Optimizing Liquified Natural Gas (LNG) Transportation & Logistics – Application of Compressors and AI-Driven Analytics

Shankar Narayanan

Energy Technology Professional
San Francisco, California, USA
narayan.shankarb@gmail.com

Received Fer 20, 2025, **Revised:** Mar 04, 2025, **Accepted:** Apr 10, 2025, **Published Online:** Apr 27, 2025
Reviewers: Anonymous Peer Review
Citation: Narayanan, S. (2025). Optimizing Liquefied Natural Gas (LNG) Transportation & Logistics- Application of Compressors & AI-Driven Analytics. *International Journal of Supply Chain Management, 14*(2), 1-11, https://doi.org/10.59160/ijscm.v14i2.6299

***Abstract*— Liquefied Natural Gas (LNG) transportation is not just a fascinating process but also a crucial activity in the international energy market. Countries across the world are switching over from coal and crude oil to natural gas to lower carbon footprint. But natural gas has to be transported, generally over long distances, from source to place of consumption and that to in the form of liquid. Conversion of natural gas into LNG facilitates its comparatively easy and safe transport, particularly where distances are large. The entire process of transformation and transportation is very complex, but demands study due to the growing importance of LNG as an alternative fuel – a crucial element in energy transition and sustainability. This article explores the role played by compressors in the transportation of LNG. The article while adding to the pool of literature on LNG transport optimization, establishes that compressors are vital to optimizing LNG transportation and logistics. This article also establishes the utility of Artificial Intelligence (AI) in improving profitability of the players. It shows how predictive analytics be useful in enhancing the efficiency and economy of LNG transportation through the churning of huge volume of data generated at every step of the transportation process and then use it effectively to improve performance.**

***Keywords*—** *LNG, Logistics, Transportation, Compressors Artificial Intelligence, AI, Generative AI, Supply Chain, Supply Chain Management, SCM, eCommerce.*

1. Introduction

Liquefied Natural Gas or LNG is a crucial player in the international energy landscape and its popularity as an alternative source of energy is increasing by the days as it offers a low-emission transport option [1]. The global demand for natural gas is set to peak out in 2040 powered by growth of global Liquefied Natural Gas (LNG) market on the back of industrial decarbonization measures undertaken by China, India, and other Asian countries [2]. Asia is the leading importer of natural gas. Where the transportation is across countries and continents and the transportation using pipelines is not feasible natural gas is usually transported in its liquefied state, called liquified natural gas (LNG), having a temperature of -162 °C and a density lower than water and is transported using tanker ships [3]. LNG transportation and logistics, therefore, comprises the movement process of natural gas from areas of abundance, such as the U.S.A. to regions that are experiencing robust demands, such as China and India [4].

LNG has a crucial role to play in the contemporary global maritime transport and port operations. It is proposed to play an important role in reducing Sulphur and nitrogen oxides emissions together with particulate matter in the process of transition to sustainable shipping [5]. A wide range of agents are involved in LNG transportation - an industry that is expanding rapidly. However, research into LNG supply chain (SC), especially transportation and logistics management, is still in its infancy. The objective of this article is to underscore the crucial role played by compressors in optimization of LNG transportation and logistics. This study expands upon the findings of the studies previously done on the subject.

2. Literature Review

There is a plethora of research materials, reports and government statistic available that establish the growing importance of LNG in energy transition from non-renewables to renewables, the growing global demand, and the problems of transportation.

2.2 Global Warming

The threat of global warming is very real. The severity of the problem is growing every day and is evident from the rise in average temperature across the globe along with changes in climatic conditions [6]. Globally, January 2025 has been warmer than January 2024 with temperature rising by 0.09 degrees C which was previously the hottest January. The average temperature was 1.75oC warmer than before industrial times, Copernicus calculated [7]. Global temperature has been rising gradually. However, 1981 onwards the rate of increase has more than doubled. The last 4 decades has seen the global annual temperature rise by 0.2oC, per decade caused by increasing emission of greenhouse gases including carbon dioxide (CO_2) due to vehicular and industrial pollutions.

A key contributor to global warming is the ballooning fossil fuel demand. Increased combustion of fossil fuel keeps adding to the greenhouse gases (GHG) present in the atmosphere, thereby intensifying the blanket effect. Coal and crude oil are undoubtedly the biggest contributors to global climate change, accounting for more than 75% of GHG emissions worldwide and almost 90% of all carbon dioxide (CO_2) emissions [8]. Fuel demand growth is directly linked to the growing global energy consumption caused by population growth, increased urbanization, greater industrialization, and modernization. The global demand for energy is at its highest and it has become necessary for nations to make sure that they are able to fulfil that demand. Nations across the world are trying to meet that demand using an increasingly wide range of cleaner sources of energy generated from renewables, such as wind energy and solar power. They now have an increased interest in nuclear power and bio-based sources to generate fuel that can act as sustainable sources for fuel for all purposes including aviation fuel [9].

2.3 Natural Gas as Alternative Fuel

Irrespective of the diversity in fuel sources and the innovation that backs it, there is a source of energy that a large number of countries are increasingly turning to as strategic step towards attaining a fuel mix that will ensure energy security. It is liquefied natural gas or LNG. Over the last 10 years, in particular, there has been a noteworthy rise in the popularity of natural gas as a fossil energy sources. While being a viable option for satisfying the growing global energy consumption, natural gas also addresses the increasing need for giving attention to environmental aspects. Despite being a fossil fuel, it is at an advantageous position due to its large remaining reserves and its low carbon-hydrogen ratio that will help to reduce carbon footprint making natural gas a satisfactory alternative [10].

For transportation and storage, natural gas is cooled to its liquid state. Immediate effect of replacing higher carbon emitting fossil fuels with LNG is voluminous reduction in carbon intensity – an almost 100% decrease in particulate pollution, while being a reliable and consistent source [9]. Unlike compressed natural gas that is transported through pipelines with rigid physical points as well as flow direction, LNG is flexible and is crucial for integration of the international natural gas market [1]. The LNG industry in the U.S.A. plays an important role in serving the global energy demand. It is fast becoming an integral part of the US economy making meaningful contribution towards its GDP ($400 billion) and supporting numerous high-quality domestic jobs since 2016. As of 2023 LNG was a larger export earner than corn and soyabean [11]

2.4 Demand Growth of LNG & US Exports

According to U.S. Energy Information Administration (EIA), the increase in demand for natural gas (nearly 3%, or 3.2 billion cubic feet per day or Bcf/d), both domestic consumption and exports, will continue in 2025 and will outrun supply increases (@ 1.4 Bcf/d) from domestic production and imports, causing approximately 43% increase in the Henry Hub price. 2026 is expected to be even faster driving prices higher by 27% [12]. By 2040 global demand for LNG is expected to rise by 50% plus, as per Shell's LNG Outlook 2024 [13]. Besides improving energy security, the move towards LNG will foster economic development. Substantial investments are involved in establishing and running manufacturing facilities, power plants and gas distribution networks and that process leads to significant jobs creation thus pushing growth of the local economy.

LNG trade patterns have been expanding continuously over recent years. Volumes continue to rise with the export capacity of the US LNG sector expected to double over the next 5 years, creating over 500,000 jobs per annum signifying an additional $1.3 trillion boost to the U.S. economy through 2040 [11]. Thanks to affordable U.S. LNG exports, switching from industrial coal to gas has gathered pace in China, India, and other South and South-east Asian countries. This, while magnifying global trade in LNG to 404 MT in 2023, from 397 MT in 2022, has also mitigated the geopolitical risks arising from import of fossil fuel from Russia and the Middle East. However, constricted supplies of LNG are restricting growth [2]. U.S. is the world's leading producer of natural gas and largest LNG exporter [13].

3. LNG Transportation

The very basis of LNG international trade is transportation, due to the simple reason that it enables and ensures movement of LNG beyond the territorial boundaries of a country. Over the last few decades rapid technological development, interlaced with impacts of various national and international policies related to energy and environment, along with growing miscellany of sources of supply, transportation of LNG across border, specifically across see using maritime vessels and LNG carriers, has progressively become popular [14].

Natural gas reaches consumption destination either via pipes as a gas or in the form of LNG. The natural gas remains inflexible throughout the entire process of transportation. In case of LNG, natural gas is first liquefied in a special plant and then transported using LNG tanker under controlled temperature (163ºC) and pressure before being turned back into a gas in a regasification plant [15].

Traditionally pipelines are used to transport Natural gas from gas fields to consumer sites. However, for long distances, the total cost of transportation using pipeline becomes unfeasible. The most feasible way to transport natural gas to faraway places and to new, scattered areas is to transport it as liquefied natural gas (LNG) [10]. There are, however, safety issues as accidents can happen if LNG carriers are involved in collisions and grounding, which can cause explosions and fires. Hence transportation of LNG offers major challenges [16].

Transporting LNG from the U.S. to the rest of the world faces several challenges, including safety, environmental concerns, and economic issues. In this article we discuss the physical technological difficulties and how compressors can address the challenges of transportation as a measure of optimizing LNG supply chain.

LNG carriers, which transport the liquid from place of origination to its destination, when they are either empty or partially loaded would generally use ballast water. Such small-sized vessels as the bunker vessels or LNG feeders can navigate with partial cargo loads without much hassle. However, the liquid motions in some partially loaded scenarios can impact the containment system in a manner that can present bigger difficulties compared to situations when the vessels are either fully loaded with cargo or are almost empty [17]. Normally when a tank is full in the range of 10% to 40% of its capacity, the LNG stored inside can generate considerable forces on the tank walls because of the sloshing motion which puts significant pressure on the containment system that is to hold the liquid, requiring special design considerations to manage these forces [18].

Special transportation for energy products is a highly monopolistic market. It impacts and is impacted by economic events due to its close association with the economy and national livelihood. There are problems of sequential, systematic, and complex decision-making that are involved in the process of LNG transportation. Resolving these issues demands considering several factors such as, the ways to sensibly deploy a wide variety of dissimilar LNG ships in the fleet to proper routes and transportation projects for meeting the freight demand and at the same time bring down the total annual cost of fleet operation to the minimal [19]. It is possible to achieve 5-50% savings on fuel consumption though optimization of sailing time, reduction of waiting time, and a virtual arrival policy implementation in most of the shipping lanes, including provide-reexport, receive-reexport, reexport, and without-reexport lanes [1]

4. Discussion

4.2 Optimizing Transportation

Optimization of LNG transportation entails enhancement of the efficiency of LNG shipping and hence LNG supply chains. This can be done by improving data collection, vessel design, and port operations.

Conversion of natural gas into a liquid makes transportation of greater energy content possible as LNG occupies just about 1/600th of the natural gas volume. This allows for the LNG to be pumped and transported across long distances via short liquid pipelines, highway trucks, and maritime vessels. LNG must be changed back to natural gas at the regasification plants that are located at the receiving terminals where the LNG is delivered in order to get it ready for commercial use [20].

The expansion of global LNG trade has made the natural gas market more complex and unpredictable. Energy security of LNG importers can be threatened by the unreliability of supply sources and inconstant demand is likely to have adverse impact on the economy exporting LNG. Further, the rapid growth of international trade in LNG makes it essential for the industry participants to consider emissions that occur at the time of maritime transportation to ensure a sustainable marine environment [1]. Such initiatives as the Green Marine Initiative and Carbon Neutrality Initiative aim are the outcome of the efforts to address environmental concerns.

4.3 Vessel Design

LNG carriers are high-tech tankers specially designed to contain the cargo at a little above atmospheric pressure and at a cryogenic temperature of −169 °C approximately [21]. Such tankers allow transportation of natural gas from gas fields located in other countries to consumer markets that are impossible to reach using pipelines [22]. The problems of sloshing that is associated with smaller tankers that are full between 10 to 40% of the height of the tank that requires increased reinforcements because of the loads created on the containment system, are also applicable to ballast-water tanks, that are usually filled to approximately 70-80% of their capacities [18].

Of late, companies like GTT have designed novel LNG Feeder vessels having a couple of identical cargo tanks which are equipped with technologies that allow a membrane system (a containment and insulation system), that is directly supported by the ship's hull structure, to accommodate any shapes and capacities of tanks using standard prefabricated components [23]. The new designs, built on ballast-split principle, allow minimization of hull and containment system reinforcements, and can be used by every LNG filling levels. The benefits of this novel design are undeniable. For starter, it implements ballast-split solution to mitigate the sloshing activity significantly. Dividing the ballast tank system into lower bottom and separated upper-side tanks, is deduced to improve vessel stability across all operating conditions [24].

The efficiency of this design has been established by means of validation, across all filling levels under North Atlantic conditions, using only standard foam reinforcement (without the requirement for high-density foam). Cost reductions and improvement in the Boil-Off-Rate (BOR) is achieved employing 100% standard foam. In addition to this, the adoption of double cargo tanks that are exactly similar contributes to cost efficiency besides streamlining operations. Similar kinds of potential have been discovered through the application of these principles in the design of novel state-of-the-art Bunker Vessels [18].

Care must also be taken for proper insulation of the tanks carrying the LNG. Use of membrane-type tanks that possess significant surface-to-volume ratio, which results in greater economic efficiency. For transporting LNG safely, these tanks are painstakingly designed to maintain the precise low temperatures and for prevention of any amount of LNG leakage [25]. Studies revealed that the most cost-effective solution, in terms of economic feasibility [26] and safety of LNG tanks, is the one in which the total use of mastic ropes was reduced by approximately 42% compared to the conventional manual design [25]. Optimization of LNG carrier allocation, LNG storage planning, and LNG transport planning, are essential for the minimization of the total cost of transport [27].

4.4 Port Operation, Fleet Structure & Cost Minimization

An LNG vessel is required to transfer the gas between the two installations. Specialized maritime vessels called LNG carriers are used to transport LNG from place of production to place of consumption. The source needs loading infrastructure (hosting the liquefaction plant) while the destination requires the unloading infrastructure or facility (located at the regasification plant) - a process that demands 2 port distinct facilities for loading and unloading [28].

Due to the exclusive and risky nature of LNG shipping, both the time and costs involved in transportation are high. This entails significant investment outlay that covers such expenditure heads as the capital cost, the voyage cost, and the running cost.

Case studies supported by the latest market data from Clarkson, Lloyd's Register, Shanghai Oil and Gas Trading Center, and CLNG (China Hong Kong LNG Shipping (Holdings) Limited) validate that capital outlay, running costs and voyage costs can be reduced through the implementation of a model of hybrid optimization that allows LNG shipping fleet deployment the under an assortment of factors, which includes cost resulting from longer transportation time, evaporation loss, and deployment of both self-owned vessels and time charter ships, etc. [19].

Similar to liner shipping, LNG shipping is carried out along fixed routes, following predefined shipping schedules and static voyage plans, to predetermined ports, and has a freight rate that is determined by a long-term COA (Contract of Affreightment). Complexity is the outcome of a mix of factors such as the diversity of ship registries, age of the ships, self-owned ships, and time charter ships, that are ultimately determined by the fleet structure.

The global demand for LNG is anticipated to grow at an approximate annual rate of 5% which is also supporting the rapid growth of the cost-effective LNG storage and transport businesses [29]. The adverse impact of fluctuations in fuel price on fleet operations can be reduced by LNG shipping companies through the signing of fuel price agreements with LNG filling stations and receiving stations at the ports where the cargo is loaded and unloaded. Shipping organizations can exchange certain freight concessions to negotiate stable long-term marine LNG fuel prices. Construction of own bunkering stations or renting them at loading and unloading ports for LNG storage makes it possible for the LNG shipping companies to successfully deal with the cost escalation caused by economic factors driven fuel price increases. Events such as political unrest, war, trade friction, economic crisis, or economic sanctions, push up fuel prices significantly driving up the cost of transportation.

LNG shipping companies should try to participate directly in the upstream, midstream, and downstream of LNG projects (producers and suppliers, energy consumers, shipyards, specialized equipment manufacturers, software technology providers and ports, etc.). This will enable their presence across the total supply chain, contract chain, and the entire value chain of LNG projects which will serve the purpose of having a strong initiative and voice in the LNG market and that can help optimize LNG transportation [19]. Supply chain integration establishes cohesion, improves nexuses, and enhances collaboration amongst businesses and their associates thus helping to establish linkages between trading partners also streamlines the supply chain thereby bringing down costs [30,31].

4.5 Role of Compressors

Within the energy value chain, compressors form as a crucial link. Compressors are essential not only in the processing of natural gas and in the process of its liquefaction, but also in the storage of LNG. The services of these compressors necessitate the use of specific different design features – each compatible with a different operating condition and is exclusively for a different compressed fluid [20].

Natural gas compressors are used by companies to bring down the total volume of the gas which in turn makes it easier to transport and distribute the same. A variety of natural gas compressors are put to use at different stages within the pipeline, spanning across extraction to distribution of the product until it is delivered to the end users. The key factor inducing the using compressors all along is the possibility of the gas losing pressure while and because of the transportation across long distances and the friction during the travel [32]. Compressors, as the name suggest, enable the liquefaction process by compressing and also help in the cooling by keeping the temperature below 161°C [33]. Compressors, therefore, have a vital part to play in the LNG industry. At various stages of the entire process of transportation of LNG, they increase the pressure of natural gas which makes it possible to transport LNG efficiently using pipelines as also vessels, their proper subsequent liquefaction, followed by recovery of vaporized gas (also known as boil-off gas) from storage tanks. The effective functioning of the whole LNG production and distribution chain or the LNG supply chain hinges crucially on the application of appropriate system of compressors [34].

Gas fields being generally located far from the location of use, the gas must be transported by ships or through pipelines. Pipelines, such as the ones connecting Russia to western Europe or Canada to U.S.A., typically run thousands of miles connecting the source and the destination. In locations where transportation through pipelines is impractical or impossible, like between Australia and Japan, natural gas has to be compressed by a factor of 10 or higher for it to cool down and liquefy and be ready for transport in dedicated maritime vessels. On arrival at its destination, this liquefied natural gas has to be re-gasified so that it can be transported further to industrial clusters, cities, towns, and other large consumers of energy, using gas pipelines [35]. This is also the reason behind building compression stations at approximately every 70 miles, to make sure that the natural pressure is not lost so that the gas can be 'pushed' to the next station along the line [35].

It is, therefore, evident that compressors are crucial to the transport, storage, and efficient combustion of natural gas. Reliability is of essence, as manufacturers focus on prolonged maintenance intervals and robust designs for the minimization of downtime [36]. It is essential to choose a compressor which has features and specifications for trouble-free maintenance. Furthermore, it is essential to choose an engine that has a competitive edge in comparison to others in the market, from the perspective of price of natural gas compressor is considered [32]. It is necessary for LNG manufacturers to find solutions that offer energy efficiency, minimum possible seal leakage rates, lowest possible GHG footprints, and little and effortless maintenance [37].

Maximization of cargo capacity though the minimization of boil-off gas (BOG) using advanced vessel technology is one of the effective strategies for optimizing LNG. LNG is stored in the LNG fuel tank. The level of fuel consumption and voyage time of the vessel determine the volume of the tank. One key issue is the management of boil-off gas in the LNG fuel tank. The heat ingress from the environment is the key reason behind the generation of BOG. It is, therefore, necessary to contain the increase in pressure within the LNG fuel tank without releasing the boil-off gas to the atmosphere. Pressurized tanks are able to withstand high pressure, provide an easy BOG management solution, and are economical due to need for least maintenance; and are hence the preferred option [38]. Compressors can be employed not only to manage the BOG in the LNG fuel tanks but also to transfer the LNG from the tanks [39].

In the oil and gas industry, compressing natural gas that contains both gaseous and liquid hydrocarbons throughout upstream production will generally ask for as much as two times the power required during gas-only compression. [40]. Compressors are generally not tolerant to liquids [41]. Due to the ability of even the minor amounts of liquid substantially influencing compressor efficiency and power requirements, performance of fluid becomes a complex phenomenon [42]. Other than this, compressors also play a part in the transition of energy through its assistance in reducing emissions.

4.6 Compressor controls suite

A compressor controls suite provides a collection of sensors, electrical components, and controls which helps in monitoring and adjusting the operation of a compressor. These controls make sure that the compressor is operated efficiently and safely. System performance and efficiency hinges crucially on the selection of appropriate compressor type and system controls.

A control system is especially beneficial for LNG compressors because it offers advanced capabilities both in terms of surge protection and detection [43]. It allows combining technologies for superior and reliable detection and protection capabilities. For instance, it allows integration of compressor control features of GE with vibration monitoring technology offered by Bently Nevada, which makes surge detection more reliable besides improving overall performance of the compressor [43]. LNG supply chain is extremely intricate in nature [44]. Such integration makes it possible for the LNG facilities to operate their compressors at close proximity to optimal efficiency points with very little or no risk of surge events. This again is vital to the maximization of the efficiency of the LNG production process [29]. The ability of the system to identify delays in rotating and greater efficiency at detecting surge when combined with Bently Nevada 3500 systems, increases both safety and reliability of LNG compressors manifolds [45]. This, ultimately, contributes towards much higher operational efficiency together with reduction in downtime in LNG plants, thus helping to optimize transportation and the entire supply chain.

4.7 Application of AI

Artificial Intelligence (AI) provides a powerful tool that can be successfully applied to improve the efficiency of the LNG transportation and logistics system. AI is not only capable of route planning but is also an extremely useful tool in predictive maintenance. While route optimization applying AI has the ability to adjust routes dynamically and on real-time basis that factors in such unexpected events such as route closures, weather changes, or accidents. AI-powered predictive maintenance solutions help to avoid or reduce downtime and prevent unexpected breakdown. The combined impact is a 15% reduction in logistics costs [46]. These straightaway impacts the profitability of the company as it helps to improve margins.

Application of AI requires a significant insight into the interactions of variables such as fleet structure, vessel design, cost drivers and port operation with the transportation system and an understanding of the relationships between AI and data [47]. Leveraging advanced algorithms allows Generative AI to analyze the massive volume of data created at every step of LNG transportation and logistics operations to predict demand, optimize inventory levels, and create efficient delivery routes, thus leading to lower operational costs while improving delivery times. AI can be used to predict equipment failures before they can occur which can be instrumental in early detection of surges that can avoid disruption [48]. AI application also allows seamless processing of data associated with the flow of raw materials and products to and from LNG facilities.

Predictive analytics can be effectively used to optimize in LNG transportation. Predictive models use historical and transactional data to identify patterns for risks and opportunities within a particular set of conditions, which helps guide decision-makers and anticipate specific events [49]. A study by the Council of Supply Chain Management Professionals showed that an overwhelming 96% of third-party logistics (3PLs) and 86% of transporters have migrated to the cloud while 80% of 3PLs and 77% of shipping transporters are making investments in such tools as predictive analytics to maximize Internet of Things (IoT) data [50].

Using data analysis techniques such as machine learning (ML) and statistical algorithms for anticipating the issues that are likely to arise and to optimize operations through forecasting of such factors as market demand, vessel performance, weather conditions, and potential disruptions, which allows LNG transportation enterprises to make proactive decisions pertaining to delivery schedules, maintenance requirements, and risk mitigation strategies, that ultimately improves both efficiency and reliability of LNG transport.

Using ML algorithms for prediction and optimization of the BOG generation rate allows better efficiency in gas utilization by forecasting weather conditions, tank heat ingress, and vessel operations, which, in turn helps to minimize waste thus offering maximum economic benefits in LNG transportation and storage processes.

5. Conclusion

Climate change being the most pressing concern of the modern world, an increasing number of nations are fast adopting transition to fossil fuels that promise lower emissions, if not completely doing away with the use of fossil fuels. There is no denying the fact that the demand for energy is likely to continue its fast upward journey mostly on the back of population growth, industrialization, and climate change. This article adds to the pool of literature on the subject of LNG logistics. It highlights the possibility of applying sophisticate technologies such as AI in optimizing LNG transport. The application of such modern technologies while making the supply chain leaner also leads to considerable improvement in margins of the oil and gas enterprises through cost rationalization.

The rise in environmental concerns, has led to the surge in the popularity and hence use of LNG which highlights the significance of its uninterrupted transport from source to place of application and greater need for optimization of the transport and storage operations. The stringent environmental regulations have already resulted in the significant surge in LNG demand across globe.

Stability of the energy sector and stable supplies of fuel play vital roles in modern global. Energy supply chains are spread across the globe.

Any disruptions can have significant adverse impact on global stability. Transportations have a vital part to play in ensuring uninterrupted LNG flow – an essential input to stability, which necessitates optimization of the transportation to ensure efficiency and economic viability of the activities involved.

Most countries import and U.S.A. is the largest exporter. This heightened demand has magnified the need for LNG carriers by several times, specifically the ones that are equipped with LNG tanks. These tanks are meticulously designed for maintaining low temperatures and preventing any LNG leakage thus restricting environmental damage while safely transporting LNG. Membrane-type tanks are preferred extensively, from the wide array of tanks that are at the disposal of the LNG transport industry, since their surface-to-volume ratio is significantly large. This translates into enhancement of economic efficiency [51]. There are advanced technologies in use that allow LNG Feeder vessels having identical twin cargo tanks to be equipped with a membrane system thus making transportation easy, safe, and economic. Resilience and reliability along with affordability and ease of maintenance are of paramount importance in this context.

This article's novelty lies in the fact that while adding to the existing literature on LNG transportation, it underlines the crucial role played by compressors and compressor suites in optimizing LNG transportation. By maintaining the pressure of the gas, compressors allow efficient transportation using pipelines, maritime vessels, and tankers, essentially enabling large volumes of LNG movement through reduction in gas volume and maintenance of necessary pressure all along the transport process; especially important in long distances transfers. This article also sets the stage for further and detailed investigative studies into the make and utility of compressor suites in building LNG supply chain resilience and efficiencies. The article also highlights the possibilities of using AI to effectively enhance the efficiency of LNG transportation while bringing in meaningful reduction in costs which ultimately improves both operational and financial performance of the players. It also creates the scope for in-depth study of the application of AI and predictive analytics in enhancing efficiency of LNG transportation

References

[1] H. Yu, W. Wu, X. Zhang, Z. Fang, X. Fu, L. Xu and J. Liu, "Optimization-based global liquefied natural gas shipping network management for emission reduction," Ocean Engineering, Vols. March 2025, 120366, 2025.

[2] Shell, "Shell LNG Outlook," 2024. [Online]. Available: https://www.shell.com/what-we-do/oil-and-natural-gas/liquefied-natural-gas-lng/lng-outlook-2024.html#:~:text=LNG%20for%20transport,transport%2C%20shipping%20and%20industrial%20users.. [Accessed 07 Feb 2025].

[3] MET Group, "Natural gas transportation," 03 Sep 2020. [Online]. Available: https://group.met.com/en/media/energy-insight/natural-gas-transportation#:~:text=If%20transport%20by%20pipeline%20is,and%20transported%20via%20tanker%20ships.. [Accessed 12 Feb 2025].

[4] Maersk Training, "What is the Process of Liquefied Natural Gas (LNG) Transportation?," 2025. [Online]. Available: https://maersktraining.com/news-and-insights/industry-insights-blog/what-is-the-process-of-liquefied-natural-gas-lng-transportation. [Accessed 10 Feb 2025].

[5] A. Hörteborn and I.-M. Hassellöv, "Economic incentives and technological limitations govern environmental impact of LNG feeder vessels," Journal of Cleaner Production, Vols. 429, 139461, 2023.

[6] K. Cawdrey, "Warming Makes Droughts, Extreme Wet Events More Frequent, Intense: NASA," 13 Mar 2023. [Online]. Available: https://www.nasa.gov/centers-and-facilities/goddard/warming-makes-droughts-extreme-wet-events-more-frequent-intense/. [Accessed 12 Feb 2025].

[7] Climate Copernicus, "Copernicus: January 2025 was the warmest on record globally, despite an emerging La Niña," 06 Feb 2025. [Online]. Available: http://climate.copernicus.eu/copernicus-january-2025-was-warmest-record-globally-despite-emerging-la-nina. [Accessed 08 Feb 2025].

[8] United Nations, "Causes and Effects of Climate Change," 2025. [Online]. Available: https://www.un.org/en/climatechange/science/causes-effects-climate-change#:~:text=Fossil%20fuels%20%E2%80%93%20coal%2C%20oil%20and,forms%20of%20life%20on%20Earth.. [Accessed 14 Feb 2025].

[9] World Economic Forun, "How LNG is helping to deliver responsible energy security," 06 Jan 2025. [Online]. Available: https://www.google.com/search?q=lng+to+fight+global+warming&sca_esv=0fc7dd398656b67a&rlz=1C1PNBB_enIN1082IN1083&ei=BI-sZ5uMMdSO4-EP0-LdgQM&ved=0ahUKEwibnqzKjL6LAxVUxzgGHVNxNzAQ4dUDCBA&uact=5&oq=lng+to+fight+global+warming&gs_lp=Egxnd3Mtd2l6LXNlcnAiG2xuZyB. [Accessed 10 Feb 2025].

[10] A. Bittante, R. Jokinen, F. Pettersson and H. Saxén, "Optimization of LNG Supply Chain," Computer Aided Chemical Engineering, vol. 37, pp. 779-784, 2015.

[11] D. Yergin, C. Pascual, M. Stoppard, E. Eyberg, L. Caputo, M. Bonakdarpour, E. Kelly, M. Jowdy, A. Montero and H. Cuenca, "Major New US Industry at a Crossroads: A US LNG Impact Study – Phase 1 | S&P Global," 17 Dec 2024. [Online]. Available: https://www.spglobal.com/en/research-insights/special-reports/major-new-us-industry-at-a-crossroads-us-lng-impact-study-phase-1#:~:text=The%20US%20LNG%20industry%20is,contributor%20to%20the%20US%20economy.&text=US%20LNG%20industry%20growth%20is,US%20econo. [Accessed 15 Feb 2025].

[12] EIA, "EIA expects higher wholesale U.S. natural gas prices as demand increases," 23 Jan 2023. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=64344#:~:text=Demand%20increase%20driven%20by%20more,an%20additional%202.1%20Bcf%2Fd. [Accessed 12 Feb 2025].

[13] American Security Project, "White Paper – Strategic Implications of U.S. LNG Exports," 17 Jan 2025. [Online]. Available: https://www.americansecurityproject.org/white-paper-strategic-implications-of-u-s-lng-exports/#:~:text=Over%20the%20past%20decade%2C%20affordable,of%20cheap%20U.S.%20LNG%20exports.. [Accessed 11 Feb 2025].

[14] M. Schach and R. Madlener, "Impacts of an ice-free northeast passage on LNG markets and geopolitics," Energy Policy, vol. 122, pp. 438-448, 2018.

[15] Cryospain, "Regasification: characteristics and process," 25 Jan 2024. [Online]. Available: https://cryospain.com/regasification#:~:text=What%20is%20regasification?,back%20into%20their%20gaseous%20state.&text=The%20heating%20process%20generally%20exploys,be%20in%20a%20gaseous%20form.. [Accessed 15 Feb 2025].

[16] I. d. l. Peña-Zarzuelo, M. J. Freire-Seoane and C. Pais-Montes, "Optimisation of the LNG supply chain: a literature overview," International Journal of Oil Gas and Coal Technology, vol. 24, no. 4, pp. 523 - 542, 2020.

[17] Anish, "A Guide To Ballast Tanks On Ships | Marine Insights," 16 Mar 2024. [Online]. Available: https://www.marineinsight.com/naval-architecture/a-guide-to-ballast-tanks-on-ships/. [Accessed 18 Feb 2025].

[18] GTT Group, "Enhanced Operations and Efficiency: Introducing GTT's 'Ballast-Split' Design for LNG Carriers | The GTT Newsletter," 2025. [Online]. Available: https://gtt.fr/enhanced-operations-and-efficiency-introducing-gtts-ballast-split-design-lng-carriers. [Accessed 18 Feb 2025].

[19] Z. Zhao, X. Wang, H. Wang, S. Cheng and W. Liu, "Fleet Deployment Optimization for LNG Shipping Vessels Considering the Influence of Mixed Factors," Journal of Marine Science and Engineering, vol. 10, no. 12, pp. 1-17, 2022.

[20] J. Casey, "Turbomachinery in LNG production plants – Part one | LNG Industry," 15 Feb 2024. [Online]. Available: https://www.lngindustry.com/special-reports/15022024/turbomachinery-in-lng-production-plants-part-one/. [Accessed 15 Feb 2025].

[21] N. Alonso-Vante, M. Antonia Folgado, A. M. Chaparro, S. Citalán-Cigarroa, J. J. Conde and e. al., Portable Hydrogen Energy Systems: Fuel Cells and Storage Fundamentals and Applications, P. Ferreira-Aparicio and A. M. Chaparro, Eds., London, U.K.: Academic Press, Elsevier Inc., 2019.

[22] R. Raj, S. Ghandehariun, A. Kumar, J. Geng and M. Linwei, "Techno-Economic Study of Shipping LNG to the Asia-Pacific from Western Canada by LNG Carrier.," J. Nat. Gas Sci. Eng, vol. 34, p. 979–992, 2016.

[23] GTT, "Mark III Systems," 2025. [Online]. Available: https://gtt.fr/technologies/markiii-systems. [Accessed 18 Feb 2025].

[24] M. Cavcic, "French player's new LNG carrier design gets the go-ahead as deal for eight dual-fuel tankers comes its way | Offshore Energy," 30 Oct 2024. [Online]. Available: https://www.offshore-energy.biz/french-players-new-lng-carrier-design-gets-the-go-ahead-as-deal-for-eight-dual-fuel-tankers-comes-its-way/#:~:text=Employing%20an%20advanced%20tank%20configuration,and%20Lloyd's%20Register%20(LR).. [Accessed 18 Feb 2025].

[25] D.-H. Chun, M.-I. Roh, I.-C. Yeo and H.-W. Lee, "Proposed method for design optimization of LNG tanks based on the arrangement of thermal insulation panels," Ocean Engineering, Vols. 288, 116063, no. Part 2, 2023.

[26] S. K. Singal, H. Nautiyal, V. Goel and D. E. Papantonis, Small Hydropower: Design and Analysis, Amsterdam, Netherlands: Elsevier Inc., Charlotte Cockle, 2023.

[27] H. Zhang, Y. Wu, L. Zhen, Y. Jin and S. Wang, "Optimization problems in liquefied natural gas transport and storage for multimodal transport companies," Electronic Research Archive - AIMS Press, vol. 32, no. 8, pp. 4828-4844, 2024.

[28] I. d. l. Peña-Zarzuelo, M. J. Freire-Seoane and C. Pais-Montes, "Optimisation of the LNG supply chain: a literature overview," Int. J. Oil, Gas and Coal Technology, vol. 24, no. 4, pp. 523-542, 2020.

[29] Buckhardt Compression, "COMPRESSOR SOLUTIONS FOR LNG TERMINAL APPLICATIONS," Nov 2015. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.burckhardtcompression.com/wp-content/uploads/2015/11/150902_BC_LNGTerminalApplication_EN_Web.pdf. [Accessed 18 Feb 2025].

[30] E. Osir, S. Muli and E. Namusonge, "Supply Chain Integration and Performance of Classified Tourism Enterprises in Kenya," International Journal of Supply Chain Management, vol. 9, no. 5, pp. 13-40, 2024.

[31] P. Kumawat, "Impact of Artificial Intelligence in Building Supply Chain Resiliency," IJSCM, vol. 13, no. 06, pp. 10-19, 2024.

[32] Gainwell, "Necessity and Benefits of a Natural Gas Compressor," 18 Dec 2023. [Online]. Available: https://www.gainwellindia.com/blog/2023/12/18/necessity-and-benefits-of-a-natural-gas-compressor. [Accessed 15 Feb 2025].

[33] CompressorTech2, "Latest Advances In LNG Compressors," 05 Sep 2017. [Online]. Available: https://www.compressortech2.com/news/latest-advances-in-lng-compressors/8002127.article. [Accessed 13 Feb 2025].

[34] K. Jiao, P. Wang, Y. Wang, B. Yu, B. Bai, Q. Shao and X. Wang, "Study on the multi-objective optimization of reliability and operating cost for natural gas pipeline network," Oil & Gas Science and Technology – Rev. IFP Energies nouvelles, Vols. 76, 42, no. 2021, 2021.

[35] ENLIT, "5 things you should know about compressor technology," 02 Apr 2024. [Online]. Available: https://www.enlit.world/oil-and-gas-energy-transition/5-things-you-should-know-about-compressor-technology/#:~:text=1.,other%20big%20users%20of%20energy.. [Accessed 07 Feb 2025].

[36] FS - Elliot, "Boosting LNG Production Efficiency with FS-Elliott's PAP Plus Compressor," 19 Jul 2023. [Online]. Available: https://www.fs-elliott.com/blog/boosting-lng-production-efficiency-with-fs-elliotts-pap-plus-compressor. [Accessed 18 Feb 2025].

[37] Hellenic Shipping News, "Compressor Reliability and Efficiency are Essential in

Today's LNG Market," 05 Feb 2020. [Online]. Available: https://www.hellenicshippingnews.com/compressor-reliability-and-efficiency-are-essential-in-todays-lng-market/. [Accessed 14 Feb 2025].

[38] S. Seo, S. Han, S. Lee and D. Chang, "A pump-free boosting system and its application to liquefied natural gas supply for large ships," Energy, vol. 105, no. June 2016, pp. 70-79, 2016.

[39] H. Park, S. Lee, J. Jeong and D. Chang, "Design of the compressor-assisted LNG fuel gas supply system," Energy, vol. 158, no. September 2018, pp. 1017-1027, 2018.

[40] South West Research Institute, "Wet Gas Compression & System Performance," 2025. [Online]. Available: https://www.swri.org/markets/energy-environment/machinery/centrifugal-compressors-gas-turbine-services/wet-gas-compression-system-performance. [Accessed 18 Feb 2025].

[41] B. S. Prasad, "Effect of Liquid on a Reciprocating Compressor," Journal of Energy Resources Technology, Transactions of the ASME, vol. 124, no. 3, 2022.

[42] A. Giuffre, P. Colonna and M. Pini, "The Effect of Size and Working Fluid on the Multi-Objective Design of High-Speed Centrifugal Compressors," International Journal of Refrigeration, Vols. 143, November, pp. 43-56, 2022.

[43] Bently Nevada, "Axial and Centrifugal Compressors Application Guide, GEA 31971A,," Jan 2016. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.bakerhughes.com/sites/bakerhughes/files/2022-01/GEA31971A%20Centrifugal%20Compress%20App%20Note_R4.pdf. [Accessed 19 Feb 2025].

[44] M. Al-Khatib, M. Haouari, A. AlNouss, H. Mkacher, M. Kharbeche and S. Al-Haidous, "Enhancing resilience in the liquefied natural gas supply chain: A focus on chemical supply continuity," Energy Reports, Vols. 12, December, pp. 2758-2772, 2024.

[45] Hspiers, "GE's Control Solutions," 29 Mar 2016. [Online]. Available: https://gecontrolsolutions.wordpress.com/2016/03/29/ges-opticomp-bn-compressor-control-solution-increases-reliability-at-u-s-refinery/. [Accessed 19 Feb 2025].

[46] Svitla, "AI in Logistics and Transportation: Implementation and Opportunities," 22 Oct 2024. [Online]. Available: https://svitla.com/blog/ai-in-logistics-and-transportation/. [Accessed 03 Mar 2025].

[47] S. Adıgüzel, "Use of Artificial Intelligence In Logistics Management," in 1st International Conference on International Conference on Interdisciplinary Applications of Artificial Intelligence, Yalova, TURKEY, 2021.

[48] Vassar Labs, "Transforming LNG Production: Unleashing the Power of Artificial Intelligence | LinkedIn," 07 Mar 2024. [Online]. Available: https://www.linkedin.com/pulse/transforming-lng-production-unleashing-power-artificial-intelligence-xikwc/. [Accessed 19 Feb 2025].

[49] Transmetrics, "Predictive Analytics in Logistics: Applications & Use Cases," 12 Mar 2024. [Online]. Available: https://www.transmetrics.ai/blog/predictive-analytics-in-logistics/#:~:text=So%20what%20exactly%20is%20predictive,makers%20and%20anticipate%20specific%20events.. [Accessed 18 Feb 2025].

[50] M. Zimmerman, B. Sonthalia, J. Brogan, K. Acar and A. M. Pena, "The 2024 State of Logistics Report," The Council of Supply Chain Management Professionals, 2024.

[51] M. N. Hye and M. M. Habib, "Exploring Digital Supply Chain Practices in the Maritime Industry: A Systematic Literature Review," *IJSCM,* vol. 14, no. 01, pp. 9-21, 2025.