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Article

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Midstream Supply Chain Infrastructure Facilities and Optimization Opportunities for Emerging LNG Markets

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ABSTRACT

Liquified natural gas (LNG) is a major energy market experiencing significant supply chain evolution. Supply terms are progressively changing from long-term and binding contracts to shorter-term and flexible clauses, taking into consideration demand uncertainties. This context is making heavy investments in the LNG infrastructure risky, costly, and irreversible. The focus is shifting towards small-scale midstream facilities to develop small-size markets. This paper presents a comprehensive analysis of the LNG supply chain from an infrastructure investment approach based on market size and recent technological developments in the field. It addresses the limitations of the classic conducted supply chain and investigates best practices adapted to emerging markets. If properly executed, these logistics alternatives enable emerging markets to access LNG in a short period with lower investment. The objective is to maximize added value while minimizing cost and operational risks. This work suggests an alternative supply chain process replacing onshore terminals and pipeline delivery by Floating Storage Regasification Unit and truck delivery in the midstream market. A Strengths, Weaknesses, Opportunities, and Threats analysis is conducted for the alternative supply chain model, showcasing the strengths and weaknesses alongside opportunities and threats. The result and discussion section develop the main aspects of strategic and operational supply chain decision-making for LNG to find new developing opportunities and faster growth.

Keywords: Midstream Natural Gas, FRSU, Emerging Gas Markets, Investment Strategy, Hydrogen

JEL Classifications: A1, F2, L1, R4

1. INTRODUCTION

A decade ago, only 23 countries had access to the liquified natural gas (LNG) market (Savickis et al., 2021); the complexity of the liquid natural gas supply chain, infrastructure investments, and timeline execution are substantial market barriers. Despite the natural gas trade's important size and global potential, the corresponding supply chain operations are not flexible and practical.

Natural Gas projects are amongst the world's most cost-demanding projects, with total capital expenditure reaching tens of billions of USD. The overall cost to build a large-scale LNG Plant with a 1 million tonnes per year (TPA) capacity is estimated to be around 1.5 billion USD (Steyn, 2021), which stands as a barrier against the emergence of small-scale markets. The impact of geopolitical uncertainty on energy volatility and international price trends can expose mega investment projects to the risk of becoming a financial liability and source of important energy issues nationwide. The impact of the Ukraine-Russia conflict can be listed as a perfect example (Martin, 2021), pipeline circuits costing billions, and power plants and industries found themselves overnight in a state of crisis. On the other hand, the current and projected energy policies rely on natural gas to play an instrumental role as a transitional energy source toward net-zero carbon emissions (Barnett, 2010). Therefore, the natural gas supply chain is expected to experience significant development in its liquid form, any country with access to the sea can be considered a potential LNG market, able to access this energy source as soon as an importing infrastructure is established. Many profitability studies of onshore importing facilities present long-term paybacks and discouraging return on investments (El Ghazi et al., 2019).

Adopting suitable technological and logistical solutions can ensure significant flexibility and reduce financial and operating risks. Developing natural gas is challenging for emerging countries, which must learn from mature markets' supply chain experience and look for optimized and suitable alternative solutions without taking important risks in costly onshore importing facilities or rigid infrastructure.

2. METHOD AND STRUCTURE

Compared to other fossil fuels, Natural gas is relatively new (Chiu, 2008). It is largely linked to the energy transition process. The supply chain has benefited from other fossil fuel experiences and developed through large-scale operations, long-term engaging contracts, and heavy investments (Neumann et al., 2015). Natural Gaz projects are among the most technically challenging and expensive energy infrastructures. This heavy process is among the reasons why till recently, Natural Gaz is still accessible only to selective importing countries and markets (Harris and Gavin, n.d.). The complexity of its supply chain is due to methane characteristics, and optimizing its process can be challenging. With contemporary perspectives on market evolution toward the liquid form, it is important to keep developing new approaches and supply chain strategies.

With the energy context continuously evolving, researchers and field specialists can benefit from insights to understand better the natural gas market and its supply chain alternatives. To our knowledge and until now, only a few scientific research papers have investigated this theme. This work required a background review of the LNG sector and analysis of the existing supply chain models, including importing terminals, transportation infrastructures, supply chain disruption precedents, recent infrastructure projects development, or failures. A top-down approach is adopted from the perspective of an importing country, starting with LNG maritime importation infrastructure until final delivery to the end consumer.

After investigating the current market development, the existing mid-stream structure, and barriers for small markets, this paper presents an alternative supply chain model regarding recent LNG process and equipment developments. Most data come from various resources, including analytics reports issued by specialized field organizations, supply chain research papers, and international databases such as Statista. This paper is structured into four main sections as below:

Section 1 provides an overview of LNG market developments, summarizing the most relevant gas molecule chemical properties, analyses of natural gas demand trends, and price evolution. This section showcases the recent growth and scalability of emerging markets.

Section 2 describes the classical supply chain components and investigates their challenges and limits for small-size importing markets, focusing on the heavy construction process of an importation terminal and profitability constraints.

Section 3 introduces the alternative LNG supply chain best suited for small market scales, starting with the description of Floating Storage Regasification Unit (FRSU) as a replacement to a classical importation and storage onshore site, then small-scale storage facilities at the end consumer with a truck-based transportation model instead of pipeline routing, suitable for small volumes and reaching more geographically dispatched industrials.

Section 4 presents results and discussions; the supply chain alternatives are presented as one midstream optimized model. Nevertheless, several concerns are to be addressed. This section developed a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis to highlight the strengths, weaknesses, opportunities, and threats of the proposed supply chain model and discuss the influence of state policies in its successful adoption.

This work presents the finding from exploring the different logistical alternatives, using a qualitative research approach to synthesize relevant literature and recent energy-related international reports.

3. LNG DEVELOPMENT AND MARKET TREND REVIEW

3.1. Natural Gas Properties and Characteristics

Natural gas consists mainly of 80% and 98% of methane but also contains other hydrocarbon components such as ethane, propane, butane, and pentane (Learn About Natural Gas, 2017). After extraction, natural gas is treated to remove the corrosive and toxic gas H2S and convert it to elemental sulfur (Dutton, 2020).

Depending mainly on the natural gas extraction origin, the composition and quality of natural gas can differ. Table 1 shows the typical natural gas characteristics mainly used; countries can, however, set different characteristics to meet local industrial requirements. LNG does not contain sulfur, generating little SOx emissions compared to other fossil fuels (IEA, 2021a). As for CO_2

Table 1: Natural gas composition, Enbridge Gas Inc 2021 data (Learn About Natural Gas, 2017).

Component	Typical analysis (mole %)	Range (mole %)
Methane	94.7	87.0–98.0
Ethane	4.2	1.5–9.0
Propane	0.2	0.1–1.5
Iso-Butane	0.02	trace–0.3
Normal-Butane	0.02	trace–0.3
Iso-Pentane	0.01	trace–0.04
Normal-Pentane	0.01	trace–0.04
Hexanes plus	0.01	trace–0.06
Nitrogen	0.5	0.2–5.5
Carbon Dioxide	0.3	0.05–1.0
Oxygen	0.01	trace–0.1
Hydrogen	0.02	trace–0.05

emissions, it is very important to consider the origin of natural gas extraction, its physical properties, and its transportation process to reduce CO_2 emissions as much as possible.

LNG is sought as an excellent alternative toward greenhouse gas emissions reduction and the fight against global warming, mainly due to its low carbon emitting properties compared to other fossil fuels (IEA, 2021a) and also because it makes it possible to develop an energy transition strategy while ensuring optimal operation combined with renewable sources of energies for electricity generation (EIA, 2021).

The physical properties of natural gas present many advantages in the industrial fields (US Department, 2005). Natural gas is:

- Colorless and odorless: For safety reasons, an odorant is artificially injected to give a strong smell allowing gas detection in the event of a leak (Learn About Natural Gas, 2017).
- Non-toxic and non-corrosive: The use of natural gas does not present any toxicity danger for humans and does not cause corrosion of pipelines or storage facilities (Learn About Natural Gas, 2017), which helps preserve them over time and reduces maintenance costs.
- Lighter than air: Due to its lightness, natural gas rises in the air and disperses rapidly in case of a leak.
- In the gas phase above −161°C: To be liquefied, natural gas requires a specific process with cryogenic materials to preserve the liquid phase conditions. Otherwise, natural gas can be transported in its gaseous phase through pipelines.

Many advantages are associated with natural gas liquid form. Unlike the gaseous phase that needs pipeline circuits, LNG can be transported worldwide, both offshore and onshore, without the constraint of fixed infrastructure and rigid location prerogatives.

3.2. Supply and Demand Trends

Traditionally, natural gas is considered a volume market but recently started to interest small market use. The discovery and exploitation of natural gas are relatively recent compared to other types of fossil energy (Chiu, 2008). Its technology is undergoing continuous developments and technical progress; it contributes positively to improving effectiveness and efficiency at all product value stream levels.

Natural gas development is driven by its availability as a resource and by its preference by industrials in many fields. Cooling natural gas to −160°C can liquify the gas and reduce its volume by a factor of 600 (US Department, 2005), guaranteeing easier transport and storage. There are large reserves of natural gas, shale gas is also developing rapidly, and new resources are continuously explored. Figure 1 shows the countries with the largest LNG export and import capacities (Global LNG Export Capacity by Country, 2022). As of 2022, Australia has the largest LNG export capacity with 87.6 million metric tons per year in LNG export; Australia and Qatar are currently the major exporting countries, followed by the United States, which has an annual capacity of 73.9 million metric tons. The United States is expected to add nearly 300 million metric tons of yearly exporting capacity in the future.

As for LNG importing capacities, Japan has the largest import capacity in the world, with 227.7 million metric tons per year capacity. Which is more than double the importing capacity in South Korea, ranking second. Meanwhile, China has the largest LNG import capacity under development and is expected to add over 200 million metric tons in annual capacity (Global LNG Import Capacity by Country, 2022). Some regions are still not listed among the important consuming energy markets, yet they are developing rapidly and seeking LNG market access, such as North Africa et Eastern-South Europe (Ouki, 2022).

The subsequent sanctions of Europe on Russian natural gas tightened supplies of natural gas and led to a shift toward LNG to reduce energy's dependence on Russian pipelines in the future; it also surged the need for faster emergence and development of LNG Export facilities (Gas Market Report, Q3-2022-Analysis, 2022). Ahead of the 2022/2023 winter, and as an anticipation of the energy's peak demand, the European Union (EU) member states adopted several measures by setting a threshold of 80% of minimal storage level at the opening of winter to be increased to 90% in the following years. The Russo-Ukrainian conflict stimulated the extension of LNG import capacity within the EU either through the expansion of existing onshore regasification plants or by hiring offshore floating storage and regasification units; EU-based companies secured several short-term LNG contracts. In this context, the global LNG trade increased by +6% year over year from January to August 2022, mainly driven by a spiking demand in Europe that rose by +65% during the same period (Gas Market Report, Q4-2022-Analysis, 2022).

Since natural gas consumption is mainly driven by its use in power generation, Table 2 shows the global natural gas installed power generation capacity outlook (Global installed natural gas generation capacity 2050, 2021); it is observed that the power generation capacity will reach about 2.4 terawatts by 2050, the forecast growth is expected to be over 31% between 2020 and 2050. Accordingly, the LNG trade is expected to increase significantly.

The evolution of the contractual supply model is among the main driving factors of the supply chain model evolution. In the Take Or Pay (TOP) contract model, the provision requires the buyer to take and pay for a quantity of LNG in a contract year or otherwise pay an agreed price for any LNG not taken. The seller must honor the volume delivery at prior nominated periods. The TOP clauses offer a mechanism that guarantees a certain level of

Table 2: Worldwide installed natural gas power generation capacity with a forecast until 2050 (in gigawatts) (Global Installed Natural Gas Generation Capacity 2050, 2021).

Year	Installed capacity (Gigawatts)	Growth (%)	Cumulative growth (%)
2020	1.839	-	-
2025	2.027	10	10
2030	2.183	8	19
2035	2.195	1	19
2040	2.223	1	21
2045	2.304	4	25
2050	2.414	5	31

Figure 1: Countries with the largest LNG export and import capacities in operation worldwide as of July 2022 (in million metric tons per year). (a) Countries with the largest LNG export capacity. (b) Countries with the largest LNG import capacity

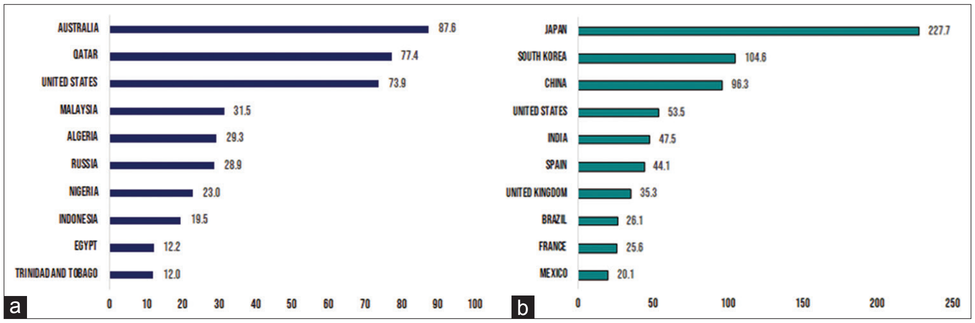
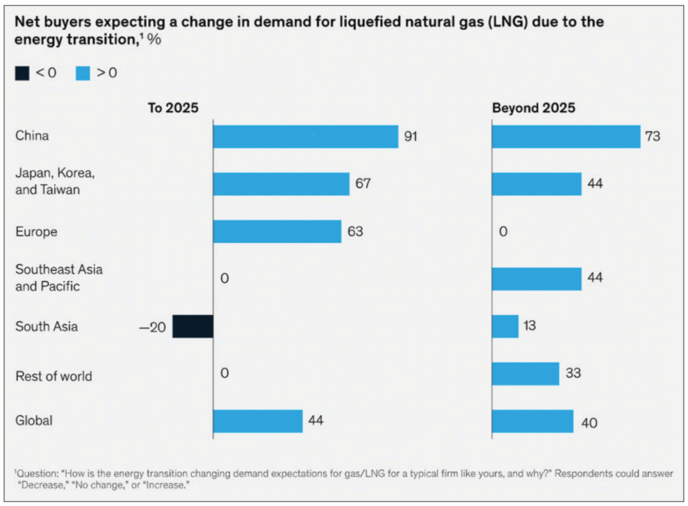


Figure 2: McKinzey company survey on how the energy transition is changing LNG demand (McKinsey, 2022)



revenue for the duration of the contract to benefit suppliers that can help finance greenfield LNG developments (Freehills, 2020). Figure 2 summarizes the 2022 McKinsey survey on how the energy transition changes LNG demand (McKinsey, 2022).

The 2022 natural gas market was disrupted by significant uncertainties relating to the forecast of elevated prices for the next five years. To deal with this situation, many buyers are reverting to long-term contracts with concerns rising about supply shortages. This level of confidence varies by region. Southeast and south Asia regions lost short-term confidence because of high costs and their direct impact on end-users. Concerning Europe, buyers remain uncertain beyond 2025, despite their need for gas, given the rapidly changing energy transition that can reshape the energy mix. They are confident about natural gas prices going down by then. As for Chinese buyers, confidence is balanced over both time frames with a slight preference for short-term contracts, confirming that LNG is a key vector of their energy transition.

LNG price evolution has experienced many disruptions in recent years; Figure 3 shows the monthly natural gas price index worldwide from January 2020 to October 2023 (Statista, 2022b). The global natural gas price increased until reaching 893.1 index points in August 2022, which is 19 times the index point of August 2020. The price spike is due to a global supply shortage from the post covid economic recovery and a surge in electricity demand, particularly in Europe. This situation was worsened by the Russia-Ukraine conflict, driving up prices for natural gas in the latter half of 2021. The decrease noted in October 2022 is due to weather conditions, this year's winter being warmer than expected, reducing overall demand.

There are many uncertainties regarding LNG price evolution and market demands, making it challenging to conceive an optimal logistic model. Apart from inflecting the commercial trade, price evolution is an important input for supply chain investment and interregional flows, especially for estimating profitability and payback. Given the multitude of actors from sellers, traders, exporters, explorers, and consumers, with many regional particularities and geopolitical aspects. It is nearly impossible to predict price evolution. The market is experiencing growing trade, new players, stronger competition, and new technology developments.

4. CHALLENGES AND LIMITS OF THE CLASSICAL SUPPLY CHAIN MODEL FOR LNG IMPORTING COUNTRIES

4.1. Natural Gas Classical Supply Chain Description

In general, the LNG supply chain doesn't include a heavy chemical process; it consists mainly of extracting natural gas offshore or onshore, transforming it from the gaseous state to the liquid form after a few processing operations. Natural gas is liquefied and stored in liquefaction plants. Figure 4 describes the full LNG extracting and refining process with different scales (Tcvetkov, 2022). It has been proven that beyond 2,500–3,000 km, the transport of LNG by sea tanker becomes more attractive compared to pipeline transportation (Khan and Osiadacz, 2015).

For maritime transportation, LNG tankers unload in receiving terminals once arrived at their destination. LNG is temporarily stored in convenient storage tanks. To be marketed, LNG is regasified by heating or pressure; the gas is then transported by pipeline to the consumption areas. Pipelines are considered among the safest means of transport because they are ground-fixed, but at the same time, they are very costly due to heavy drilling work, expensive material use, and considerable environmental impacts (Ferris, 2021). The pipeline is traditionally used to transport gas

Figure 3: Monthly natural gas price index worldwide from January 2020 to October 2022 (Statista, 2022b)

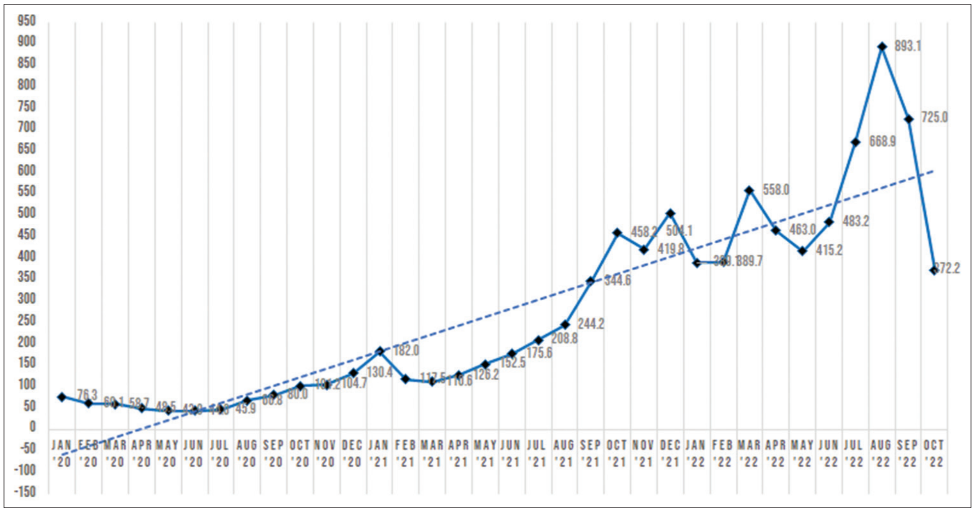
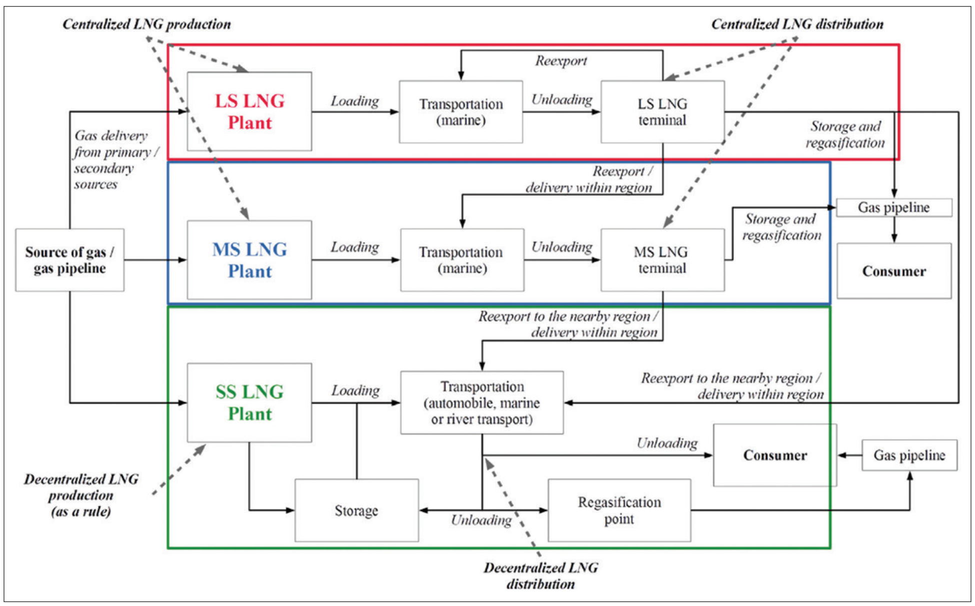


Figure 4: Description of the full LNG extraction and refining process (Tcvetkov, 2022)



from importing terminals to consuming locations, with multiple compression stations to sustain pressure and temperature control.

This classical natural gas supply chain takes a long time to be established, and long-term contracts to ensure profitability, considering geopolitical risks in pipeline routing between countries and regions. Pipeline construction on large distances needs proper authorizations, environmental impact studies, and risk analyses, including corrosion protection mechanisms and non-destructive inspection methods. All the different logistics components take time to develop. Once natural gas reaches its destination, it can be kept in the pipeline indefinitely without being used or needed immediately.

This model structurally presents a lack of optimization based on a seller's approach, which pushes the gas toward the customer without adapting to his actual consumption need. A better optimal strategy would be for the customer to pull the energy source instead of the seller pushing it, depending on his consumption level, production rate, price context, and seasonality factors.

4.2. Market Size Requirements and Profitability Constraints

Profitability is usually the most important criterion for decision-making. Even if the combined ecological and industrial advantages of natural gas can provide sufficient motivation to invest, a long-term profitability study must be conducted to assess the economic impact of such an investment decision. The Capital Expenditure (CAPEX) estimate is a very important step. Considering the scope of an onshore importing terminal alone, the storage tank represents the most significant investment after considering the coastal environment, such as the pumping and vaporization process. Based on the cost allocation for some LNG terminals realized in different environments (El Ghazi et al., 2019), the CAPEX composition of an importing terminal is as follows:

- Allowance for land
- Jetty and port access

- Technical and economic feasibility studies
- Storage and instrumentation
- Vaporizing, boil-off handling, pump-out
- Utilities, offsites, fire, and safety
- Project management team.

The regasification alone represents 35% of the total cost of the project. Port equipment and LNG tanks generally concentrate heavy investments, with very large disparities related to land conditions. As for the Operating Expenses (OPEX), the specificity of the market makes it challenging to estimate operating expenses, imported quantities depend on variable consumption, purchase prices are very volatile, and their trend is unpredictable and depends on several variables: exchange rate, geopolitical stability, contract conditions, sea freight, supplier countries, price indexation, etc.

The operating costs of a terminal are generally made up of the following elements:

- Operating maneuvers: such as supply reception costs dedicated to LNG harbor, cargo reception, storage, and product delivery
- Maintenance costs, including corrective and preventive maintenance
- Energy consumption related to conducting daily operations
- Human resources and salaries: it is essential to provide an organization chart; wages are generally subject to variation, depending on countries' legislations.

Based on OPEX data from various LNG terminals, the first year of OPEX is estimated at 2.5% of project CAPEX (Zhang et al., 2017). accordingly, a higher CAPEX investment would result in higher operating costs. Profitability is generally simulated on an economic lifespan of 20 years despite a longer real lifespan (Ferris, 2021). Since volume is not the only parameter affecting profitability (Giranza and Bergmann, 2018), we consider minimizing cost in a non-predictable price evolution market to be a synonym for maximizing payback and profitability.

5. LNG SUPPLY CHAIN DESIGN AND OPTIMIZATION ALTERNATIVES FOR EMERGING MARKETS

5.1. FRSU

To overcome the challenges and constraints of the classical supply chain, this section gradually introduces LNG supply chain alternatives, starting from importing facilities until client delivery. The approach is driven by cost reduction targets within the CAPEX investment. The logistic process should be tailored to the demand level, the target being continuous optimization at all levels while keeping operational reliability and safety.

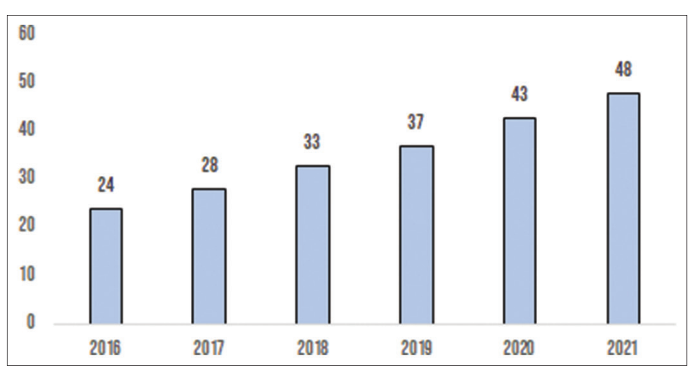
FRSU was first developed in 2005 (Zawadzki, 2018). Originally, it is an LNG tanker re-used as an onshore floating terminal. Some equipment and process modifications are required to ensure this transformation. FRSU can receive and unload LNG while ensuring berthing stabilization and operations delivery. The growth of the LNG market is driving the growth of FRSU, especially for emerging countries wishing to develop natural gas or reduce their CO_2 impact and replace coal with natural gas for electricity production. Currently, FRSU storage capacities start from 30,000 m^3 (Putra et al., 2019),; the smaller the capacity, the more it conditions small volume reception. The standard design model is between 120,000 m^3 and 200,000 m^3 capacity; the frequency of unloading LNG carriers depends on the FRSU capacity in terms of natural gas effective use. The FRSU has a regasification unit that sends natural gas according to demand by heating or high pressure; it also has the following main features:

- LNG tanker unloading station
- LNG unloading transfer pipes
- LNG storage capacity
- Temperature and pressure control equipment
- Pumps and vaporizers
- Transfer station to the regasification unit
- Pipeline refueling station
- LNG tank truck or container loading station
- Control and count units.

According to the 2021 Bloomberg LNG market analyses, FSRU ships are in high demand as buyers seek quicker and more efficient facilities (Shiryaevskaya, 2021). At the end of 2021, the total LNG tanker fleet is around 700, among which 48 operate FRSU worldwide (GIIGNL, 2022). In 2020, There were 43 floating terminals in operation worldwide, a nearly 11% increase between 2021 and 2020, while the LNG market increased by 4,3 % (Weetch, 2022). Figure 5 showcases the growth of the FRSU fleet; units doubled between 2016 and 2021 (Statista, 2022a). This trend reflects an unprecedented gain of interest in FRSU. Three floating terminals started commercial operations in 2021, respectively, in Brazil, Croatia, and Indonesia (GIIGNL, 2022). Croatia then joined the ranks of LNG-importing countries in 2021.

FSRU can be either newly constructed or transformed from an existing LNG tanker. The transformation process includes adding trans-shipment, regasification equipment, and mooring systems. Since LNG tankers have an accentuated specialization with no other area of application, it favorises future development of FSRU projects, steadily growing the proportion of LNG floating receiving terminals. According to Timera Energy (Crawford, 2018), the top 3 advantages of FRSU are:

Figure 5: Number of floating storage regasification units (FSRUs) worldwide from 2016 to 2021



- Lower capital cost
- Shorter lead time
- Greater flexibility.

Profitability is the most important decisional factor; Figure 6 summarizes a comparative study between the CAPEX required by classical onshore terminals and FRSU for a 3 MTPA (Zhang et al., 2017). The comparison shows a 35% cost difference, with 560 m$ for an Onshore terminal investment and only 350 m$ for an FRSU. As for the operating costs, they are between 20,000 USD and 45,000 USD/Day for the FSRUs against a range from 20,000 USD to 40,000 USD/Day for onshore terminals. Therefore, the cost of a new FSRU is approximately only 60% of the cost of a new onshore terminal.

Modularity adds up to FRSU's advantages; it is an attractive option for growing markets. With limited volume trade, and land availability, the choice of seaport remains very important; it must allow berthing stability and favorable weather conditions (Wood and Kulitsa, 2018). FRSU requires minimal onshore space and offers flexibility in terms of possible relocation. Timeline is also an important factor in favor of FRSU. It can be constructed considerably faster than onshore terminals with less technical complexity. It can be considered higher quality and security due to its fabrication process in a controlled shipyard instead of temporary labor on a remote site (Wyllie, 2021). Buyers can either own their FRSU vessel or use a leasing process to start operating for a period. Depending on the business model, the leasing option is generally cheaper than purchasing.

FRSU is allowing faster LNG access for emerging countries. They are increasingly considering this option. For instance, the Moroccan government issued in Mai 2021 a call for tender for its first LNG terminal, an FRSU technology based at Mohammedia Port (procurement Kingdom of Morocco, 2022). Poland announced building 2nd FSRU due to Czech and Slovak demand for buying more LNG (Pekic, 2022).

5.2. Calibrating Supply to Demand: LNG Small-scale Storage at End Consumer Site

As the predominant natural gas onshore transportation is the pipeline, gas consumers need to have a continuous and important consumption level with little exposure to volatility and seasonality effects. The pipeline logistic model is currently challenged for its limited geographic coverage in this context of demand and price uncertainties. Consumers are looking for flexibility, and the supply chain model needs to adapt rapidly, especially since the natural gas context is favorable to take over other fossil fuels markets to drive the energy transition. Except for power stations whose conditions of use and pressure parameters differ, the industrial plants use vaporized natural gas pressure that is generally low (<4 bars). Using LNG storage at the end consumer site can provide the required gas pressure. Since the storage contains natural gas in a liquid phase, the most common vaporizing process uses ambient air vaporizers. LNG storage capacities have the following main components:

- LNG tank truck unloading station or an LNG container storage
- Pressure control equipment
- Withdrawal pumps
- LNG vaporization equipment
- A gas pressure regulator unit
- Control and security units.

During flow operations and due to the very low temperature of the natural gas liquid phase, vaporizers tend to freeze, which is why two vaporizers are recommended. Each one operates alternately to ensure continuous functioning. It is also necessary to ensure the gas is supplied at a positive temperature. At the outlet of the vaporizers, a heater is therefore installed to help raise the gas temperature in a cold environment. The storage capacity must be dimensioned to enhance flexibility regarding production and supply uncertainties and also to benefit from the seasonal patterns in gas prices.

5.3. LNG Distribution Trucks

LNG transportation is adapting to best respond to market developments. Transportation is among the key elements when studying the natural gas supply chain. It is the main part of the midstream; the increase of LNG trade is naturally increasing demand for LNG transportation. Once an LNG storage is installed at the industrial site, LNG can be delivered by trucks or iso-containers. LNG iso-containers are pressurized storage tanks containing LNG in liquid form that can be transported through a simple logistical chain consisting of pickup and delivery. They are double-jacketed (Muttaqie et al., 2022) to maintain very low temperatures, with inner casing in stainless steel, thermal insulation made of aluminum laminate, and external casing in carbon steel or stainless steel. Once the iso-container is delivered to the consumer site, the LNG transfer can be done by a pressure difference or using an external pump.

LNG trucks are equipped with a small LNG vaporizer to maintain the pressure in the tank by vaporizing liquid and injecting it into the gaseous phase if the pressure drops. Most LNG Trucks are equipped with pumps; otherwise, LNG Trucks must unload by pressure differential and a pressure build-up Unit (RoadLinx, 2021). The transport distance is a key element affecting both security and profitability aspects. LNG trucks cannot replace or compete with pipelines but are considered an alternative solution to overcoming pipeline limits and challenges

Figure 6: CAPEX comparison of terminal with FRSU (3MTPA) (Zhang et al., 2017)

Component	LNG Terminal	FSRU
Jetty including piping	US$60m	US$60m
Unloading Lines	US$100m	N/A
Tanks 1X180000m3	US$85m	In FRSU
FSRU Vessel	N/A	US$250m
Process equipment	US$130m	In FRSU
Utilities	US$60m	N/A
On-shore Infrastructures	N/A	US$30m
Land Fee and others	US$125m	US$20m
Total	US$560m	US$360m

for emerging markets. While pipelines are adapted to large volumes, trucks can operate with a spot delivery principle, allowing more flexibility. Also, pipelines represent point-to-point rigidity and geographic inflexibility, while LNG trucking provides a competitive supply option for larger geographical coverage.

Finally, since the transportation sector is generally linked to pollution generation, it is important to address the development of LNG truck transportation with a sustainability dimension. It can contribute to developing a new LNG market, also called compressed natural gas (CNG), an eco-friendly alternative to gasoline. Natural gas can be a reliable fueling energy source for transportation with less pollution impact compared to other fossil fuels (Safari et al., 2019). It is also important to consider technical development in truck types adapted to road profiles to optimize energy consumption aspects.

6. RESULTS AND DISCUSSION

6.1. Towards an Open Supply Chain: Mid-stream Model and SWOT Analyses

After identifying LNG midstream challenges and presenting supply chain alternatives. Figure 7 summarizes in one midstream model the suggested supply chain process for small-scale LNG markets. Natural gas is liquefied to reduce its volume by 1/600 factor, whether by sea vessel or container, or truck. Once the LNG is received and stored in FRSU tanks, LNG can either be sent to onboard regasification for pipeline injection (in the case of already existing pipes or a large provisional demand) or be sent out in liquid form for LNG truck transportation for small to mid-scale demand. The consumer's site must be already equipped with an LNG storage capacity, allowing it to maintain the flow and production demand while supply is discontinuous.

While the classical mid-stream model is a supply-driven flow best adapted to large-volume transactions, making gas available to the consumer regardless of its demand, this model is more adapted to market fluctuations. It is developed on a demand-driven flow basis. All the composing components: FRSU, storage capacity, fleet size, and truck transportation rotations, are customized to meet consumer needs. As a business model, it breaks with the habit of having a single operator for the entire supply chain; it creates new LNG submarkets and introduces new competitors. However, this model requires important aspects of planning and product transfer. Strategic and operational planning are key aspects of this model's success. Operational management prerequisites are stricter; any decision should be taken on reliable and precise performance indicators, requiring agility to adapt to rapid market changes. We summarized Table 3, the SWOT analyses for this model, which reflects this supply chain's strengths, weaknesses, opportunities, and threats. This analysis enlightens the investment decision-making process by presenting the different aspects and dimensions of this model.

As an emerging LNG market, rapid access to the molecule is an important decision-making factor. The most important advantage is the investment cost of FRSU, which is only 60% cost of the onshore terminal delivered in nearly half the time. The emergence of short-term LNG contracts with more flexible volumes will further enhance this supply chain model, even in large consuming countries wishing to develop regional access and autonomy. However, this model comes with its own set of challenges, especially operational planning. Maximizing profitability comes through minimizing both CAPEX and OPEX expenses, including fleet dimensioning, optimum routing, storage inventory, and delivery. The proliferation of intermediary players presents an opportunity for emerging LNG submarkets but exposes the supply chain to vulnerabilities and possible flow interruptions. The ownership and risk transfer are also important to consider. Government policy can play a major role in enhancing market development through adequate incentives and policies.

6.2. Energy Policy Impact

The maturity of local regulations is often perceived as a strong market development barrier. Natural gas future might be brighter compared to other fossil fuels due to its lower pollution emissions that remain the subject of controversy and a critical question for the industry's future. Currently, the four largest global LNG markets, namely the EU, China, Japan and South Korea, have introduced carbon neutrality aspirations in 2020 that may

Figure 7: Natural Gas logistic distribution model adopting FRSU

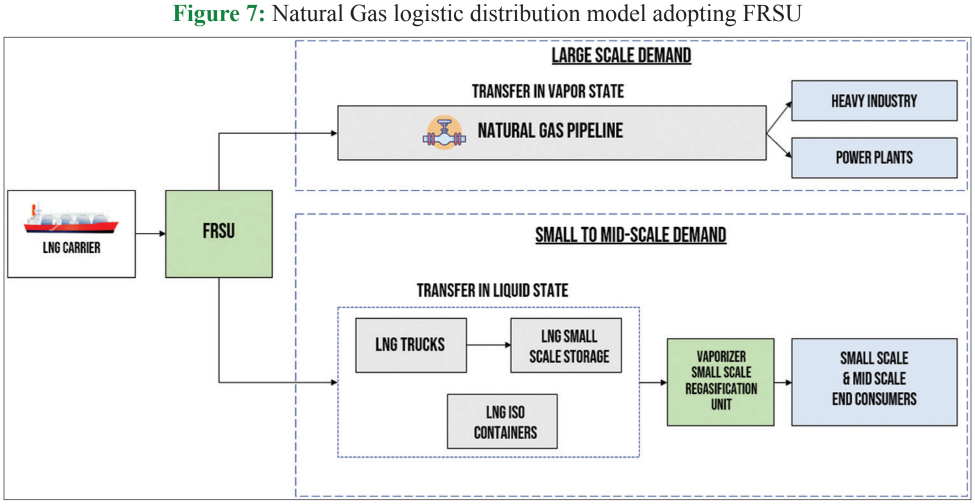


Table 3: SWOT analyses of the optimized supply chain model

Strength	Weaknesses
• Lower operational cost • Delivering spot markets • Time delivery • Relocation possibility • Better geographical coverage • Operational flexibility • Less investment, better profitability • Financing flexibility: leasing options • Adapted for small electricity plants • New LNG markets development (retailers)	• Limited storage capacities • Less adapted for 24 h/24 gas consumption • Planning complexity: multi-operation supply chain • HSE logistics risks • Interdependency between logistic components • Risk and ownership transfer
Opportunities	**Threats**
• Short-term supply contracts • Energy transition • Regional markets developments • Industrialization in developing countries	• Supply uncertainties • State policy and regulations • Seasonal pricing patterns • Net Zero emission regulations

potentially restrict opportunities to supply LNG for higher-emission projects (McKinsey, 2021). LNG characteristics, in terms of high standards and compliance with safety rules, make it subject to legal authorizations and specific permitting processes. Various regulatory reforms may be needed to promote the development of the gas sector, such as licenses for facility construction and LNG truck acquisition, and distribution licenses should be standardized.

The proposed business model can accelerate market regulatory development. The clear separation in logistics segments makes it possible to reduce the potential vertical monopoly and increases fair competition. This model will benefit third-party operators' access. In addition to manufacturers, this model can be adapted to domestic consumption. Incentives such as tax exemptions can encourage the development of the sector. Investment in an FRSU facility can be made by a state institution to ensure its legal governance; it is the case in several countries, such as Morocco, or by foreign investors with the required expertise in the field.

Many scientific research papers developed natural gas pricing liberalization but limited their scope to mainly mature LNG markets. Emerging ones should benefit from state regulation and sometimes even subsidies for faster development. Incentives can take many forms; the International Energy Agency (IEA) report (IEA, 2021b) stated that tax exoneration and subsidy could have similar incentive effects as they both decrease investment costs and enhance profitability. It's the government's role to give a strong push for rapid LNG development and help accelerate steady emerging markets with adapted infrastructure and supply chain models.

6.3. LNG Development Challenges in a Net Zero World

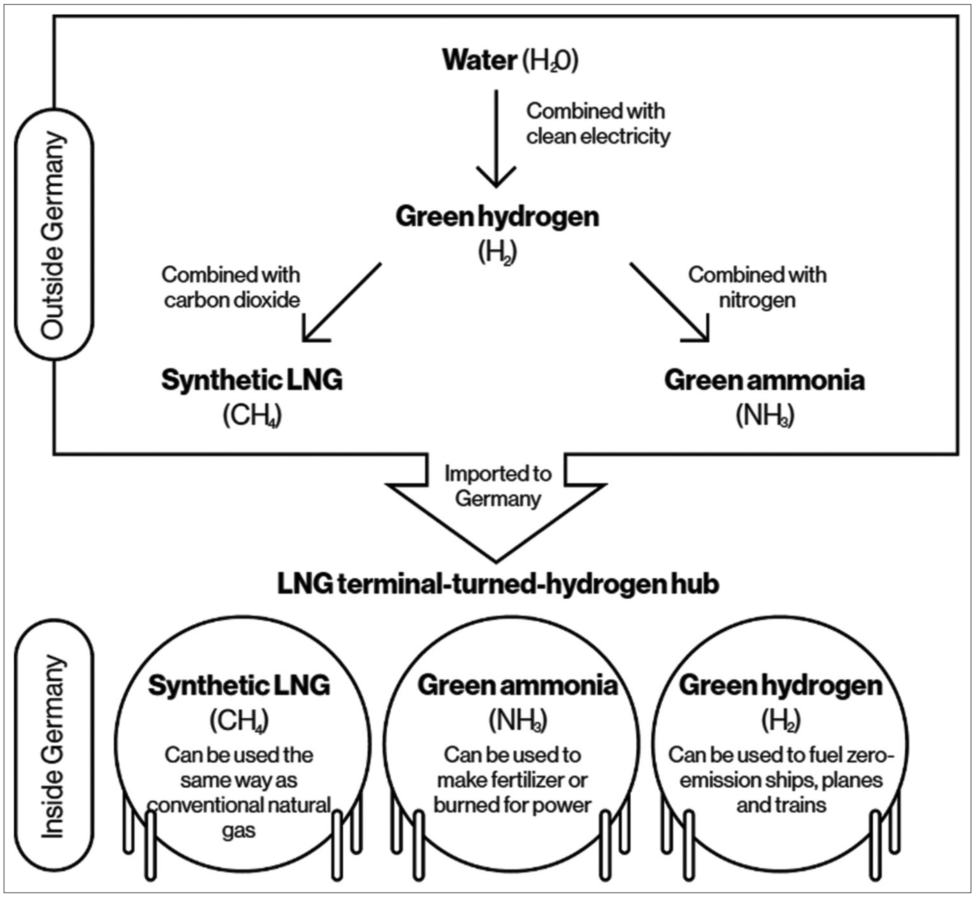
The global LNG Market is more than ever facing a pronounced climate of uncertainty, between the current energy crisis with an imminent need to reduce dependence on Russian Gas and the pledges to achieve a net zero emission to get onto the 1.5°C pathway. Despite the pressure put on fossil fuel energy-based demand, Gas will remain resilient and vital for this transition as it will gradually replace coal and serve as feedstock for the production of blue hydrogen (Van Dorsten and De la Cruz, 2022). In a net-zero future, Gas can play a fundamental role if the carbon capture and storage technology evolves and allows better cost-efficiency in lowering emissions (Mckenzie, 2022).

In the accelerated energy transition at 1.5°C, the gas demand can be projected to decline. The market can be subject to more competition with the development of green alternatives like hydrogen and ammonia that could be available for a lower price. This would challenge the profitability of costly LNG supply projects that would be assessed differently and will take into consideration new parameters like carbon off-setting (Filippenko, 2022).

To reconcile the need to address the short-term energy crisis with the net-zero environmental ambitions, LNG importing terminals can be an option to cover for the Russian gas and convert in the future to handle green fuels, a technical compromise that remains at this stage theoretical. LNG Importation terminals are designed to receive the liquified product at −160°C; the cryogenic fluid is pumped into pipelines and storage tanks also designed to withstand cryogenic temperatures before turning it back into gas for final delivery. Despite the conceptual similarity from a supply chain perspective between LNG and Hydrogen, almost none of the equipment used in an LNG infrastructure can handle hydrogen because its molecules are smaller than methane and require cooling to −250°C. A technically possible way to switch and adapt LNG infrastructure for Hydrogen is to convert the latter into ammonia that can liquefy at −33°C. Ammonia can be used for power or to make fertilizers, or converted into hydrogen fuel. The adaptation costs are estimated to be 15% of a new facility, according to a Bloomberg case study on Germany's energy transition (Shiryaevskaya, 2022). Figure 8 demonstrates how the approach can be conducted in an LNG importation facility.

The adjusted technical configuration must adapt to the additional product flows, where pumping systems must be installed and dedicated for Ammonia and crackers to break the compound for customers looking only for hydrogen, two energy-consuming processes for which clean power sourcing must consider to guarantee the net-zero emission. The integration of synthetic LNG in the importation process can also be an important contributor to the net-zero emission path, in a process where hydrogen is combined with captured carbon dioxide to form methane. As of today, there is no facility producing synthetic methane at large-scale. If it reaches mass production level and with competitive prices, it can easily be shipped using the existing facilities and networks and turned into green hydrogen; the generated carbon dioxide can be captured and used again in the production of synthetic LNG in a zero-carbon emitting loop (Shiryaevskaya, 2022).

Figure 8: From LNG to hydrogen facility: what Goes In and Comes Out of a Hydrogen Hub (Shiryaevskaya, 2022)



7. CONCLUSION

Beyond the cyclical effect of the energy crisis that favored the development of LNG, we have demonstrated that, due to its composition and characteristics, LNG structurally presents an interesting alternative to other fossil fuels. Several countries are integrating LNG as a key component of their energy transition strategy. Having initially emerged as a mass product, the classically adopted supply chain was designed to better suit large consuming markets. The long-term profitability of heavy investments in natural gas condemns the emerging markets to seek logistics alternatives adapted to their industrial needs, especially since the increased volatility experienced in the LNG market does not provide long-term visibility of commercial conditions. There are numerous countries wishing to develop LNG and can benefit from supply chain optimal facilities. The FRSU is the first step toward this development, especially in the absence of existing import and pipeline infrastructure. FRSU is only 60% cost of the onshore terminal delivered in nearly half the time. If pipelines are recommended in some cases, such as continuous electricity production, the case of industrial consumers is different and can be managed with other logistics alternatives. LNG supply by truck or iso-container allows the discontinuous supply of gas to the industrial consumer having already an installation and storage capacity adapted to its consumption needs on its proper land. This model allows better geographical coverage and better access to LNG, even for small consumption in areas far from import sources. This supply chain alternative is of particular importance in developing regions such as Africa. However, the success of this model largely depends on optimized operational management to overcome storage capacity limitations and interdependence between the partitioned logistic segments. Operational management can be enhanced by integrating machine learning or deep learning management tools for a rapid and efficient decision-making process.

LNG mature markets can also benefit from this model if wishing to develop autonomous regional markets. Even though LNG is considered mostly a cleaner alternative compared to other fossil fuels, it's still causing methane emissions to the atmosphere. It requires further optimization to ensure sustainable development and overcome its remaining threats and vulnerabilities, especially in supply planning and policy aspects. There are still some challenges to consider, especially concerning state regulations and future net-zero targets. The fact that this model, as described, can be adapted for the production of blue hydrogen is a strategic factor to be considered as an opportunity. Future research can develop this aspect and investigate the technical reuse alternatives.

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