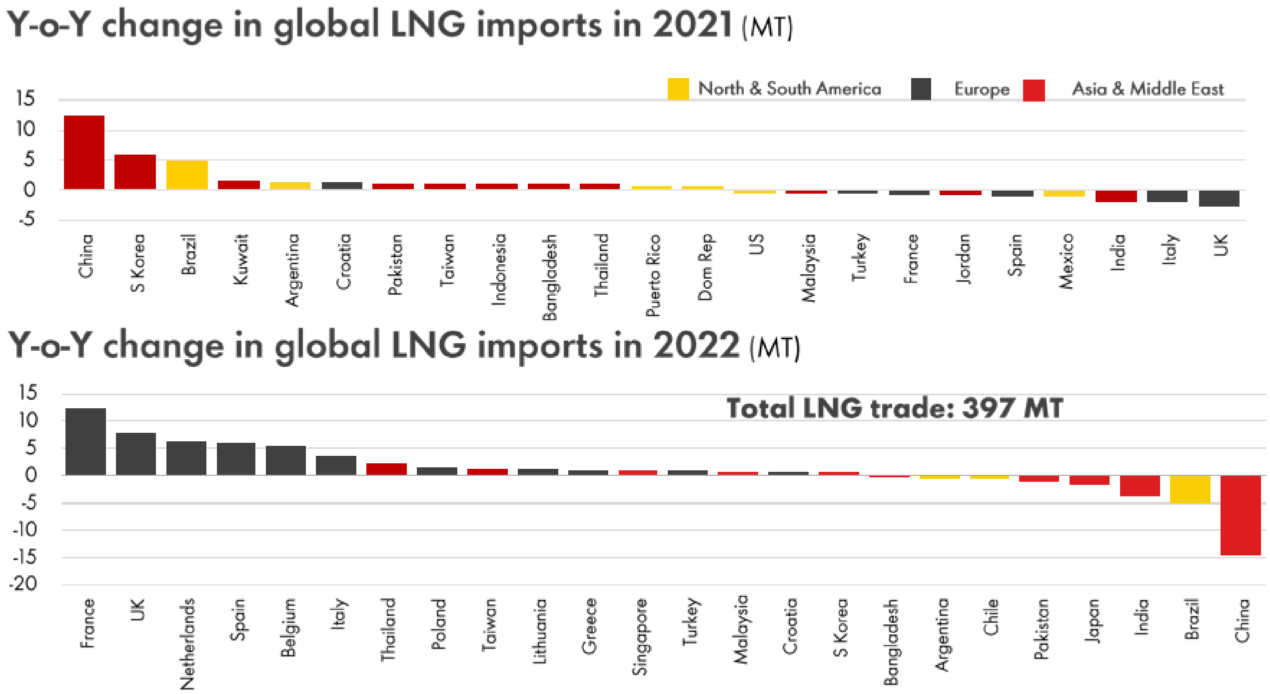
LNG exports have become a viable option for those countries to secure the financial resources required for developing their gas resources. Furthermore, LNG export projects typically allocate a portion of the gas for domestic consumption while the rest is directed towards the liquefaction plant. This approach enables countries to meet their domestic energy needs while also tapping into the global LNG market. As a result, LNG plays a critical role in promoting energy security by diversifying energy sources and reducing reliance on traditional fossil fuels.

In the context of recent events, such as the Russia-Ukraine war, the role of LNG in global energy security becomes even more significant. This conflict has highlighted the vulnerabilities associated with relying heavily on a single source or route for energy supplies. 2022 has been a year of all exceptions in the LNG market. With the cut of gas supplies from Russia, the EU needed over 45Mt of LNG to meet its energy needs. Supply routes shifted from the traditional Fareast consumers to Europe. LNG prices tripled compared to the pre-war within just three months to reach over $95 MBTU. Furthermore, Figure 5 shows how the LNG import market over the last two years flipped from the Asian market being the largest importer of LNG in 2021 to the European market leading the imports in 2022.

The ability to transport LNG from producing regions to distant countries provides an opportunity to diversify energy supply chains and reduce geopolitical risks. By unlocking stranded natural gas resources and establishing LNG infrastructure, countries can enhance their energy security and reduce their dependency on specific regions for energy imports.

LNG offers several advantages in terms of flexibility, reliability and lower emissions compared to other fossil fuels. Its ability to be transported over long distances makes it an attractive option for meeting the energy demand of countries that lack domestic gas reserves. Furthermore, LNG can contribute to a more sustainable energy future by significantly reducing GHG emissions when compared to coal or oil, especially when its Well-To-Tank CO^2 footprint has been reduced through carbon capture and storage (CCS) technologies producing blue LNG. This makes LNG an important part of the global strategy to transition to cleaner energy sources and address climate change concerns.

Figure 4: Global LNG Trade reversed in 2022



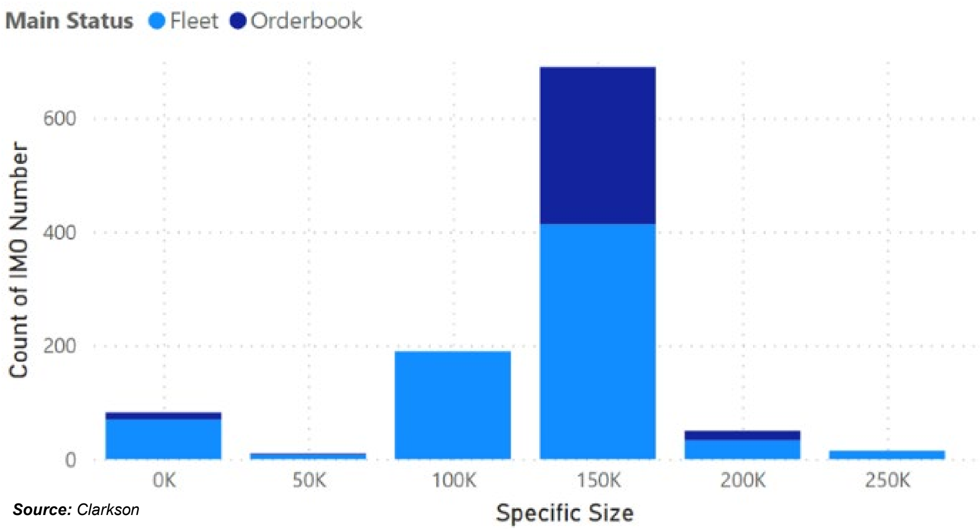
Source: *Shell LNG Outlook 2023*

In conclusion, LNG will continue to play a crucial role in meeting the future global energy demand. Its significance is amplified by recent geopolitical events and the need to enhance energy security. By leveraging LNG as a cleaner and more flexible energy source, countries can diversify their energy supply chains and reduce their reliance on specific regions. This, in turn, contributes to a more secure and sustainable energy future for the global community.

8.2. LNGC Fleet & Orderbook

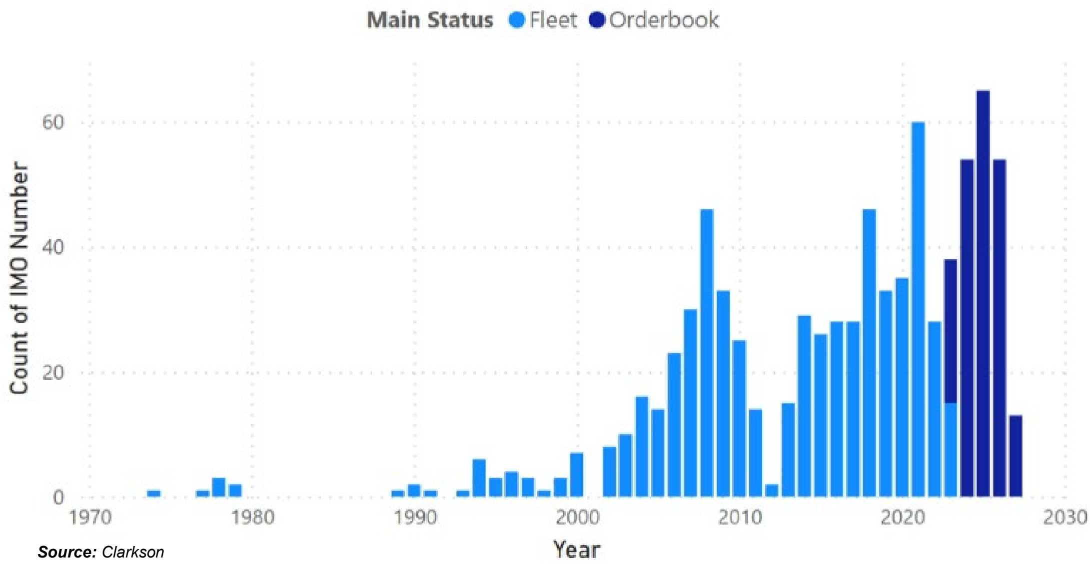
The global LNG carrier fleet plays a crucial role in the transportation of LNG from production facilities to consumption markets around the world. The LNG carrier fleet consists of specialized vessels designed to safely transport LNG at extremely low temperatures and under precise storage conditions. These vessels are equipped with advanced technology and insulation systems to ensure the integrity and safety of the cargo throughout the journey.

The LNG carrier (LNGC) fleet is constantly evolving and expanding to meet the growing demand for LNG. The LNG carriers orderbook shows almost 50 percent growth. Over 300 vessels have been ordered to the existing world fleet of just over 650 vessels (see Figure 6). This historical orderbook reflects the investments and commitments made by companies to meet the anticipated increase in LNG production and consumption. By analyzing the LNGC fleet and orderbook, industry stakeholders and market analysts can assess the supply-demand dynamics of the LNG market and make informed decisions regarding infrastructure investments and energy strategies.



Source: Clarkson

Figure 6: Gas Carrier Fleet and Orderbook by size



Source: Clarkson

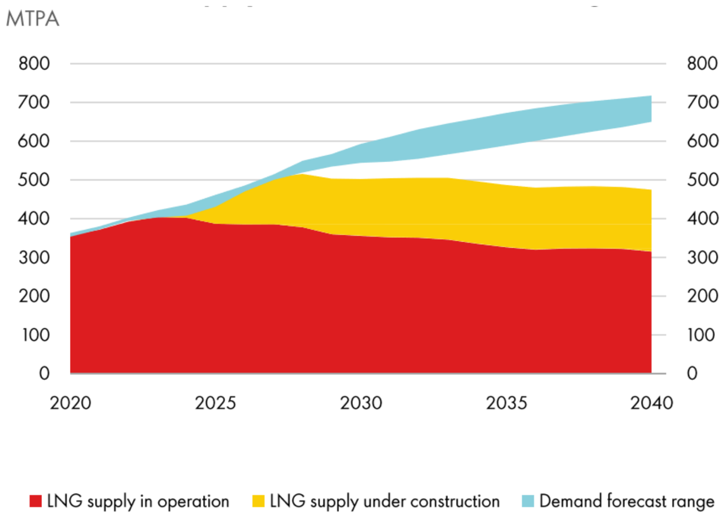
Figure 5: Evolution of Gas Carrier Fleet and Orderbook

The size and capacity of LNG carriers vary, with vessels ranging from small-scale carriers to large-scale vessels capable of transporting huge volumes of LNG. The LNGC fleet includes both single-screw and dual-screw vessels, each designed to cater to specific operational requirements and trade routes. The fleet is predominantly made up of vessels with membrane-type cargo containment systems, which provide excellent thermal insulation and allow for efficient loading and unloading of LNG.

It is important to consider factors such as vessel age, technological advancements and environmental regulations when evaluating the LNGC fleet. As older vessels are retired from service, new orders are placed for technologically advanced carriers that offer improved efficiency, safety and environmental performance. The adoption of new technologies and design features helps to reduce fuel consumption and greenhouse gas emissions, contributing to sustainability efforts in the maritime industry. The retirement of the older vessels, which are mainly steam propelled, accounts for about of a third of the existing fleet. This transition is expected to further test the resilience of the LNG supply chain in the coming years while maintaining high prices for LNG.

In recent years, the LNGC fleet has witnessed significant growth, driven by the expansion of LNG production and the development of new liquefaction plants in various regions. This growth is expected to continue as demand for LNG increases, particularly in Asia, where countries like China, Japan and South Korea have been major LNG importers. The orderbook reflects this trend, with a substantial number of LNG carriers being built to cater to the anticipated demand from these markets.

Figure 6: Global LNG Supply vs Demand Forecast



It is to be noted that there are some uncertainties related to countries' commitment in pushing regulations and implementing measures to support their respective pledges to reduce GHG emissions. With these uncertainties, investors have shied away from reaching FID for several LNG projects. Figure 8 shows that, after 2028, demand overcomes supply mainly because of a lack in investments. Unless the energy demand is met by new renewable sources of energy, this situation might stress the global energy market further.

In closing, the LNGC fleet and orderbook are critical indicators of the current and future state of the LNG industry. The fleet consists of specialized vessels designed to transport LNG safely and efficiently, while the orderbook reflects the investments and commitments made by companies to meet the growing demand for LNG. By monitoring the LNGC fleet and orderbook, industry stakeholders can gain insights into the supply-demand dynamics of the LNG market and make informed decisions to support the growth and sustainability of the industry.

8.3. Contracts & Pricing

LNG sales contracts are crucial components of the LNG industry as they define the terms, commitments and pricing arrangements between sellers and buyers. There are different types of LNG sales contracts, each with their own advantages and disadvantages. Below is a list of the various contracts with their pros and cons:

1. *Long-Term Contracts:*
   - *Pros:* Long-term contracts provide stability and security for both sellers and buyers as they typically span over several years or decades. They allow for long-term planning, investment and project

development. Additionally, these contracts often include firm commitments and fixed or indexed pricing mechanisms, providing price stability for both parties.

- *Cons:* Long-term contracts can limit flexibility and responsiveness to market changes. The fixed pricing mechanisms may not always reflect current market dynamics, and buyers may be locked into higher prices during periods of low LNG market prices. Additionally, long-term contracts may not allow for easy diversification of supply sources.

2. *Short-Term Contracts:*
   - *Pros:* Short-term contracts offer more flexibility and allow buyers to procure LNG on shorter notice, adapting to changes in demand or market conditions. These contracts usually have more flexibility in pricing arrangements, such as pricing based on gas indices. They provide an opportunity for buyers to secure LNG cargoes during periods of low prices.
   - *Cons:* Short-term contracts may be subject to higher price volatility compared to long-term contracts. The availability of LNG cargoes under short-term contracts is dependent on spot market availability and can be uncertain. Sellers may also prioritize long-term contract customers over short-term buyers during times of limited supply.
3. *Spot or Spot-Flexible Contracts:*
   - *Pros:* Spot contracts provide the highest level of flexibility, allowing buyers to procure LNG on the spot market and usually on a cargo-by-cargo basis. These contracts offer the advantage of capitalizing on favorable market conditions such as lower prices or abundant supply. Spot-flexible contracts provide the option for a mix of spot and long-term volumes, allowing buyers to optimize their procurement strategy.
   - *Cons:* Spot contracts can be subject to significant price volatility as they are influenced by short-term market conditions. The availability of spot cargoes may vary, and buyers may face challenges in securing desired volumes during peak demand periods.

In terms of trends in LNG sales contracts, there is an increasing focus on pricing mechanisms that are more gas-linked rather than oil-linked. This shift is driven by the desire for greater transparency, fairness and alignment with natural gas market fundamentals. Gas-linked pricing allows for a more direct reflection of supply-demand dynamics in the LNG market, therefore, reducing exposure to oil price fluctuations and geopolitical factors.

Another trend is the emergence of pricing review clauses in LNG sales contracts. These clauses enable periodic re-evaluation and potential adjustment of LNG prices based on specified market conditions. This mechanism allows for a degree of flexibility and adaptability to evolving market dynamics, ensuring that contract prices remain reflective of prevailing market conditions.

Moving on to LNG carrier chartering contracts, there are various types available to meet the transportation needs of LNG. Each type has its own advantages and disadvantages as indicated below:

1. *Time Charter:*
   - *Pros:* Time charter contracts provide long-term vessel availability and dedicated use for a specific period. Charterers have more control over the vessel's schedule and flexibility in terms of loading and discharge ports. This type of contract offers more predictable costs and allows for better planning and optimization of logistics.
   - *Cons:* Time charter contracts can be expensive as charterers bear the cost of vessel operations. In case of low cargo demand, charterers may face idle time or underutilization of the vessel.
2. *Voyage Charter:*
   - *Pros:* Voyage charter contracts provide flexibility and cost efficiency, as they are signed for specific voyages or cargoes. Charterers pay only for the voyage undertaken, reducing costs during periods of low cargo demand. This type of contract allows for more flexible scheduling and greater access to available vessels.
   - *Cons:* Voyage charter contracts can be subject to spot market rates, leading to price volatility. Charterers may face uncertainty in vessel availability, especially during peak demand periods. The cost per ton of transported LNG may vary for each voyage.

During the last decade, the global supply and demand trends have had a significant impact on LNG prices. The LNG market has witnessed a shift from a supply-driven market to a more demand-driven market, with increasing competition among suppliers. This change in dynamics has put downward pressure on LNG prices.

The global LNG market has experienced a surge in liquefaction capacity, particularly in the United States and Australia. This increase in supply, combined with slower demand growth in certain regions, has created an oversupply situation which leads to lower prices.

Additionally, the COVID-19 pandemic and its impact on global energy demand has further affected LNG prices, resulting in a temporary decline in prices. However, recent geopolitical events overturned this dynamic after sudden drops of approximately 82Bcm in gas supply to the European Union, therefore, creating a shortage of supply that saw historically high prices.

On the demand side, Asian markets — particularly China, Japan, Korea and India — traditionally drove the primary growth of LNG demand while Europe demand was balancing the global market. Since 2022, the roles reversed with the European market being the primary driver while the Asian markets became less demanding due to government commitment to diversify their energy mix, including more renewables, developing their own domestic production and increasing regional pipeline gas import. Figure 9 highlights the shift in LNG import between China and the EU.

Figure 7: Global LNG Imports

Source: *Shell LNG Outlook 2023*

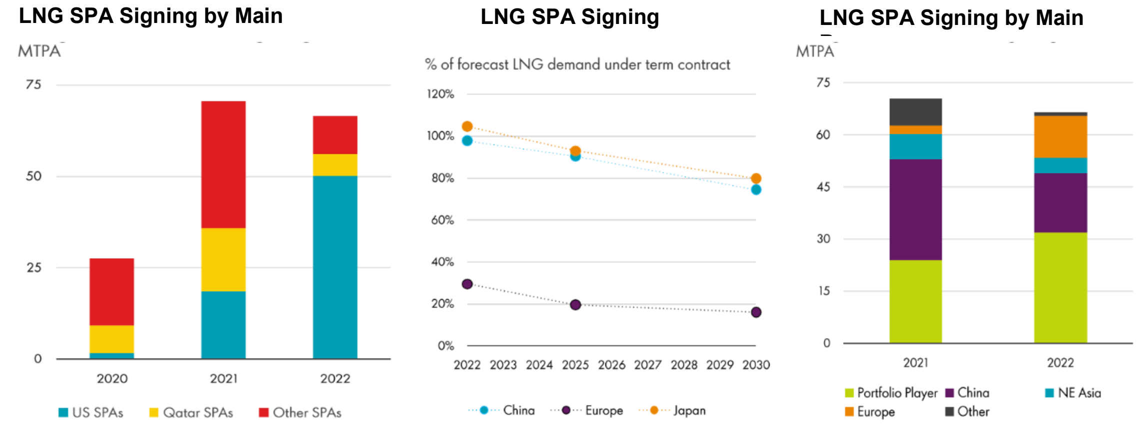
As these countries shift towards cleaner energy sources, LNG consumption is expected to increase significantly in the coming years. However, the pace of demand growth has varied, and temporary market imbalances have led to periods of higher LNG prices.

The recent trend of global LNG supply and demand has prompted a more flexible approach in LNG pricing. Buyers are increasingly seeking flexible pricing arrangements that are linked to gas indices or market fundamentals. This allows for a more transparent and responsive pricing mechanism that reflects current market conditions.

Furthermore, even though recent supply disturbances have led to an increase in signing of Sales and Purchase Agreements (SPA) between major buyers and main LNG exporters to secure their energy supply and control the volatility of LNG prices (see Figure 10), there is a growing emphasis on shorter contract durations and greater flexibility in contract terms. Buyers are seeking shorter-term contracts that provide the ability to adjust procurement strategies based on evolving market dynamics. This flexibility allows buyers to take advantage of market opportunities and optimize portfolio management.

In terms of the impact on LNG prices, the oversupply situation has resulted in a more competitive market, leading to a downward pressure on prices. Pricing mechanisms that were predominantly oil-linked in the past are being revised to ensure a closer correlation between LNG prices and natural gas market fundamentals. This trend is driven by the desire to eliminate the disconnect between oil prices and gas prices which can be influenced by different factors.

On the other hand, emerging trends such as the rise of LNG spot trading and the development of LNG trading hubs are contributing to price transparency and liquidity in the market. Spot trading allows for more short-term price discovery and flexibility while trading hubs provide a central platform for buyers and sellers to trade LNG on a more standardized basis.



Source: *Shell LNG Outlook 2023*

Figure 8: Global LNG SPA Outlook

In summary, the LNG market is witnessing changes in contract types, pricing mechanisms and transportation agreements. Long-term contracts provide stability but may limit flexibility, while short-term and spot contracts offer more adaptability to market conditions. Pricing is shifting towards gas-linked formulas, driven by the need for transparency and alignment with natural gas market fundamentals. The recent global supply and demand trends, including increased liquefaction capacity and shifting demand patterns, have impacted LNG prices, therefore, leading to a more competitive market and pressure on prices. However, market participants are adapting to these changes by seeking more flexible contracts and pricing arrangements that reflect current market dynamics and allow for optimization of LNG procurement strategies.

9. Societal Perspective

9.1. Livelihood

Liquefied natural gas (LNG) projects have the potential to significantly impact — both positively and negatively — livelihoods in communities where they are located. The impact can vary depending on the type of LNG project and its approach to environmental and social responsibility. The development of green and blue LNG, which prioritize reduced emissions and sustainable practices, can have several positive effects on livelihoods.

Green LNG, also known as renewable or decarbonized LNG, involves the production of LNG from renewable energy sources such as solar, wind or hydropower. This form of LNG significantly reduces greenhouse gas emissions compared to conventional LNG. The impact of green LNG on livelihoods can be beneficial in several ways:

1. *Job Creation:* The development and operation of green LNG projects can create employment opportunities for local communities. This includes jobs in renewable energy infrastructure such as solar or wind farms, as well as in the LNG production and supply chain. These job opportunities can contribute to the economic development and prosperity of the communities.
2. *Sustainable Economic Growth:* Green LNG projects promote sustainable economic growth by supporting the transition to a low-carbon economy. By embracing renewable energy sources, these projects contribute to energy diversification, reduce dependence on fossil fuels and foster the growth of sustainable industries. This can lead to long-term economic stability and improved livelihoods for local communities.
3. *Environmental Benefits:* Green LNG projects help mitigate climate change by reducing carbon emissions. This has positive implications for the environment and the health of communities. The improved air quality and reduced environmental pollution associated with green LNG can have direct benefits on the health and well-being of individuals, thereby positively impacting their livelihoods.

On the other hand, blue LNG refers to LNG produced from conventional natural gas sources, with carbon capture and storage (CCS) or carbon offset measures to mitigate emissions. While blue LNG may not have the same level of immediate environmental benefits as green LNG, it still offers potential positive impacts on livelihoods:

1. *Job Opportunities:* Blue LNG projects require skilled labor and expertise in natural gas extraction, processing and CCS technologies. This can create employment opportunities in the local communities, providing income and livelihood support for individuals and their families.
2. *Energy Access and Affordability:* Blue LNG projects contribute to the availability of clean and affordable energy sources. This can improve access to reliable electricity and clean cooking fuels in remote and underserved areas, enhancing the quality of life and economic opportunities for communities.
3. *Infrastructure Development:* The establishment of blue LNG projects often involves the development of infrastructure such as pipelines, LNG terminals and storage facilities. This infrastructure can facilitate economic development, attract investments and provide opportunities for local businesses and services, thereby positively impacting livelihoods.

It is important to note that while green and blue LNG projects have the potential for positive impacts on livelihoods, there should also be a focus on addressing potential negative effects. This includes ensuring that proper safeguards are in place to protect the environment, local communities and biodiversity. It is crucial to engage with stakeholders and local communities in the planning and implementation of LNG projects to ensure their voices are heard and their concerns addressed. This collaborative approach can help maximize the positive impacts of LNG on livelihoods and create a sustainable and inclusive energy future.

Acronyms

CAPEX = Capital Expenditure
CNG = Compressed Natural Gas
DFDE = Dual-Fuel Diesel Electric
EU = European Union
FEED = Front-End Engineering and Design
FID = Final Investment Decision
FLNG = Floating Liquefied Natural Gas
FPSO = Floating Production, Storage and Offloading
FSRU = Floating Storage and Regasification Unit
FSU = Floating Storage Unit
GCU = Gas Combustion Unit
GTT = Gaztransport & Technigaz
IMO = International Maritime Organization
LPG = Liquefied Petroleum Gas
MEGI = M-type, Electronically Controlled, Gas Injection
MEPC = Marine Environment Protection Committee
MR = Mixed Refrigerant
OPEX = Operating Expenditure
SPA = Sales and Purchase Agreement
STaGE = Steam Turbine and Gas Engine
SSDR = Slow Speed Diesel with Re-liquefaction plant
STS = Ship-to-Ship
TFDE = Triple-Fuel Diesel Electric
US = United States
YOY = Year-on-Year

Figures

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No table of figures entries found.

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