Asia-Pacific Economic Cooperation

Advancing Free Trade for Asia-Pacific Prosperity

Changing LNG Market Dynamics – Implications on Supply Security in the APEC Region

APEC Oil and Gas Security Studies | Series 17

APEC Energy Working Group

September 2020

APEC Project: EWG 01 2020S

Produced by
Asia Pacific Energy Research Centre (APERC)
Institute of Energy Economics, Japan
Inui Building, Kachidoki 11F, 1-13-1 Kachidoki
Chuo-ku, Tokyo 104-0054 Japan
Tel: (813) 5144-8551
Fax: (813) 5144-8555
E-mail: master@aperc.or.jp (administration)
Website: http://aperc.or.jp/

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

APEC#220-RE-01.9

ISBN: 978-981-14-7794-2

TABLE OF CONTENTS

FOREWORD

The Asia Pacific region has been focused on LNG, as the region consumes more LNG than any other regions in the world. In November 2019, the largest global LNG importer, Japan, celebrated the 50th anniversary of the introduction of LNG. The arrival of the first LNG cargo from Alaska helped transform Japan's energy mix from heavily relying on coal to a more diversified fuel mix. The year also marked the 30th anniversary of Australia exporting LNG to Japan. As the LNG market expanded, it became more global with trade reaching more areas than ever. LNG trade and demand are expected to continue to grow, especially during the energy transition period as economies switch away from carbon-intensive fuels.

Over the last decade, the LNG market has been experiencing changing dynamics and challenges. As the largest LNG consuming region in the world, it is essential for APEC economies to understand these changes in order to better prepare for them. This study examines the changes facing the LNG industry and provides insights and implications for APEC economies to review and factor into their energy policies.

I very much hope our Oil and Gas Security Studies (OGSS) series will continue to serve as useful information to help APEC economies to better address their oil and gas security policies. We will continue to work closely with governments and all other stakeholders to support your efforts for an affordable and secure energy future.

Kazutomo IRIE

President

Asia Pacific Energy Research Centre

September 2020

ACKNOWLEDGEMENTS

This report was made possible by the collaboration of the Asia Pacific Energy Research Centre (APERC) and the Institute of Energy Economics, Japan (IEEJ) through the discussion and collaboration of the people named below.

Project coordinators

Fang-Chia Yoshika LEE (APERC) and Hiroshi HASHIMOTO (IEEJ)

Authors

APERC
Fang-Chia Yoshika LEE • Christopher DOLEMAN • Diego RIVERA RIVOTA

IEEJ
Hiroshi HASHIMOTO • Monica NAGASHIMA • Atsushi SAIGUSA • Gen HOSOKAWA
Tetsuji ABE • Yosuke KUNIMATSU

Editors

Mr. James Michael Kendell (Senior Vice President of APERC) • Fang-Chia Yoshika LEE (APERC)

Disclaimers

EXECUTIVE SUMMARY

Natural gas is projected to be the fastest-growing fossil fuel in APEC region, with supply increasing by 57% to 2 633 Mtoe in 2050. The strong growth is underpinned by expected fuel switching in the industry and power sectors. Net LNG imports in the region grow by 140% through 2050, indicating that natural gas will play an essential role in the energy mix in APEC. As the largest LNG importing region in the world, it is important to understand the changing dynamics in the LNG market and the implications for supply security.

This report has five sections. The first section defines the scope of the study and discusses the definition of LNG supply security. The second section examines the recent changes in LNG project development, such as changes in LNG contracts, the increasing share of portfolio players and difficulties for LNG project construction. The third section reviews the transformation of LNG shipping, including technical developments in LNG carriers, changes in the LNG carrier market and how the portfolio model affects the carrier business model. The fourth section delves into the challenges of developing LNG terminals and gas storage. The last section summarises all the dynamics and challenges discussed in the previous chapters and outlines implications. The key findings and implications of the report are summarised below.

Significant changes in LNG contracts

Long-term contracts have always been the backbone of LNG project development. However, some of the rigid aspects of long-term contracts have been going through some significant changes in past few years, including the changing share of long-term contracts, weakening oil-indexation and more destination-free contracts.

As more LNG projects entered commercial production between 2014 and 2017, especially in Australia and the United States, oversupply resulted in a robust spot market and a drop in the share of long-term contracts in overall signed contracts, from 70% to 30% in four years. However, just when the market questioned whether the era of long-term contracts has passed, the percentage of long-term contracts increased to 90% in 2019, driven by demand growth through 2024 and avoidance of spot price volatility.

In practice, 12%-15% of the long-term contract price is linked to the oil price. However, the linkage weakened since 2014, decreasing by 3% by 2018 as more liquefaction capacity came online. In addition, the percentage of destination-free contracts signed grew from 25% of total contracts in 2017 to 89% in 2019, showing the power of the current buyers' market.

Increasing share of portfolio players strengthens LNG supply security and shapes LNG shipping industry

An LNG portfolio player is defined as a company that holds a portfolio of LNG supply from different regions as well as various shipping, storage and regasification assets. The LNG contracts signed by portfolio players have been increasing fast in recent years. This implies the

LNG business model has gradually shifted from a traditional point-to-point business model to a portfolio business model.

The portfolio model entails flexibility of supply sources and efficient cargo delivery. This helps to promote the final investment decision (FID) of progressing LNG projects, with portfolio players' abundant capital and large trade capacity, as well as bridging between sellers and buyers in making large deals in the dynamic market, and ultimately contributes to stronger LNG supply security.

The shift of business model also changes the way LNG carriers operate. They are required to operate in a more complex and flexible manner, such as short notice of shipping service, uncertain routes to various buyers, shorter contract commitment and ability to divert cargoes, etc. Also, daily charter rates paid to carriers depend on the flexibility that the carrier offers. The portfolio model gives LNG carriers an opportunity to optimise their operations via advanced trading algorithms in real-time while increasing flexibilities to accommodate the complex services required.

Modular construction approach offers a solution to ballooning costs of LNG projects

Several LNG projects have experienced cost over-runs because of construction difficulties and rising labour costs in Australia and the United States. As the average liquefaction capacity of new LNG projects increases, it poses a greater risk of cost over-runs of these mega LNG projects. To improve the cost and time efficiency of LNG project construction, the modular construction approach was introduced. The modular approach significantly drives down construction costs and time by streamlining the manufacturing process.

The Yamal LNG project in Russia is the best successful example, where the construction was completed before the scheduled deadline even under extreme weather conditions. Calcasieu Pass LNG in the US also adopted the same approach by having 18 LNG trains with only 0.626 million tons per annum (mtpa) capacity. The "design one, build many" technology not only reduces the construction time and costs, but also allows the liquefaction site greater flexibility to meet the changing demands of customers.

Technological advancement contributes to higher usage of BOG and IMO rules compliance in LNG shipping

LNG carriers have been going through technological evolution. The most fuel efficient and advanced LNG carrier propulsion systems are slow speed two-stroke dual fuel engines: the high pressure mechanically operated electronically controlled, gas injection (ME-GI) and X-DF. The orders for LNG carriers with these two systems have increased significantly since 2018, especially X-DF. ME-GI and X-DF not only increase the use of boil-off gas (BOG) during shipping, but the design of X-DF also allows the carrier to comply with IMO's restriction on sulphur contents and NOx emissions.

As International Maritime Organization (IMO) applies stricter rules, there will be a growing demand for LNG as a fuel for LNG carriers, as it is nearly sulphur-free and has lower NOx emissions. Another implication is that vessel obsolescence is expected to increase because of non-compliance with environmental regulations, poor economics, and lack of flexibility. However, these obsolete vessels could be converted into floating production storage and offloading (FPSO) units, floating storage and regasification units (FSRU) or Floating Storage Units (FSU) to contribute to LNG production and supply again.

Government's role is required for LNG terminal and gas storage development

The physical characteristics of LNG makes it highly difficult to develop related facilities. Several requirements must be met such as adequate demand, reliable and competitive sources of supply, and clear legal frameworks. The examples in Korea, Thailand and Viet Nam demonstrate the significance of how a clear and supportive legal framework could be beneficial for gas supply security by allowing private sector participation in LNG imports, and terminal and storage development.

In addition, adequate communication is also required for LNG terminal development. The examples of the Taoyuan LNG terminal in Chinese Taipei and Chile's Penco LNG terminal demonstrate how environmental concerns and insufficient communication with stakeholders could delay project development. The controversies between local communities, and project developers and regulators resulted in lengthy delays and possible project cancelation (in the case of Chile's Penco LNG terminal). These two examples underscore the importance of improving the scope and quality of both the environmental impact assessments and engagement with local communities in developing LNG importing infrastructure. This is particularly important in the APEC region, as developing LNG import terminals is fundamental not only to energy security but also to emissions reduction.

The importance of gas storage on supply security

Often the security of LNG importing sources and diversification to improve supply security are highlighted, but seldom is the importance of domestic gas storage in supply security examined. The gas supply shortage in winter 2017 in China highlighted the lack of a gas pipeline network connecting LNG receiving terminals and the gas demand region, as well as the lack of gas storage in the demand region. In 2019, China set up a new state-owned company to take charge of building and interconnecting the main oil and gas pipelines to form a unified network, along with gas storage capacity expansion.

However, the most common type of gas storage facility (underground gas storage) only exists in six APEC economies because of the special geological requirements. Above ground gas storage serves the same function but only exists in major LNG importing economies such as Japan, Korea and Chinese Taipei. There are still some APEC economies, such as Chile, Mexico and Thailand, that have limited gas storage capacity but have growing gas demand. Investment in gas storage capacity in these economies could enhance both their energy security and their energy system resiliency.

1 INTRODUCTION

Natural gas demand is projected to grow by 57%, the most rapid among fossil fuels in the APEC region, rising from 1 700 million tons of oil equivalent (Mtoe) in 2016 to 2 633 Mtoe in 2050, according to the 7th Edition of APEC Energy Demand and Supply Outlook (APERC, 2019). The increasing gas demand is mostly driven by use in industry and power generation. More fuel switching is expected given that natural gas emits 50-60% less carbon dioxide than coal (EIA, 2019).

Gas demand in the APEC region is expected to be met by both pipeline gas and LNG imports. Pipeline gas imports are projected to grow by 20% and LNG by 185% between 2016 and 2050 (APERC, 2019). This indicates that LNG will become the major source of gas and will play a more vital role in the energy mix in APEC. It makes LNG supply security critical for gas importers, especially for those importers that have no access to gas pipeline imports and hence rely on LNG imports, as well as for those that already have gas pipeline imports but wish to diversify gas sources via LNG imports.

Significant changes are taking place in LNG markets. For example, the LNG market is becoming more globalized as the numbers and types of LNG traders increases. Global LNG trade hit a record high of 316.5 million tons (Mt) in 2018 (IGU, 2019). High LNG prices in Japan also dropped from about USD 13/MMBtu in 2015 to USD 9/MMBtu, reflecting declining oil-indexed LNG prices (IGU, 2019).

These changes bring challenges and uncertainties to LNG market. LNG has a long and complex supply chain, from exploration development, production, gas processing, liquefaction, shipping, regasification and storage, all the way to final distribution to end-users. Failure of any one segment could adversely affect other segments and ultimately affect LNG supply security. This report examines the key challenges in the supply chain under changing LNG market dynamics and finally proposes suggestions to the LNG importing economies on how to mitigate and manage these challenges and ultimately improve LNG supply security.

Definition of LNG supply security

While definitions for energy security abound in the literature, there are fewer definitions for the supply security of LNG. The most extensive discussion is in *The IEA Natural Gas Security Study* published by the OECD in 1995. It states that gas security is best seen in terms of risk management and that gas security risks fall into two categories: *risk of disruptions to existing supplies* such as politics, accidents or extreme weather conditions; and *long-term risk* that new supplies cannot be brought online to meet growing demand because of economic or political changes (IEA, 1995).

Another paper that defines gas supply security is *Security of European Natural Gas Supplies – The Impact of import dependence and liberalization* authored by Jonathan Stern in 2002. Stern also defines gas security along two dimensions: first, short-term supply availability versus long-term adequacy and the infrastructure for delivering this supply to market; and second, operational security of gas markets such as strains of extreme weather versus strategic supply such as catastrophic failure of supply sources and facilities (Stern, 2002).

Stern further divides the threats to supply into sources of gas supplies, the transit of gas supplies and the facilities through which gas is delivered. Hereby, this report deals mainly with challenges in these three segments.

Objective and scope of the study

The objective of the study is to assess the key challenges along the LNG supply chain in order to provide risk mitigation measures and identify policy implications for the LNG importing economies in the APEC region in order to improve their LNG supply security.

Therefore, the study only covers challenges on the supply side, including gas production, liquefaction plant construction, and shipping and receiving terminals. Anything related to domestic gas distribution and demand issues is not included in the study.

2 CHANGING DYNAMICS IN LNG CONTRACTS, PORTFOLIO PLAYERS AND PROJECT CONSTRUCTION

Changing LNG contracts

There are various types of contracts in different stages of LNG supply chain. For example, production sharing contracts (PSC) or licenses are contracted in the upstream exploration stage. Heads of Agreement (HOA) or Memorandums of Understanding (MoU) are signed in the negotiation process before inking the actual deal. The contract this study refers to is Sale and Purchase Agreement (SPA). The SPA is the definitive contract signed between a seller and buyer for the sale and purchase of a quantity of LNG for LNG delivery during a specified period at a specified price (PwC, 2006).

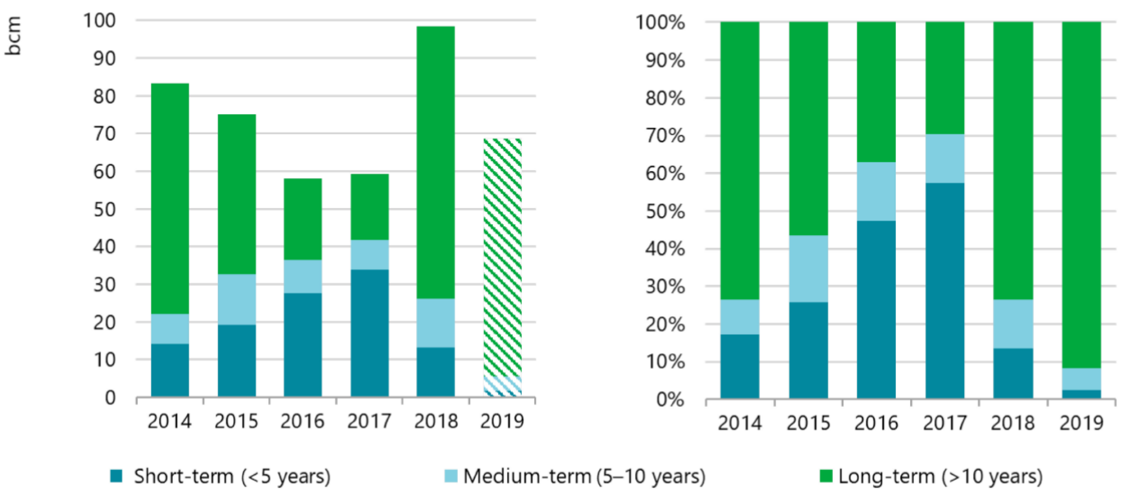
Contract duration is changing

Long-term SPAs[1] have always been the backbone of LNG project development since both sellers and buyers need them to justify the investment in liquefaction projects and receiving terminals, given that these projects are capital-intensive. A liquefaction plant would not reach FID without having long-term contracts signed. An average of 85% of the liquefaction throughput is tied into these long-term contracts to enable developers to secure project finance (IEA, 2017).

However, the share of long-term contracts dropped from about 70% to 30% between 2014 and 2017 (See Figure 2.1). This was mainly driven by the strong growth of supply in LNG market. Global liquefaction capacity grew by 39 million tons per annum (mtpa) to 340 mtpa between 2014 and 2017 driven by new projects such as Gorgon LNG in Australia and Sabine Pass LNG in the United States, as well additional trains being added to existing projects in Gladstone LNG, Queensland Curtis LNG and Malaysia LNG (IGU, 2015; IGU, 2017).

[1] There is no specific definition of the duration of long-, medium- and short-term contracts. Usually long-term is more than 10 years, medium-term is 5-10 years and short-term is less than 5 years.

Figure 2.1 • Contract length of signed LNG SPAs, 2014-19



Source: (IEA, 2019a).

Liquefaction capacity further grew to 406 mtpa in the 2018. This growth was largely driven by Yamal LNG in Russia; Wheatstone LNG and Ichthys LNG in Australia; and Corpus Christi LNG, Cove Point LNG and Sabine Pass in the United States. In addition, Kribi floating liquefaction unit (FLNG) in Cameroon, the world's first FLNG converted from an LNG carrier, also contributed 2.4 mtpa (IGU, 2019).

As a result, the supply glut of LNG coupled with sluggish oil prices drove LNG contract prices down. The average Japanese import price declined from about USD 15/MMBtu to USD 7/MMBtu between 2014 and 2017 (IGU, 2017). Consequently, buyers were hesitant to sign long-term contracts at prices underpinning liquefaction projects, which made the share of long-term contracts fall to a very low level of 30 % in 2017.

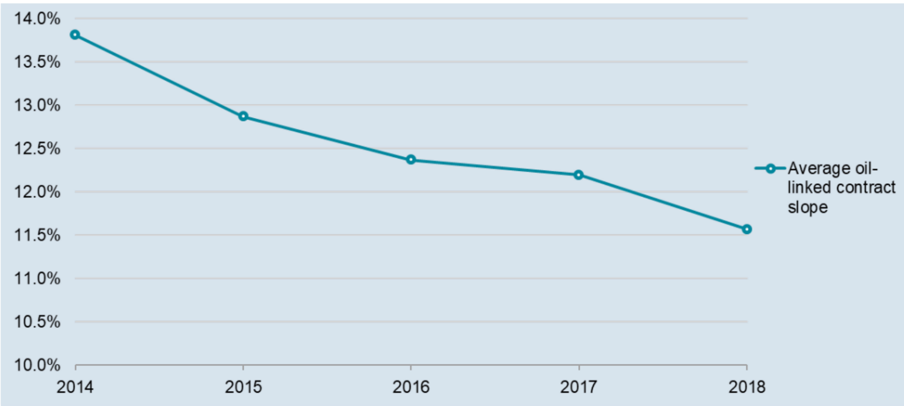
However, the LNG market remains dynamic. The share of long-term SPAs in 2018 surged to 74% and further to 92% in 2019, the highest in six years. The IEA's analysis suggested that the change was driven by strong growth in LNG demand and projected that world LNG trade would grow by another 26% between 2018 and 2024,. This shift was also driven by the need to avoid spot price volatility (IEA, 2019a). Northeast Asia spot prices have high volatility and one of the reasons is seasonal variation. The spot prices rise in the winter because China buys large amounts of LNG on a spot basis, while in summer the prices fall as demand decreases. In 2018, Northeast Asia spot prices fell from USD9.88/MMBtu in January to USD7.20/MMBtu in May (IGU, 2019).

Oil-indexation is weakening

There are three major natural gas pricing mechanisms in the world. In North America, the Henry Hub gas price is the main benchmark while in the Northern Europe, the U.K. National Balancing Point (NBP) is the benchmark. However, natural gas trade in the Asia-Pacific region does not yet have a benchmark that is widely accepted. Therefore, LNG contract prices are traditionally linked to crude oil prices such as Brent crude or the Japanese Crude Cocktail (JCC). The rationale of oil indexation is that end-users have choices between burning natural gas and oil products, so that using oil prices as a benchmark offers gas a discount to oil parity which stimulates greater use of gas.

A typical LNG price formula is P = A*crude oil price + B, where P is the LNG import price, A is the slope linking oil and gas which is usually between 12% and 15%, and B is a constant (IEEJ, 2003) (World Bank, 2018). The slope indicates the level of oil-to-gas indexation; the larger the slope, the tighter the linkage. However, the slope started to decline in 2014 as liquefaction capacity from Australia and the United States continued to come online and new capacity obtained FIDs (See Figure 2.2).

Figure 2.2 • Average oil-linked contract slopes by signing year, 2014-18

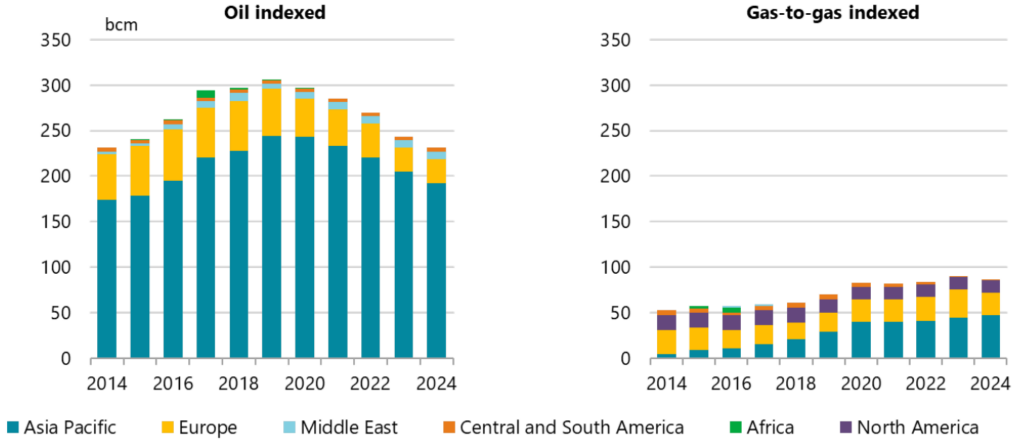


Source: (IEA, 2019a).

However, oil-to-gas competition is seeing a transition in Europe where such pricing is gradually being replaced by gas-on-gas competition.[2] A similar transition is also seen in Asia since the first US LNG exports in 2016. There are more contracts signed with Henry Hub-link prices. IEA forecasts that oil-linked contract volumes signed in the Asia Pacific will continue to decrease while gas hub-linked contract volumes continue to grow through 2024, presenting a shift from oil indexation to gas-to-gas indexation (IEA, 2019a).

Figure 2.3 • Oil indexed vs gas-to-gas indexed import volumes by region, 2014-24

[2] The gas-on-gas competition in Europe is mostly UK NBP and Dutch TTF (Title Transfer Facility).



Source: (IEA, 2019a).

More destination-free contracts signed

A destination clause is a contract term usually attached to an LNG SPA to restrict the buyer's ability to resell purchased LNG to destinations that are not specified in the contract. The main reason to include the clause is to prevent competition with the seller as well as to ensure LNG supply security for the buyers.

However, this long-practiced convention has lately been changed. In June 2017, the Japan Fair Trade Commission (JFTC) released a review Survey on LNG Trades – Ensuring of fair competition in LNG trades. The review stated that inclusion of a destination restriction clause[3] in LNG contracts is highly likely to be in violation of the Antimonopoly Act. JFTC advised LNG sellers not to impose a destination clause that restrains competition when signing contracts.

The destination clause, in fact, is not a new concern. Back in 2000, the European Commission started a series of investigations about whether the territorial sales restrictions[4] in LNG contracts breach European Union (EU) competition law. The Commission reached settlements with companies in most cases although some cases are still pending. Another case is Singapore. In 2014, Singapore's government requires that LNG importers must ensure there are no destination clauses in their upstream Sales Purchase Agreements (EMA, 2014).

The JFTC review triggered a series of discussions as well as change in practices. Tokyo Gas aims to sign deals that come without destination clauses (Reuters, 2019a). In May 2019, JERA announced that they had signed a 17-year contract with Anadarko[5] to import LNG from Mozambique. JERA stated that the destination clause is in line with the JFTC report (JERA,

[3] A destination restriction clause requires the buyer to take delivery at a specified port or only sell the LNG in a specified geographic area.

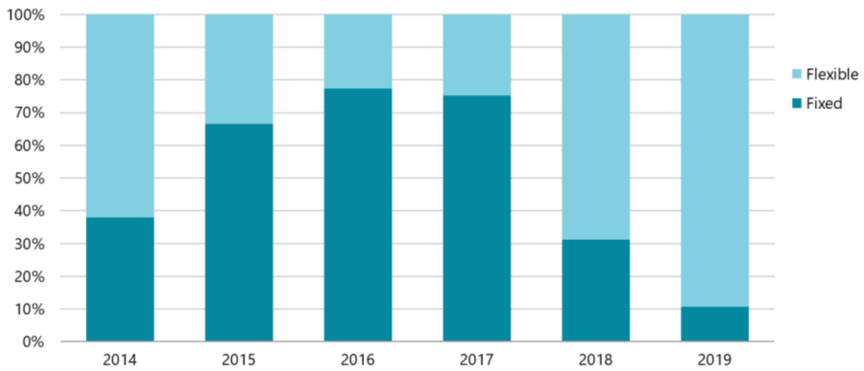
[4] A destination clause is referred to as a territorial restriction in the EU.

[5] Total acquired Anadarko's LNG assets in Mozambique in September 2019, which makes Total the current contractor with JERA.

2019). The changing attitude is also seen in ASEAN. The ASEAN Council on Petroleum (ASCOPE) published a standardised LNG contract template with limited destination restrictions, promoting LNG trade in the ASEAN common gas market.

Destination-free contracts not only allow buyers to have more flexibility when their LNG demand is unexpectedly low, but also let them optimise their portfolios when there is a better trading opportunity. The share of contracts signed with a flexible destination increased to 69% in 2018 and 89% in 2019 (see Figure 2.4). This shows that the suppliers are more willing to remove destination clauses in the current buyers' market.

Figure 2.4 • Contracts signed by destination clause, 2014-19



Source: (IEA, 2019a).

Increasing share of portfolio players

Definition of portfolio players

An LNG portfolio player is defined as a company that holds a portfolio of LNG supply from different regions as well as various shipping, storage and regasification assets (IEEJ, 2018). And this is not a one-size-fits-all definition, as different LNG players have different business strategies and business models, as well as different levels of diversification of supply sources and market outlets.

Portfolio players have contributed and are expected to continue contributing to development of more flexible LNG markets by handing over and receiving cargoes at different locations around the world, responding to market signals. LNG volumes owned by portfolio players have increased not only in the short-term sales but also in the long-term contract markets. More recently, an increasing number of and different types of LNG market players are trying to take on portfolio activities these days.

Types of LNG market players

This study categorises LNG portfolio players into three types: a multinational oil and gas company, a utility company or a trading company. The first type of portfolio players includes the oil and gas majors such as BP, Shell and ExxonMobil; the second type is energy companies that are not oil and gas majors, for instance, Petronas and Osaka Gas. Petronas is a Malaysian state-owned oil and gas company and it has investment in overseas LNG assets, including Egyptian LNG in Egypt and Gladstone LNG in Australia as well as domestic LNG assets including MLNG 1 Satu, MLNG 2 Dua, MLNG 3 Tiga, MLNG T9 and PFLNG Satu. In addition, Petronas also participated in LNG Canada with a 25% equity stake. Osaka Gas also has various LNG assets including Freeport LNG in the US, Qalhat LNG in Oman, Gorgon LNG and Ichthys LNG in Australia. The last type is trading company like Mitsubishi and Mitsui. They actively participate in LNG projects worldwide in the US, Oman, Qatar, UAE, Australia, Brunei, Indonesia, Malaysia, Russia and Equatorial Guinea. These Japanese trading companies make significant contributions toward stabilising LNG supply in Japan with various LNG assets around the world (GIIGNL, 2020).

Of these three types, the multinational oil and gas company is the most active of the LNG portfolio players. Therefore, this study chose to analyse multinational oil and gas companies' major LNG assets to further illustrate the meaning of portfolio. Table 2.1 lists the major LNG projects, regasification terminals that multinational energy companies currently participate in, as well as the FIDs taken in 2018 and 2019 and the portfolio contracts that are in force. All these major gas players have rich LNG portfolios ranging from LNG upstream operations to shipping carriers and regasification terminals. With the diversity of portfolios, they can serve customers with greater flexibility and meet growing demand more easily.

Shell has a wealth of LNG production projects in 10 countries and leads the LNG market. It had 35.6 Mt of LNG liquefaction volumes in 2019 (Shell, 2019). Shell has major interests in two regasification terminals, Hazira in India with 100% of ownership and Dragon in UK with 50% of ownership (GIIGNL, 2020). The company has been growing mainly by acquisition, of Repsol's LNG assets in 2014 and BG group in 2015 (Shell, 2014) (Shell, 2016). In 2018, Shell took an FID along with other four participants (Petronas, PetroChina, Mitsubishi and Kogas) on LNG Canada with the largest share of 40%. The expected production is 14 mtpa (Shell, 2018a).

After the acquisition of Engie and Anadarko's LNG assets, Total became the world's second largest LNG player (Total, 2018; Total, 2019a). It has currently 13 LNG projects on stream with 40 Mt of LNG capacity around the world, a 10% of share of the world market. It expects to further reach 50 Mt in 2025. Its major LNG projects are Yamal LNG and Ichthys LNG. It also owns 8.35% of the largest regasification terminal, South Hook in Europe (Total, 2019b; GIIGNL, 2020).

ExxonMobil has participation in production of 86 mtpa of LNG, which is nearly 25% of global LNG production. ExxonMobil's major interests are located in Qatar and Papua New Guinea (PNG) and is operating PNG LNG with production of 8.5 mtpa. In addition to existing LNG projects, ExxonMobil took an FID in 2019 on Golden Pass in the US in 2019 with its partner Qatar Petroleum. This project is positioned to export low-cost LNG to customers in Europe and Asia (ExxonMobil, 2019b; GIIGNL, 2020).

As one of world's largest oil and gas companies, BP's LNG portfolio includes a mix of long-term equity projects and mid-term and spot purchases. The company currently has five LNG projects and one regasification terminal in Guangdong, China, with 30% equity stake (BP, 2020). In addition to these projects, BP also signed an agreement with the Alaska Gasline Development Corporation (AGDC) together with ExxonMobil to collaborate on ways to advance the Alaska LNG project (AGDC, 2019). In 2018, BP signed a Gas Sales Precedent Agreement with AGDC, which is an important milestone for pushing the project forward (BP, 2018a).

Table 2.1 • Major portfolio players' LNG portfolio assets

	On-stream LNG projects	LNG regasification terminals	FID taken in 2018 and 2019	Portfolio contracts in force
Shell	12 projects Brunei: Brunei LNG Australia: North West Shelf, Queensland Curtis LNG, Gorgon LNG, Prelude FLNG Russia: Sakhalin-2 Egypt: Egyptian LNG Oman: Oman LNG Qatar: Qatargas IV Nigeria: Nigeria LNG Trinadad & Tabago: Atlantic LNG Peru: Peru LNG	India: Hazira UK: Dragon Gibralter: Gasnor	Nigeria: NLNG Train 7 (7.6 Mtpa) Canada: LNG Canada (14 Mtpa)	18 contracts (~31 Mtpa)
Total	13 projects Angola: Angola LNG Egypt: Egyptian LNG Nigeria: Nigeria LNG Norway: Norway LNG Russia: Yamal LNG US: Cameron LNG Oman: Oman LNG Qatar: Qatargas I T1-T3, Qatargas II T2 UAE: ADNOC LNG Yemen: Yemen LNG Australia: Gladstone LNG, Ichthys LNG	US: Cameron LNG, Golden Pass UK: South Hook LNG	Mozambique: Mozambique LNG (12.9 Mtpa) Russia: Arctic LNG-2 (19.8 Mtpa) Nigeria: NLNG Train 7 (7.6 Mtpa)	13 contracts (~7.7 Mtpa)
ExxonMobil	7 projects Qatar: Qatargas I T1-T3, Qatargas II T1-T2, Rasgas I T1-T2, Rasgas II T1-T3, Rasgas III T1-T2 Australia: Gorgon LNG Papua New Guinea: PNG LNG	Italy: Adriatic LNG UK: South Hook LNG	US: Golden Pass (15.6 Mtpa)	1 contract (~1Mtpa)
BP	5 projects Australia: North West Shelf Angola: Angola LNG Trinadad & Tabago: Atlantic LNG UAE: ADNOC LNG Indonesia: Tangguh LNG	China: Guangdong LNG	Mauritania, Senagal: Great Tortue Ahmeyim FLNG Phase 1 (2.5 Mtpa)	7 contracts (~11.6 Mtpa)
Chevron	4 projects Angola: Angola LNG Australia: North West Shelf, Gorgon LNG, Wheatstone LNG	None	None	3 contracts (~1.82 Mtpa)

Sources: (BP, 2020), (GIIGNL, 2020), (Shell, 2020a) and (Shell, 2020b).

The concerns over emerging portfolio players for consumers

The emergence of portfolio players does not necessarily mean a growing number of the players because of the nature of portfolio model. In order to take maximum advantage of their portfolios, players often make alliance deals, including outright mergers and transfers of LNG assets. For instance, Royal Dutch Shell acquired BG Group in 2016; Total acquired Engie's portfolio of upstream LNG assets in 2018. The LNG industry has seen in recent years deals among the biggest players.

There may be legitimate concern from LNG consumers that the LNG market may be dominated by a small number of powerful LNG sellers, as these portfolio players might control most of the LNG supply assets through acquisitions. Such powerful sellers could offer very attractive deals to consumers thanks to their power – including different pricing arrangements and more flexible delivery conditions.

In short, portfolio players have contributed, and are expected to contribute, to enhanced security of supply, although there has been concern over market concentrations by those portfolio players as well.

Contributions of portfolio players to LNG supply security

More flexibility on supply sources and more efficient cargo delivery

As the gap among regional gas prices became narrower in past few years, LNG sellers watched their profit margins decline as they can only provide certain supply sources according to their contracts. However, the contracts signed with LNG portfolio players provide the sellers flexibility on supply sources without specifying certain supply sources, which can allow the sellers keep certain profit margins by optimising their LNG assets.

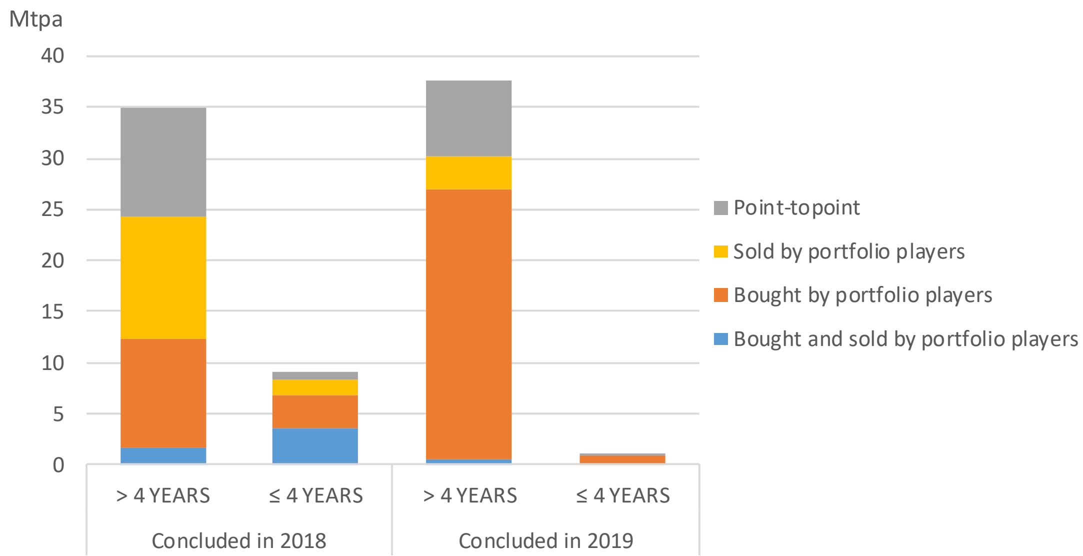
In this regard, a portfolio seller can arrange and operate its LNG assets such as LNG terminals and LNG carriers to optimise LNG cargo delivery. LNG shipping route arrangement plays a crucial role as LNG assets are widely spread around the world. This benefits not only the sellers but also the buyers, which can receive the cargoes more efficiently and quickly.

Responding quickly to fluctuating market demand

In recent years, LNG buyers have been demanding flexible supply contracts because of uncertainties regarding future LNG demands. LNG portfolio players have started to offer destination-free contracts to respond to the demands. LNG projects in the US also helped boost the share of destination-free contracts, reaching 40% of LNG traded in 2018 (IEA, 2019b). As mentioned above, an LNG portfolio player can enhance flexibility in the LNG market by assembling multiple LNG supply sources. An LNG portfolio player can optimize its position by having various ways of selling its LNG volumes.

Figure 2.5 shows the contracted volume by types of contractors in 2018 and 2019. Portfolio deals are now common for both spot and term contracts. Point-to-point contracts accounted for 31% of total contracts in 2018, but only 20% in 2019. The largest portfolios traders are BP, Shell, Total, Chevron and ExxonMobil.

Figure 2.5 • Contracted volumes by type of contractors, 2018 and 2019



source: (GIIGNL, 2019).

Promoting FID of progressing LNG projects

LNG portfolio players can have a big role in developing an LNG production projects. Their abundant capital and large trade capacity enable them to be relatively competitive to those with less flexibility. This advantage allows them to help facilitate the financing of LNG projects through signing up for the entire offtake of LNG projects. For example, Shell took an FID on LNG Canada and announced a $31 billion investment in 2018 with the largest share of 40% among the joint venture participants[6] (Bloomberg, 2018; Shell, 2018b). In the same year, BP also announced an FID for phase I of Greater Tortue Ahmeyim LNG, which is a cross-border development offshore Mauritania and Senegal. Greater Tortue is the deepest offshore project in Africa up to date with joint participants BP, Kosmos Energy, Societe des Petroles du Senegal (Petrosen) and Societe Mauritanienne des Hydrocarbures (SMHPM). BP as the operator holds the largest share of 60% of Senegal's block and 62% of Mauritania's block (BP, 2018b). In the US, ExxonMobil made an FID with its partner Qatar Petroleum on the Golden Pass LNG export project with an estimated investment of more than $10 billion (ExxonMobil, 2019a).

In the case of these LNG projects, LNG portfolio players have agreed to take and sell LNG to buyers. Therefore, the sales risk is on the portfolio players instead of other companies participating in the LNG project. In addition, these portfolio players also have to plan how to

[6] The other participants are PETRONAS (25%), PetroChina (15%), Mitsubishi Corporation (15%) and KOGAS (5%).

raise funds. The financial strength of the portfolio players allowed them to take risks about marketing and financing and hence made these LNG projects possible.

Table 2.2 • LNG project's FIDs taken in 2018 and 2019

		Expected production (Mtpa)	Participants	SPA signed
FID in 2018	US: Corpus Christi Train 3	4.5	Cheniere	CNPC
	Canada: LNG Canada	14	Shell, Petronas, PetroChina, Mitsubishi, Kogas	(HOA) Toho Gas, Tokyo Gas, Vitol, JERA
	Mauritania, Senagal: Great Tortue Ahmeyim FLNG Phase 1	2.5	BP, Kosmos Energy, Petrosen, SMHPM	Kosmos Energy
FID in 2019	US: Calcasieu Pass	10	Venture Global LNG	Shell, BP, Edison SPA, Galp, Repsol, PGNiG
	US: Golden Pass	15.6	ExxonMobil, Qatar Petroleum	Shell, CNOOC, Tokyo Gas-Centrica
	US: Sabine Pass Train 6	4.5	Cheniere	Petronas, Vitol
	Mozambique: Mozambique LNG	12.9	Total, Mitsui, ENH, ONGC, Bharat PetroResources, PTTEP, Oil India	Shell, Pertamina, JERA/CPC, EDF, Tohoku Electric Power, Tokyo Gas/Centrica
	Russia: Arctic LNG-2	19.8	Total, Novatek, CNPC, CNOOC, Mitsui, JOGMEC	CNOOC, CNPC, Mitsui, JOGMEC
	Nigeria: NLNG Train 7	7.6	NNPC, Shell, Total, Eni	Shell, Total, ENI, BG, Occidental Energy

Sources: (Natural Gas Intelligence, 2018), (Offshore Energy, 2018), (Rigzone, 2018), (Gas Strategies, 2019), (Oil & Gas Journal, 2019a), (Wood Mackenzie, 2019), (GIIGNL, 2020) and (LNG Industry, 2020).

Bridging between sellers and buyers in a market transition period

An LNG portfolio player can be a bridge between buyers and sellers. An LNG portfolio player has diverse supply sources around the world and a sales force taking advantage of its large LNG assets. When it is hard for a seller and a buyer to directly deal with each other, an LNG portfolio player can act as an intermediary. In short, even if the needs of a buyer and a seller don't match or the relationship between them isn't established well, an LNG portfolio player can leverage its assets and reliability to solve the problem by taking LNG from sellers and reselling it to buyers.

This is particularly the case in a transition period of the LNG market. While LNG buyers demand flexibility in LNG transactions, sellers still prefer a conventional long-term sales contract with a Take or Pay clause to assure return on investment in an LNG project.

An LNG portfolio player may be able to respond to buyers' diverse needs for flexibility, including fewer destination restrictions and delivery flexibility by combining multiple LNG sources.

The total LNG production capacity controlled by major LNG portfolio players and major LNG players with multiple supply sources - including Shell, Total, BP, Woodside, Petronas, ExxonMobil and ConocoPhillips - represents almost 40% of the global total (JOGMEC, 2020).

This in turn means that those players are very influential in the LNG market. They are expected to lead the evolution of the LNG market and support more flexible and expanded LNG trades.

Challenges during LNG projects construction phase

Ballooning cost of LNG production projects

According to *IEEJ Outlook 2020*, USD 2.7 trillion investment will be required worldwide in LNG related facilities including liquefaction plants, receiving terminals tankers etc. between 2018 and 2050. The LNG market in Asia, where natural gas demand is expected to increase by 2.8% annually, is expected to require a significant share of that investment (IEEJ, 2019). The *Shell LNG Outlook 2020* projects that 74% of increased LNG demand in the world by 2040 will be in Asia (Shell, 2020c). However, most LNG production projects that have started operations in recent years have experienced overruns of construction costs. The resulting unstable financial situation can lead to a loss of momentum for investment. This section describes the factors that have inflated the costs of LNG production projects.

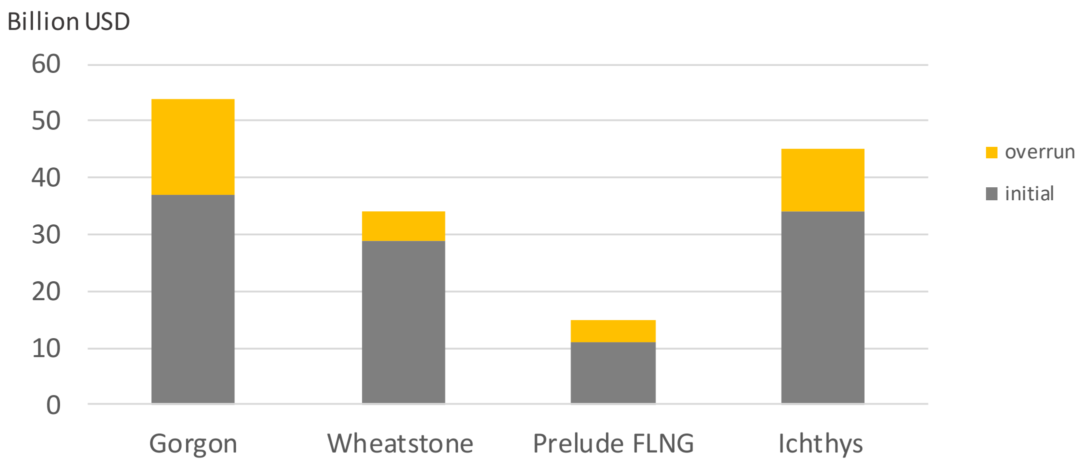
Australia: construction difficulties and rising labour costs are main factors in cost overruns

Cost overruns and construction delays in LNG production projects have occurred frequently in the past. One notable example is the Gorgon LNG project in Western Australia led by Chevron. The project cost USD 54 billion, USD 17 billion more than the initial estimate at the time of the final investment decision in September 2009.The project turned out to be very complex and the sponsors couldn't accurately grasp its magnitude at the initial engineering stage (Chevron, 2009; Chevron, 2013). Chevron also experienced a USD 5 billion cost overrun at the Wheatstone LNG project, also in Western Australia. It is suspected that it was mostly due to module manufacturing delays, although there may have been an engineering error (Reuters, 2016). Especially at a large-scale project, small design defects can have a significant impact on the project. Chevron said it would focus on design review work (The West Australian, 2017).

The latest four projects started in Australia (Gorgon, Wheatstone, Ichthys and Prelude) are estimated to have experienced cost overruns of USD 37 billion in total. Ichthys LNG experienced increased costs and delayed operations due to delays in the construction of power generation facilities that supply the power to the facility (Reuters, 2017). Prelude LNG was delayed because of design and manufacturing problems (Rystad Energy, 2019).

In addition to construction delays and manufacturing difficulties, a rise in labour costs pushed up project costs even further. As many of LNG projects in Australia are megaprojects that use advanced technologies seldom adopted in the past, few people have relevant skills and experience, and a shortage of human resources caused delays in construction schedules and increases in labour costs. Additionally, as some projects were located far from urban areas, the labour costs for general workers also increased because of transportation and accommodation costs (Reuters, 2017).

Figure 2.6 • Initial and additional cost of Gorgon, Wheatstone, Prelude LNG and Ichthys



Sources: (Chevron, 2009; Chevron, 2013; Reuters, 2016; Reuters, 2017; Reuters, 2019b; Rystad Energy, 2019).

United States also facing cost overrun challenges

In 2019, cost overruns in LNG projects also attracted attention in the United States. In the case of the Cameron LNG project led by Sempra Energy where Train 1 started operation in 2019, Chiyoda Corporation, a member of the Engineering, Procurement and Construction (EPC) contractor consortium, announced a huge loss of USD 953 million dollars, citing increased costs in construction (Chiyoda Corporation, 2019). The engineering and construction firm for Cameron LNG, McDermott, also announced an additional cost of USD 815 million between the second and fourth quarter in 2018 (McDermott, 2018a; McDermott, 2018b; McDermott, 2019). The losses were mainly from an escalation of labour costs due to a shortage of skilled labour. This occurred because of the surge in LNG projects in the Gulf Coast region due to rising oil prices during the construction period and reconstruction labour demand after the damage from Hurricane Harvey. In addition to the escalating labour costs, the shortage of skilled labour also caused an unstable supply of workers and lower productivity, which led to cost overruns (Global Construction Review, 2018).

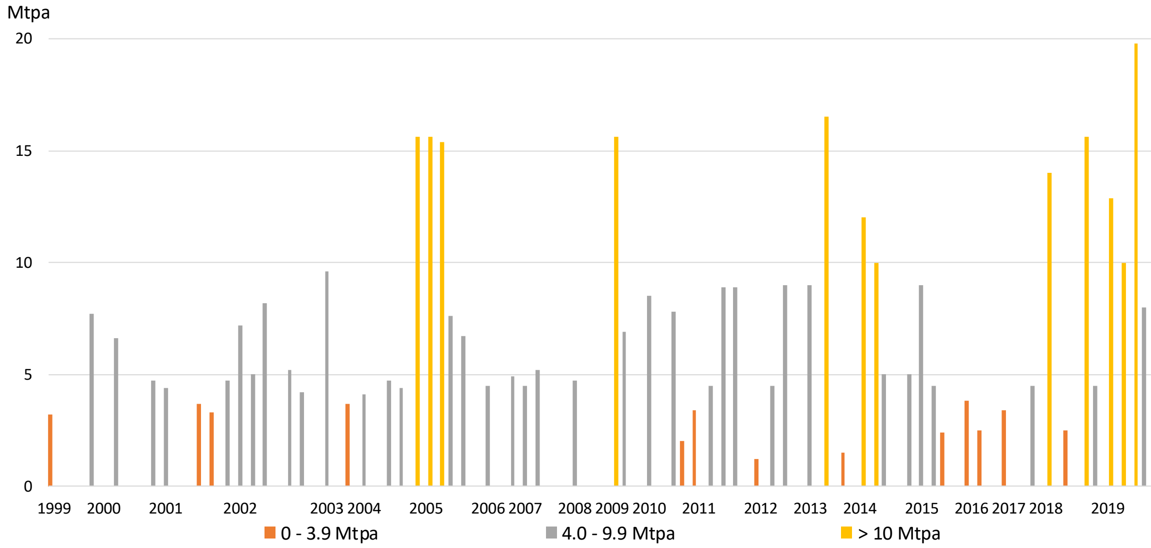
Cost overruns in recent years have occurred in Australia and the United States. In those two economies, the intensive upstream development in the same period caused a rise in labour costs, which contributed to the cost overrun. In the current investment decision boom, although there are still many projects in the United States, the remaining projects are distributed among Africa, Russia, and other economies. At least in terms of local workers, a shortage of capacity may not be as large as in the past.

Increasing size of LNG projects also increases cost overrun risks

The increase in the size of LNG facilities has contributed to the increase in the total cost of LNG facility construction. The larger the project, the longer the construction period and the greater the risk of cost overruns because of the market environment and other factors. On the other hand, increasing the liquefaction capacity leads to a reduction in the cost per unit liquefaction capacity. In fact, although Gorgon had caused significant cost overruns, the cost per liquefaction capacity is lower than Wheatstone.

Figure 2.7 compiles the liquefaction capacities of each LNG project by the year of FID. It shows that the number of LNG projects with liquefaction capacity greater than 10 mtpa increases after 2013, especially in 2018 and 2019, which puts the LNG projects at a greater risk of cost overrun.

Figure 2.7 • The liquefaction capacity of LNG projects, 1999-2019



Sources: (NLNG, 2020; JXTG, 2004; NTNU, 1998; Atlantic LNG, 2020; Qatar Petroleum, 2020; North West Shelf Gas, 2020; ConocoPhilips, 2020; JERA, 2019; Oman LNG, 2020; Egyptian LNG, 2020) (Equinor, 2020; Mechademy, 2019; Gazprom, 2020; EG LNG, 2020; Chiyoda Corporation, 2017; Total, 2009; Peru LNG, 2020; Woodside, 2020; Hydrocarbons, 2020a; Angola LNG, 2020) (The Economist, 2013) (Chevron, 2020a) (PNG LNG, 2020) (Shell, 2017) (Santos, 2020) (Hydrocarbons, 2020b) (Donggi Senoro, 2020) (Shell, 2020d) (Hydrocarbons, 2020c) (Chevron, 2020b) (Inpex, 2020) (Venture Global LNG, 2019) (Petronas, 2017) (Australia Pacific LNG, 2020) (Cheniere, 2019a) (Cheniere, 2019b) (Petronas, 2019a) (Cameron LNG, 2020) (Freeport LNG, 2020) (Dominion Energy , 2020) (Golar LNG, 2020) (Kinder Morgan , 2015) (Eni, 2020) (LNG Canada, 2020) (BP, 2018c) (Golden Pass LNG, 2020) (Mozambique LNG, 2019) (Total, 2019c).

Miscommunication with local government may also result in cost overruns: The Case of Indonesia

Cost increases at the application stage of development are also possible. In Indonesia's Masela block acquired by Inpex, the company was initially considering an offshore LNG production project with FLNG vessels. However, the progress of the project has been significantly delayed because the Indonesian government was concerned that an offshore LNG project would not increase Indonesian employment and the company was encouraged to switch to a land-based plan (Inpex, 2019). For new projects (greenfield), coordination with the relevant national and local governments is a major mission. Delays in permits and political decisions may cause delays of the project. In addition, since the facility is large, it may be necessary to make additional plans to reduce environmental impacts.

Environmental concerns could also be a potential risk to financial support

Although it is unlikely now, in the future development of natural gas resources may be heavily restricted by regulations. Climate change has led to the emergence of banks and investment funds that are reluctant to invest in coal, or have already stopped doing so. Natural gas is considered to be a bridging fuel to a low-carbon future, but as a fossil fuel, concerns will eventually grow about its CO_2 emissions.

Cost reduction measures for LNG projects

More realistic about costs

In the wake of cost overruns of LNG projects in Australia and the US, LNG project contractors expressed their concerns over LNG developers' planning processes. In 2018, major LNG project contractors such as Bechtel, Fluor, and McDermott stated that developers should be more realistic about the costs that are necessary to ensure the completion of projects. As construction of LNG projects is a major challenge, especially with so many ongoing projects, it is harder to come by skilled workers. The developers should scrutinize the cost estimates they initially receive. To commit to not making the same mistake again, McDermott backed away from signing an EPC contract for NextDacade's proposed Rio Grande LNG export terminal in Brownsville, because of unrealistically low cost estimates (Construction Dive, 2018; S&P Global Platts, 2018).

Modular train approach: Calcasieu Pass LNG

Project sponsors always try to keep costs down. Venture Global LNG's Calcasieu Pass LNG in Louisiana, which reached an FID in 2019, adopted a highly efficient, modular, mid-scale LNG liquefaction technology with lower capital costs. Calcasieu Pass LNG has 9 blocks, each consisting of two 0.626 mtpa trains that altogether would form a 10 mtpa export facility (Venture Global LNG, 2020).

The technology is different than traditional large-scale and customised trains, as the unit of each train is smaller and prefabricated offsite with modular designs. The "design one, build many" technology not only reduces the construction time and costs, but also allows the liquefaction site greater flexibility to meet the changing demands of customers (S&P Global Platts, 2017).

The mid-scale trains also allow the investor to disperse the risk by investing in gradual phases. For example, Cheniere had four phases of investment in Sabine Pass LNG in Louisiana. Sabine Pass LNG had six trains with each designed for approximately 4.5 mtpa. Phase 1 (train 1 and 2) began in operation in 2016, and later Phase 2 (train 3 and 4) and Phase 3 (train 5) were also in service in 2017 and 2019 after acquiring commercial deals. Phase 4 (train 6) received an FID in 2019 and will proceed with construction (Cheniere, 2019a).

The world's largest modular construction project: Yamal LNG

Yamal LNG is located in the estuary of the Ob River in the Russian Arctic, a region typically ice-bound for nine months of the year. The project consists of a total of 16.5 mtpa of LNG capacity which is built in three phases, each featuring a 5.5 mtpa train. One of the biggest challenges of Yamal LNG is the extreme weather conditions and remoteness of the facility. TechnipFMC, one of the Engineering, Procurement, Supply, Construction and Commissioning (EPSCC) contractors, chose a modular construction approach to build 142 modules and 365 pre-assembled pipe racks weighing more than 480,000 tonnes. Each module is prefabricated in shipyards in Asia and shipped to Russia. The modular approach not only kept Yamal's costs within budget, but even shortened its construction time with the streamlined work. On December 2018, Yamal LNG reached its full capacity one year earlier than planned (Alten, 2019; Chiyoda Corporation, 2018; TechnipFMC, 2019).

FLNG technology can reduce costs

The emergence of FLNG may result in lower initial costs, especially in offshore gas fields far from land. Ships equipped with liquefaction units are built at docks and no land equipment and long submarine pipelines are required. In April 2017, Malaysia's PFLNG1 led by Petronas launched the world's first commercial operation as an FLNG project. Later in 2019, Prelude LNG, the first FLNG project that took FID, also started shipping LNG cargoes from off the coast of Australia. The construction period is shorter than that of land-based facilities. After the completion of production at one site, the FLNG vessel can be transported to another gas field or (temporarily) can be operated as an LNG carrier, utilising the capacity and function of the vessel. However, there may be some technical problems such as difficultly in expanding the liquefaction capacity when gas demand increases.

Table 2.3 • LNG projects adopting FLNG

Project	Region	Operater	Operation year	Capacity (mtpa)
Petronas FLNG 1	Oceania	Petronas	2017	1.2
Cameroon FLNG	West Africa	Golar	2018	2.4
Prelude	Australia	Total, Inpex, KOGAS, CPC	2019	3.6
Tango	South America (Argentina)	YPF	2019	0.5
Petronas FLNG 2	Oceania	Petronas	2020	1.5
Coral South	East Africa (Mozambique)	Mozambique Rovuma Venture	2022	3.4
Tortue FLNG	West Africa (Senegal,Mouritania)	BP,Kosmos Energy	2022	2.5
Delfin FLNG	Gulf of Mexico USA	Fairwood paninsula Energy	still expecting FID	13

Sources: (Petronas, 2017) (Golar LNG, 2020) (Shell, 2020d) (Exmar, 2020) (Petronas, 2019b) (Eni, 2020) (BP, 2018c).

US launches special office to assess LNG project applications

In July 2019, the Federal Energy Regulatory Commission (FERC) of the United States announced that it had launched a new division in its Office of Energy Projects to regulate the construction and operation of LNG export projects as a response to increasing applications. It was expected to improve the accuracy and rapidity of investigation and evaluations of applications. An office was scheduled to be established in Houston in the spring of 2020 (FERC, 2019). In Australia, the federal government is actively supporting expansion of LNG liquefaction facilities. The application process is expected to be smooth in these economies and there should be fewer risks of project delays.

In the past LNG project operators have been plagued by frequent cost overruns. However, as shown above, countermeasures are also being considered, and have already been applied to projects that are currently under construction or are going to reach FIDs. If these projects are successfully completed, cost risks will be reduced, and such countermeasures will be utilised for future projects.

3 How the LNG business model shapes the LNG shipping market

The evolving LNG model

The traditional LNG business model

The role of shipping is to manifest the contractual commitment between buyers and sellers. Because of this, shipping markets will always be subject to the whims of the market they are serving and the evolution of the contract structures in that marketplace. Accordingly, this section will touch on how LNG shipping has been altered by the development of both the LNG market and its contracting structure over the past two decades.

The traditional LNG business model used contracts to integrate a series of large-scale, independently operated and capital-intensive facilities into a complete, dedicated value chain, from the wellhead to the regasification terminal in the buyer's home market (GIIGNL, 2015; Tusiani & Shearer, 2007). In Asia, long-term, sale and purchase (SPA) agreements between sellers and buyers were embedded with fixed destination clauses and oil-indexed prices. Long-term contracting thus underpinned the entire LNG value chain, providing the certainty needed to reach a positive FID throughout it.

Sellers were often integrated owners of the entire upstream chain, investing from the wellhead to the exporting terminals. Such large-scale, risky investment required buyers to commit to purchasing defined volumes over a long enough period to achieve project financing. Buyers were often integrated utilities or gas merchants, interested in securing long-term, stable gas supply to meet the substantial gas requirements of their domestic markets (Finizio, 2019). Long-term contracts, sometimes in excess of 20 years in length, governed the role of LNG carriers in this model, obligating them to a fixed route to link LNG from a seller's export terminal to a buyer's regasification terminal.

Embracing flexibility and the emergence of the portfolio player model

However, several market developments over the last few decades have embedded an irreversible flexibility into the LNG value-chain.[7] Because shipping exists to cater to the market it is serving, LNG carriers have had to change their business models to embrace flexibility, which yields uncertain carrier routes, a requirement to operate at and shift to and from a variety of operational speeds, shorter contract commitments and an increased ability to both

7 Such developments include the liberalization of natural gas markets in North America and Europe, the rising aversion to oil-indexation and destination clauses by Asian buyers, the emergence of new buyers that prefer more flexible supply arrangements, and periods of oversupply that have depressed prices and encouraged more flexible contracting to capitalize on global arbitrage opportunities. For a more detailed description please see Howard Rogers's paper for the Oxford Institute for Energy Studies (OIES) that examines whether the portfolio model will eventually phase-out oil-indexation (Rogers, 2017).

divert cargoes, and handle a series of partial cargo deliveries. This has increased the logistical complexity of the service requirements by LNG carriers.

The rising share of short-term and spot transactions illustrates the shift from point-to-point service to a more flexible chartering of carrier services. The percentage of LNG supply governed by spot trades has increased from around 14% in 2006 to 27% in 2019 (GIIGNL, 2020; Howard Rogers, 2017). This indicates that LNG ships that knew of their delivery point by at most 90-days prior to delivery carried more than a quarter of imports in 2019, an increase over the 20% observed in 2017.

Furthermore, deliveries under short-term contracts, which cover the chartering of LNG carriers for periods between 91 days and 4 years, have grown from zero in the mid-2000s to 7% of the current market. Clearly, LNG carriers are required to operate in more complex, flexible conditions in 2018 than they did in 2006.

Looking only at spot and short-term trade volumes understates the flexibility transformation of the LNG carrier market. It is important to regard this gradual adoption of irreversible flexibility as part-and-parcel of the ascension of the portfolio player model (see more of portfolio player model in chapter 2). The opportunity to optimize the inherent optionality born of flexibility via advanced trading algorithms in real-time is what provides the portfolio model its inherent value (Howard Rogers, 2017). Thus, LNG carriers under medium- and long-term contracts with portfolio players are explicitly embracing flexibility by committing to move cargoes to fulfil the optimization strategy. Because these players can have several supply and demand nodes in their portfolios, the carriers may not know their routes until the portfolio charterers alert them of a just-in-time delivery.

According to GIIGNL, the medium and long-term portfolio volumes that have defined sellers, which were almost non-existent at the start of the millennium, grew to 58 mtpa in 2019, or 16% of the global import market (GIIGNL, 2020). Adding this together with the spot and short-term market suggests that flexible arrangements could be responsible for half of current LNG imports.

Adequate LNG carrier capacity is necessary but not sufficient to ensure the smooth operation of this business model, where LNG carriers are now variables subject to the optimization problem that portfolio players and traders are constantly solving. Flexibility is both valued and demanded throughout the value-chain to maximize the intrinsic value of an LNG portfolio. Thus, the daily charter rates paid to carriers depend on the flexibility that the carrier offers.

The chartering of LNG carriers involves paying a daily charter rate, vessel fuel costs, canal fees and other associated costs. Charter rates can be long-term (more than four years), short-term (between 90 days and up to four years), or spot rates, and the value of a vessel’s charter is determined by the value of the services that it offers the charterer. Because the portfolio model values flexibility and efficiency, its rise has created a tiered LNG carrier market, where the more efficient and flexible carriers earn higher rates and those that are unable to offer flexibility are fading into obsolescence. Section 3-2 details the current and future state of the carrier market.

The next section will detail how LNG carriers have evolved over the first 35 years of the LNG industry to streamline the traditional LNG model and the following two sections will detail how they have changed over the last two decades to deliver the incremental efficiency gains required by this portfolio model.

Technical developments in LNG shipping

The technical evolution of LNG carriers in the 20th century

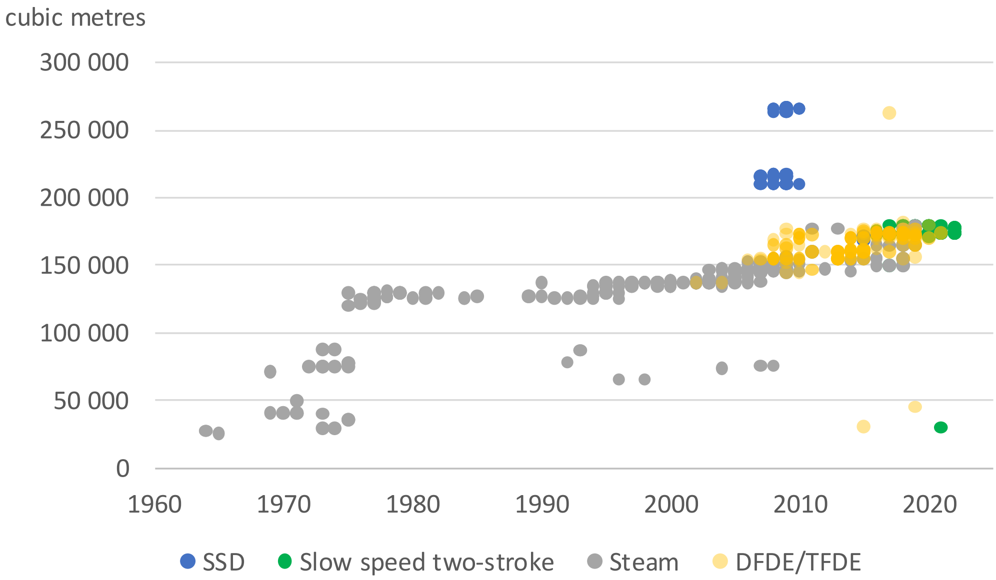
As the LNG industry transitioned through its experimental stage and into its first phase of commercialization, there was a gradual increase in the general capacity of an LNG carrier. The first two purpose-built methane carriers, the *Methane Princess* and the *Methane Progress*, where commissioned in 1964 following the successful trail shipments of LNG by the *Methane Pioneer* in 1959, a 5 000 m^3 demonstrative vessel. Each had an individual capacity of 27 400 m^3, about five times smaller than the size of the average carrier commissioned today (Pacific Maritime Magazine, 2017). Figure 3.1 illustrates the capacity of all LNG carrier orders since these first two vessels, segmented by propulsion system[8].

Vessel size increased over the following two decades to achieve the economies of scale that optimized the shipping route of the long-term contract underpinning the vessel. A wave of carriers in the 30 000 m^3 to 40 000 m^3 range were built in the 1970s to service short-distance Mediterranean voyagers between north African suppliers and southern European buyers. Two 71 500 m^3 carriers were built in 1969 to bring LNG from Alaska to Japan, and several vessels with capacity close to 75 000 m^3 were built to bring Brunei supply to Japan.

Additionally, in the late 1970s, several vessels in the 125 000 m^3 range were built to connect Algerian gas supply to United States. While the Algerian trade volumes declined earlier than expected, the economies of scale brought by these carriers set the standard for LNG carrier size for the next few decades. An exception to this trend would be the several vessels built in the 65 000 m^3 to 70 000 m^3 range in the 1990s and 2000s which were an optimal size to service the Mediterranean market (GIIGNL, 2014).

Figure 3.1 • Capacity of LNG carrier orders segmented by propulsion type, 1960-2020

[8] Includes carriers currently on the orderbook at year-end 2019, as long as the order included a vessel capacity and propulsion type. Does not take into any conversions of a vessel's propulsion system.



Note: SSD refers to slow speed diesel propulsion that is equipped with a reliquefaction system; Slow speed two-stroke refers to both the ME-GI, mechanically operated electronically controlled, gas injection engine and the X-DF refers to low-speed, two-stroke and dual fuel engine; Steam refers to the three broad types of steam engines: steam turbine, the steam reheat system, and the steam turbine and gas engine (STaGE) system; DFDE refers to dual-fuel diesel electric propulsion system; TFDE refers to tri-fuel diesel electric.
Sources: IEEJ and APERC analysis.

The development of containment and propulsion systems was less dynamic than vessel size in the first 40 years of the industry. Containment systems evolved from their rudimentary full secondary barrier[9] and prismatic designs to the membrane[10] and Moss[11] spherical systems that emerged in the late 1960s and 1970s. Because membrane and spherical systems remain the basis for designs today, this paper does not review containment systems.[12]

On the propulsion side, the steam turbine, consisting of two dual-fuel boilers that can burn mixtures of heavy fuel oil and natural gas, in the form of boil-off gas (BOG),[13] to generate

---

[9] The secondary barrier of the tank is to contain any leakage for at least 15 days.

[10] According to *The Handbook of Liquefied Natural Gas*, "membrane tanks are non-self-supported cargo tanks surrounded by a complete double hull ship structure. The membrane containment tanks consist of a thin layer of metal (primary barrier), insulation, secondary membrane barrier, and further insulation in a sandwich construction" (Phalen, et al., 2014).

[11] The Moss spherical system is named after the Norwegian company Moss Maritime which designed it and the spherical containment systems that protrude out of the containers.

[12] This is not to trivialize the impact of containment system development on the shipping industry but to point out that the basic structure of containment systems has been constant for over 40 years. For an historical exploration of the development of containment systems, please see GIIGNL's LNG Shipping at 50.

[13] Because LNG containment systems cannot provide perfect insulation, outside heat gradually causes the LNG cargo to evaporate, producing a product known as boil-off gas (BOG). Traditionally, best practice was for LNG carriers to generate about 0.15% of its cargo in BOG per day; however, this rate can rise much higher in suboptimal conditions. Eventually this gas can cause pressure issues inside the container, so a means of alleviating the problem is necessary.

steam for propulsion, was the primordial propulsion system and remained the technology of choice until the mid-2000s (Figure 3.1). Despite the low efficiency of this process, which suffers from both low peak efficiency and the inability to operate economically at lower speeds, it remained in favour because it was able to deal with the BOG problem inherent in the LNG shipping business. However, the emergence of the diesel engine as a solution for all other merchant ships in the 20th century created a large relative inefficiency that would incentivize the future development of LNG carriers.

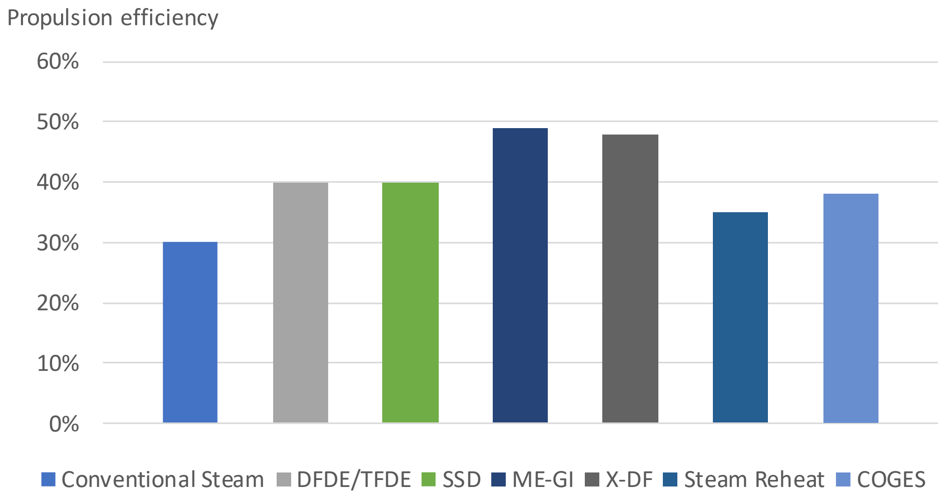
The technical evolution of LNG carriers in the first decade of the 21st century

The 2000s brought about several developments that incentivized the industry to identify viable technical improvements to the LNG carrier. First, the gradual improvement in the insulation of LNG containment systems reduced the natural BOG rate to an insufficient level for inefficient steam propulsion systems. The commercialization of an alternative propulsion system with a lower BOG fuel rate was required to unlock the economies of scale of these larger carriers. Second, increases in the stringency of marine nitrous oxide (NOx) regulations in the engines of new ships created the need for propulsion systems with lower fuel and emission intensity (IMO, 2019a). Last, the emergent needs for operational flexibility by LNG carriers clashed with the operational stability required by the traditional model. The old LNG model lowered transport costs by scheduling trips to minimize time spent in idle and low-speeds; the flexibility demanded in new model would require ships to embrace idling, low-speeds and cargo diversions.

GIIGNL states that the industry was "pushing to cut costs and improve efficiencies along the transport chain in order to improve the economics of gas projects" (GIIGNL, 2014). In his 2002 paper outlining possible alternatives to the steam turbine, Janne Kosomaa cites a key driving force behind these cost reductions as the search for operational flexibility to serve a growing number of short-term contracts and spot cargoes (Wartsila, 2002). The high inefficiency of steam turbines, particularly at lower speeds, was irreconcilable with the growing needs for LNG shippers to provide incremental flexibility, which would involve lower-speeds and idling, while reducing both transport costs and NOx emissions. Research is needed to create and demonstrate the viability of propulsion systems that reduce fuel use at various engine speeds. Kosomaa also highlights the flexibility needs of an emergent class of speculative carriers that had not yet secured contracts or routes as a "previously unheard of [practice] in the LNG business." GIIGNL and Kosomaa appear to be describing the flexibility that is characteristic of and demanded by the portfolio model. While there is no definitive moment when the portfolio model of the LNG began, it is certainly first evident in the mid-2000s.

This research led to the creation of the dual-fuel diesel electric (DFDE) propulsion system, which could use both the BOG or diesel fuel to generate electricity with medium-speed diesel engines and an electrical motor for propulsion. These engines operated on diesel (marine gas oil or heavy fuel oil) and BOG, increased full-speed propulsion efficiency over steam turbines by about a third (Figure 3.2) and had a BOG fuel rate that is 26% below that of steam turbines (Tu, Fan, Lei, & Zhou, 2018; McKinsey, 2019). Gaz de France took the first order of these DFDE engines from Wartsila[14] and commissioned the first DFDE-propelled carrier by 2006. Soon after came the tri-fuel diesel electric engine (TFDE)[15], a similar but improved iteration of the DFDE that offered higher operational flexibility through optimizations at various engine speeds (IGU, 2019).

Figure 3.2 • Efficiency of various LNG propulsion types



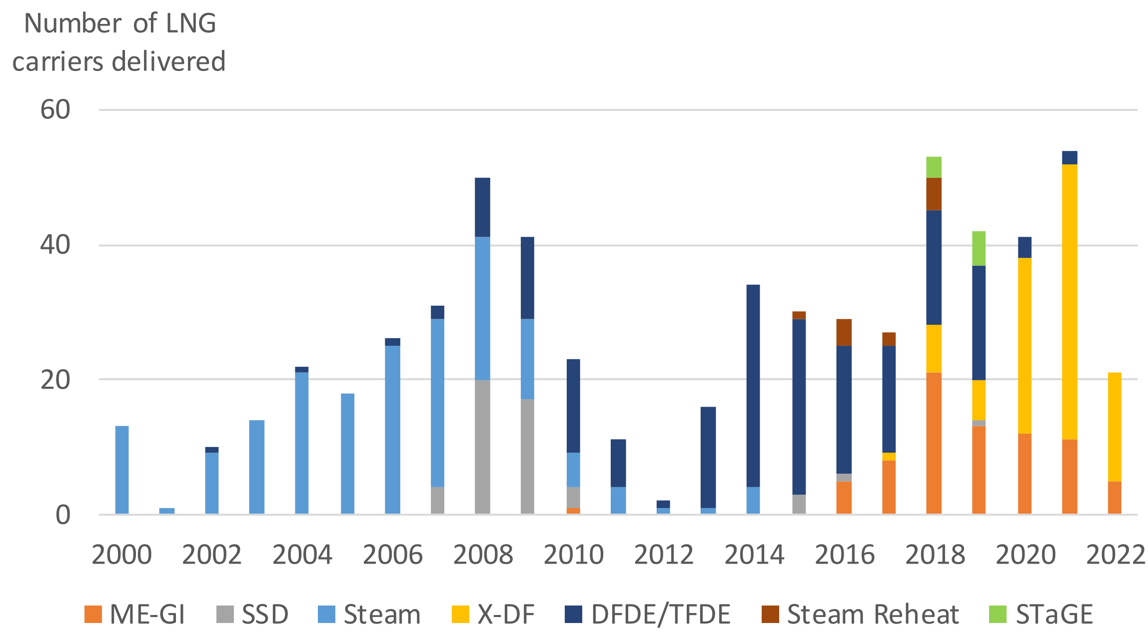
Sources: (Maran Gas Maritime Inc., 2016; Tu, Fan, Lei, & Zhou, 2018).

Figure 3.1 illustrates how this engine improvement allowed for further improvements in containment systems, which allowed for the gradual increase in the size of new carriers. By 2010, the average DFDE/TFDE-propelled carrier build was 166 000 m^3, 22% larger than the steam carriers built a decade earlier. Containment systems, like the Gaztransport and Technigaz (GTT) Mark III membrane that reduced BOG rates from 0.15% to 0.135% (GTT, 2018), began to penetrate the market. Conventional steam technology was losing market share to a technology that could reduce fuel costs, meet the IMO's increasing NOx standards, and deliver the flexibility required by the portfolio model (Figure 3.3). Despite its higher capital costs, these benefits incentivized the adoption of the technology, and it quickly became the dominant technology in new ships by 2010.

Figure 3.3 • LNG carriers delivered by propulsion type, 2000-2022

[14] Wartsila is a Finnish company that manufactures equipment for LNG carriers.

[15] The difference between TFDE and DFDE is mostly marketing, as manufacturers began highlighting the fact that DFDE engines can technically run on natural gas in addition to marine gas oil and heavy fuel oil (Riviera, 2016).



Sources: IEEJ and APERC analysis.

Parallel research yielded other solutions to improving the economics of LNG transport. To support the economics of its desired LNG expansion, Qatar decided to achieve economies of scale in transport through the dramatic increase in the size of the carrier. This led to the creation of

Q-class carriers,[16] with carrier capacities more than 200 000 m^3. However, the large BOG associated with such large carriers combined with market dynamics of high natural gas prices and low oil prices drove Qatar to pursue a unique propulsion solution: dual slow-speed diesel (SSD) engines that burned solely diesel fuel combined with a re-liquefaction system to recycle BOG into the cargo as LNG. The efficiency of its propulsion system is similar to that of TFDE engines (Figure 3.2). Nakilat, the owner-operator of Qatar's LNG carriers, charters all the world's 45 Q-class carriers. However, the prices of gas and oil diverged from Qatari expectations in the latter half of the 2000s as the shale revolution decreased the cost of gas and the commodity supercycle increased oil prices.[17] This would later lead them to consider converting the propulsion systems.

The Q-class carrier never caught on as a long-term shipping solution as their size limited prevented access to key global canal points and was incompatible with several liquefaction and regasification terminals. This effectively reduced the flexibility and optionality of the carrier;

16 There are two types of Q-class carriers. The capacity of the Q-flex carrier is around 216 000 m^3 and of the Q-max carrier 266 000 m^3.

17 This divergence likely contributed to the rise in DFDE/TFDE adoption in the latter half of the 2000s.

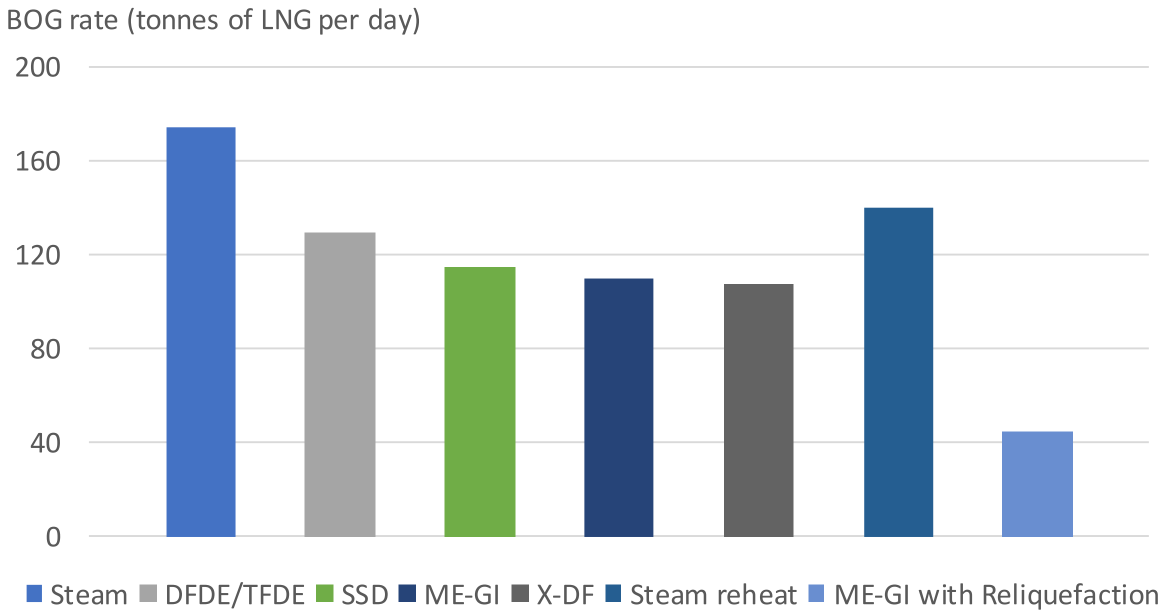
the last one was built in 2010. SSD also saw limited success to date, as the release of the IMO Tier II/III NOx standards in 2008 rendered the heavy fuel oil-burning carriers noncompliant in certain emission control areas (ECAs). However, SSD is expected to see niche applications in some vessels in latter stages of the 2020s.

The technical evolution of LNG carriers in the second decade of the 21st century

While TFDE continued as the choice propulsion technology for most of the decade (Figure 3.3), environmental regulations and the search for cost reductions throughout the value chain have driven LNG carriers toward new technologies. The IMO's regulations targeting sulphur oxide (SOx) emissions became particularly important. The first, ratified in July 2010, restricted the sulphur content of fuel burned in ECAs to be less than 0.1% starting in 2015 (IMO, 2014). This limited the flexibility of LNG carriers using steam turbines and SSD technology. The second, known as IMO 2020 regulations, restricted the sulphur content of fuel to be less than 0.5% outside of ECAs starting in 2020. This set the stage for the current phase of propulsion development, where innovation focused on developing propulsion systems that can maintain flexibility and increase efficiency while maintaining IMO compliance through the almost-exclusive utilization of BOG as fuel. In this era, BOG fuel rates are more decisive for propulsion technologies than general propulsion efficiency.

The successful design of this period evolved from slow speed two-stroke dual fuel engines: the high pressure mechanically operated electronically controlled, gas injection (ME-GI) diesel engine. This two-stroke design effectively optimized the technology behind the SSD engine but used a pressure system to burn BOG in the diesel engine instead of reliquefying it (IGU, 2019). Relative to TFDE, this technology improves propulsion efficiency by 23% and reduces the BOG fuel rate by 15% (Figure 3.4). It also has the lowest methane slip of any propulsion technology (Tu, Fan, Lei, & Zhou, 2018). However, it does not comply with Tier III NOx emissions, which will reduce its flexibility in some ECAs.

Figure 3.4 • BOG fuel rates for various LNG carrier propulsion technologies



Source: APERC analysis.

The commissioning of the first ME-GI LNG carrier occurred in 2015 and the fuel cost reductions propelled it to the technology of choice in 2018. Another slow speed two-stroke design, the low-pressure X-DF engine, has demonstrated similar propulsion efficiencies to the ME-GI, the lowest BOG fuel rate to date, and complies with Tier III NOx emissions. While it does have a higher methane slip rate than ME-GI propulsion, it has a 40% CAPEX advantage. X-DF carriers were the choice propulsion system in 2019 and at year-end, its orders for delivery in 2020, 2021 and 2022 outpaced the ME-GI system. Some new orders are augmenting ME-GI systems with reliquefaction systems to reduce the BOG rate to 0.035%.

Several other propulsion developments are worth noting. The pursuit and eventual completion of Russia's Arctic-located Yamal LNG project required the development and construction of several LNG carriers with ice-breaking capability (IGU, 2019). The creation of the ultra-steam turbine (UST) increased propulsion efficiency of the steam turbine by 17% by utilizing reheat systems (Tu, Fan, Lei, & Zhou, 2018).[18] Promoted as a cost-effective alternative to the DFDE/TDFE in 2014, its high BOG fuel rate and low propulsion efficiency has limited its orders to 13 (MHIMME, 2014; IGU, 2019). Another system, the steam turbine and gas engine (STaGE), combines the UST with gas engines equipped with waste heat recover to improve efficiency. There are two STaGE systems currently on order. The combined gas turbine electric and steam (COGES) propulsion system, utilizing dual gas engines with fuel oil as back-up, has yet to be

18 These are also called steam reheat systems.

ordered, likely because of its high capital cost, low efficiency, and the lack of competition in gas turbines in the LNG carrier propulsion market (Tu, Fan, Lei, & Zhou, 2018).

While the two containment systems from initial phase of the LNG industry remain intact, the 2010s saw preference for the membrane system,[19] which now makes up 66% of the global fleet and 91% of the orderbook (IGU, 2019). Building on the insulation improvements of the 2000s, newer membrane systems have produced BOG rates in the range of 0.07% to 0.10% (GTT, 2018; Maran Gas Maritime Inc., 2016). This aligns well with the direction of the orderbook, which is opting for carriers with propulsion systems that sport low BOG fuel rates. In the portfolio model era, improvements in both containment and propulsion technology will continue to progress together to find mutually beneficial solutions for their technological developers and deliver incremental cost reductions throughout the LNG value chain.

The LNG shipping market

Current status and outlook for LNG carrier market

The fundamentals of the LNG shipping are like those of any market. The daily charter rates paid by charterers reflect the supply and demand for carrier services. Key to understanding supply are the total number of active vessels, the number of ships on order, scrappage schedules and the demographics of the global fleet, including vessel size, age and the characteristics of its technical system. Key variables to identify for the demand for carrier services are liquefaction capacity, LNG import demand, the number of LNG voyages, the average distance of carrier voyages and the number of liquefaction and regasification terminals. These markets are prone to cycles, wherein tightness in the LNG carrier market and charter rates correlate, as the latter incentivize investments in vessel construction.

However, the existence of various contract types, portfolio players and traders complicate this simple market abstraction. Contracts are subject to capacity constraints that are hard to trace due to the growing nature of just-in-time shipping services tied to portfolio shipments. Furthermore, the portfolio model is creating differentiated carrier products based on the ability of carriers to offer cost-effective flexibility. This section will briefly trace the current phase of the LNG carrier cycle, the current trends of the market's fundamentals, the expected direction that the market is taking because of these fundamental expectations, and the impact on the carrier market.[20]

The carrier market is currently in the early stage of an upcycle, with carrier demands slowly erasing the slight overcapacity that resulted from supply growth in the mid-2010s (Flex LNG,

---

[19] While both systems have their trade-offs, membrane systems offer 8% capacity advantages over Moss systems with the same principle ship dimensions, which yields significant advantages over the life of the carrier. Furthermore, membrane systems cool LNG 37% quicker and offer navigational advantages because of the increased visibility from not having spherical tanks protruding out of the main hull [Hyundai, 2005].

[20] Because the market for shipping is constantly evolving, please see the shipping sections of the recent IGU report for a detailed account on the specific rates and capacities of the shipping market.

2018). High charter rates, from the previous peak of the shipping cycle, as well as declining construction costs, were responsible for the current overhang in vessel capacity. The decline in recent ship orders combined with the occasional spiking of spot charter rates over the past two years reflect this reality. There are currently 525 vessels in the global carrier fleet, with 118 on order for delivery by 2022. Many of these vessels are set to deliver incremental LNG volumes into Asia, where APERC expects LNG imports to grow 23% over 2016 levels by 2025 (APERC, 2019).

Potential challenges

IGU believes that these vessels should satisfy this incremental LNG demand in the short term, as the 2019 ratio of newbuild vessel capacity to new liquefaction capacity is higher than the current long-term average of 0.75 ships per mpta. However, shippers are optimistic that market tightness will increase shipping rates in the early 2020s (Flex LNG, 2018; Gaslog, 2018; GTT, 2019). This is potentially worrisome for short-term LNG market participants, as it could put affordability, and thus security, at risk if charter rates spike too high, pricing spot demand arbitrages out of the market.

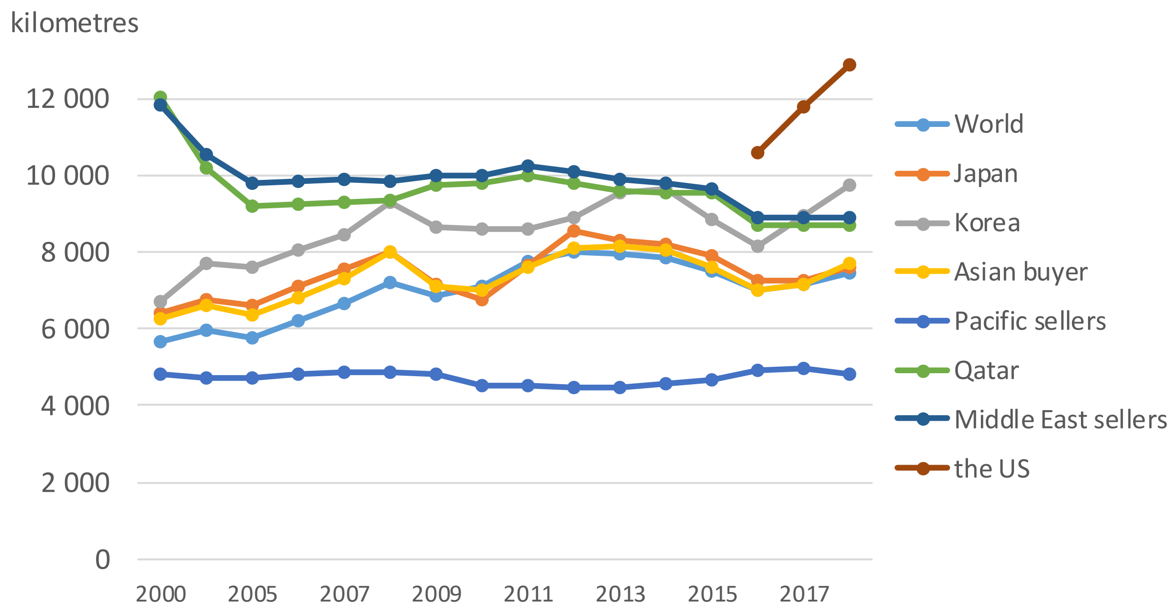
First, there is a rising risk that the scrappage and repurposing of vessels could surpass expectations as vessel obsolescence increases because of non-compliance with environmental regulations, poor economics, and lack of flexibility. GTT[21] expects that the approximately 100 vessels built before 2000 will be unchartered when their current contracts expire (GTT, 2019). Steam turbines vintages from the 2000s are also at risk, facing the dual threat of declining revenues from fewer voyages and charter rate discounts,[22] and their high fuel costs. Additionally, in the 2020s, the IMO sulphur fuel and Tier III NOx standards will force carriers to operate purely off BOG or via the use of expensive, compliant fuel oils, which could force more vessels into obsolescence (IMO, 2019a; IMO, 2019b).

Second, the LNG shipping voyages are set to become longer as the locus of supply gravitates towards the United States and that of demand concentrates in Asia. Figure 3.5 illustrates the historical growth of LNG distance travelled between LNG buyers and suppliers. The rapid growth of Australian exports and Asian demand has reduced the global average shipping distance in recent years. However, as of 2018, American LNG supply requires 2.14 vessels to move an mtpa, which is higher than the global average of 1.32 (Poten & Partners, 2018). As US supply continues to grow, more voyages and vessels will be required to move the same amount of LNG to Asian markets.

Figure 3.5 • Average distance travelled by a unit of LNG by location of supplier and buyer, 2000-2018

[21] GTT (Gaztransport & Technigaz) is a French multinational naval engineering company that designs LNG carriers.

[22] Charter rates for steam turbine vessels sell at 50% those of two-stroke vessels and 75% of DFDE/TFDE vessels (GTT, 2019).



Source: IEEJ analysis.

Third, the rise in speculative shipping vessels[23] could lead to high charter rates if shipowners attempt to valorize their investments. According to IGU, 48% of the orderbook consists of speculative vessels (IGU, 2019). Furthermore, high charter rates in the early 2010s have attracted independent shippers (Howard Rogers, 2018). There is a chance that these speculators will engage in economic withholding or reduce capacity expansion to tighten the market and allow them to valorize their investments with higher shipping rates.

However, the LNG shipping market is finding ways to alleviate tightness in capacity. The cost and lead-time to build new LNG carriers has decreased for three years in a row, increasing the ability and speed at which shippers can respond to charter rate signals (IGU, 2019). This flows directly from the increased production capacity of shipyards (Argus, 2019a). In 2018, the average delivery had a lead-time of 33 months. Charterers are increasingly looking for shorter contracts, and contract turnover should open up vessel capacity and alleviate periods of market tightness (Argus, 2019a). Furthermore, commodification of LNG is leading to an increasing role for derivative transactions (Flex LNG, 2018; Vitol, 2019). Such creative trading solutions could reduce the distance travelled and thus reduce the number of vessels needed to meet growing market demands. In turn, this would alleviate the upward pressure on LNG charter rates and maintain LNG affordability.

[23] Speculative vessels are those not assigned to a specific liquefaction or regasification project or charterer.

Shipowners response to carrier obsolescence

Because portfolio players gain value by implementing cost reduction strategies throughout the LNG value chain, the rise of efficiency gains in the LNG carrier market parallels the rise of the portfolio player. The pressure that this model has put onto LNG shippers to offer more efficient and flexible services has caused shippers to overhaul their fleets with vessels that are more efficient.

Shipowners are using a variety of strategies to protect their assets from the obsolescence threats outlined above. The declining value of aging, steam-propelled vessels has decreased their value to the point that their charter rates are not high enough to operate profitably. While scrapping these vessels is a viable option, some innovators are turning to creative conversion strategies to utilize the assets as floating LNG units. The three conversion options are as a floating production storage and offloading (FPSO) unit, a floating storage and regasification unit (FSRU), and a Floating Storage Unit (FSU). Golar LNG[24] completed the first conversion of an LNG carrier into an FLNG vessel, turning the 40-year-old *Hilli* into the *Episeyo*, a FPSO unit that began producing LNG in 2018 (IGU, 2019). Not only did this revitalize an obsolete asset, it provided small-scale liquefaction capacity for Cameroon with a relatively low capital outlay.[25] Golar will convert another vessel, the 1976-built *Golar Gimi*, into an FPSO unit in 2022 (Golar LNG, 2019). Golar has performed most of the five FSRU conversions in the global fleet and is looking to convert the *Golar Viking* into a FSRU in 2019 (Golar LNG, 2019).

Such conversions are not limited to obsolete carriers. In 2019, GasLog[26] agreed to convert its TFDE *Singapore* vessel into an FSU unit to supply a gas-fired power plant in Panama for 10 years. However, the conversion is not permanent, and the vessel will maintain the option of acting as an LNG carrier at the end of the FSU contract (Riviera, 2019).

Nevertheless, the role that conversions will play in future FLNG units may be limited. More than 90% of the vessels are below the 150 000 m^3 storage capacity threshold required by modern FLNG projects (IGU, 2019). Furthermore, most of these conversion candidates have Moss-containment systems, which can limit the ability to arrange regasification equipment, and newbuilds are more likely to last longer and offer more flexibility.

Thus far, conversions of propulsion systems have been very limited. In 2015, Nakilat[27] converted its SSD-propelled Rasheeda to an ME-GI system so that it could burn BOG instead of expensive fuel oil (Riviera, 2018). The project has not spurred any more conversions. While Wartsila floated the idea of converting steam turbines to DFDE systems in 2016, the idea has yet to take off, likely because of the higher efficiency offered by other propulsion systems

[24] Golar LNG is an LNG shipping company.

[25] USD 1.3 billion. Large-scale LNG export projects can require capital outlays that are 20 to 30 times this amount.

[26] GasLog is an international LNG carrier company.

[27] Nakilat is a Qatari shipping and maritime company that has the world's largest LNG shipping fleet.

(Wartsila, 2016). In 2015, Flex LNG[28] changed the propulsion systems from DFDE to ME-GI on two of its vessels mid-construction (Reuters, 2015). However, as mentioned above, many shipowners are now considering augmenting their propulsion systems with liquefaction systems to reduce boil-off rates. This could continue as shipowners look to improve efficiencies to maintain their competitiveness in the charter market. This would also reduce LNG carrier CO_2 emissions, which would start them on the path of achieving the IMO's currently aspirational goal of halving marine GHG emissions from 2008 levels by 2050 (Reuters, 2019c).

Could advances in LNG shipping impact the global LNG market?

These developments in the LNG carrier market could have large impacts on the broader LNG market. First, the increased use of two-stroke propulsion systems will lead to higher usage of BOG for vessel propulsion. Second, IMO 2020 regulations will lead LNG carriers to increase their share of the global LNG demand to 6% (McKinsey, 2019). Third, the conversion of carriers into FLNG units is opening up cheaper supply options for aspiring LNG adopters, which could increase LNG demand growth. The recent conversion of GasLog's *Singapore* vessel to power a gas power plant is an example of this. Last, the enhanced flexibility of services offered by improvements in containment and propulsion systems could increase the demand for on-call storage services from LNG carriers, just as crude carriers act as storage facilities for the global oil market. Recent evidence suggests that a significant number of LNG carriers are behaving as storage by taking longer-than-necessary voyage routes or parking at sea with onboard cargoes for extended periods (Bloomberg, 2019). This could become particularly acute in periods of oversupply as the LNG market becomes increasingly commodified.

[28] Flex LNG owns and operates LNG carriers.

4 Challenges for LNG infrastructure

The construction of LNG terminals and associated infrastructure faces a variety of challenges, increasing the risks of coping with situations like gas shortages and restrained gas supply. In this chapter, two non-financial factors that have hindering the development of LNG-importing related infrastructure are identified: unclear or rigid regulations, and impacts on local communities and the environment. And finally, this chapter touches upon the importance of gas storage and how it shapes energy security.

Regulatory challenges to LNG terminal development

When addressing energy security, it is common to find studies and reports focusing on concerns and risks related to suppliers. For instance, whether exporters face geopolitical risks in their production centres, questions related to the technical capacity to meet agreed volumes or congestion at busy chokepoints in transportation routes, just to mention a few. However, less attention is paid to risks related to energy importers. These risks are often related to infrastructure development, including natural disasters and political instability. When it comes to LNG, challenges and risks are even larger, given the highly technical and capital-intensive infrastructure required for LNG regasification, storage and distribution.

LNG's characteristics are a challenge to its infrastructure

In contrast to other fuels like coal or oil products, the physical characteristics of handling natural gas in a liquid state at -162 degrees Celsius with its volume compressed 300 times require dedicated and highly specific infrastructure to import LNG. This includes at least an LNG receiving jetty, storage tanks, a regasification unit and pipelines to send the volumes to the existing grid. Moreover, where there is not a developed gas pipeline grid, additional infrastructure is required such as pipelines, a truck loading terminal or a reloading unit. While investments vary depending on the regasification capacity, among other factors, they are generally in the order of USD 500 million (DOE, 2017). Apart from the huge financial challenges that an investment of this dimension entails, other issues such as local opposition, environmental concerns or regulatory frameworks could pose challenges to the development of LNG receiving terminals and associated infrastructure. The international experience in the APEC region shows that this is true, particularly in developing economies.

Some LNG importers do not have an integrated gas pipeline system across their territory, limiting redundancy and hindering the transportation of gas across demand centres. This poses a potential risk to energy security as imported LNG volumes could not flow easily from the importing terminal to cities or from one city to another. Moreover, in the case of a terminal unavailability due to technical problems, earthquakes or any unexpected disruption, the lack of alternative sources of gas supply could pose a great challenge for energy security. In recent years, unexpected increases of LNG demand in Japan and China showed the risks of not having enough LNG infrastructure to store, import and transport gas to demand centres in emergency situations.

Requirements of LNG terminal development

In general, LNG importing infrastructure requires an array of necessary conditions to be developed, including enough demand, reliable and competitive sources of supply and clear legal frameworks. Recently, regasification capacity increased globally by 2.7% (22.8 mtpa) in 2018, with about 130 additional mtpa currently under construction (IGU, 2019). However, often energy companies and organisations including the International Gas Union (IGU) have described regulatory uncertainty as one of the main risks. Most of time regulatory uncertainty is referred to as a catch-all category for a diverse set of issues ranging from rules or regulations that companies may consider burdensome to simple lack of clarity or even, legal loopholes. For instance, in some cases, local legislation restricts the development of LNG receiving terminals to state-owned companies or, alternatively, allows their construction only for large gas consumers over a certain size threshold. Moreover, some projects might be the first LNG projects in certain jurisdictions. Hence developers play a pioneer role in which they might face regulatory uncertainty or even legal vacuums; this situation might delay, postpone or even cancel planned projects.

Korea—contradictory policy as a potential hindrance to LNG imports and gas demand

Korea, the third largest LNG importer globally, provides an interesting example in which the current legal framework and regulations do not provide market-based incentives for further LNG importing terminal expansion. The state-run company, Korea Gas Corporation (KOGAS), enjoys a dominant position in the Korean gas sector, as it owns most of the transmission pipeline systems, four out of six LNG importing terminals and most of the storage capacity. Moreover, KOGAS is the only allowed wholesale gas supplier in Korea, enjoying a quasi-monopolistic role in which private companies are allowed to make direct imports only for their own-use and only if the price is below KOGAS's long-term contract (KOGAS, 2020; S&P Global Platts, 2020a). Furthermore, in early 2020, the Korean government announced a change to its LNG wholesale price formula in a bid to reduce direct LNG imports (without the participation of KOGAS).

These policies give KOGAS a dominant role in gas sector through limited participation from the private sector, which potentially hinders LNG import growth to Korea and ultimately the overall gas demand. For example, oil refiner S-oil received its first direct LNG cargo last year through Gwangyang terminal, the only non-KOGAS operated terminal, owned by steelmaker company Posco. S-oil blamed 'government regulations, insufficient infrastructure and lack of clear pricing information as obstacles to greater LNG adoption' (Argus, 2019b).

However, in a bid to encourage the use of gas, in 2019? the Korean government lowered LNG taxes by 74% while raising taxes on coal by 27% (Reuters, 2019d; S&P Global Platts, 2020b). This policy seems to encourage more LNG imports and use, but the aforementioned terminal policy limited direct LNG imports, discouraging power generators that accounted for 14% of the total LNG imports in 2018 (S&P Global Platts, 2020a). These policies create a paradox in Korea between hoping for a greater use of gas and restricted participation. With increased pressure from renewable and other power generation sources, as long as KOGAS remains as the sole gas wholesale supplier, it would be unlikely to see major LNG import capacity additions in Korea, particularly from private companies.

Thailand—relaxed regulations not fully embodied in market practices

Thailand provides another example in which the legal framework and regulatory scheme have not favoured increased LNG demand growth and further LNG receiving infrastructure development. Thailand is the largest LNG importer in Southeast Asia and its demand has increased rapidly in the last decade, while its domestic production has been decreasing It has, bridged the gas supply gap with piped imports from Myanmar and imports to its only operating LNG receiving terminal, Map Ta Phut. The 11.5 mtpa capacity Map Ta Phut terminal is wholly owned by state-controlled oil company, PTT (IGU, 2019). Despite some plans to introduce competition on the gas sector, PTT enjoyed a monopoly along the value chain both *de jure* and *de facto* until 2007, when the Energy Industry Act was introduced (Dodge, 2017). Despite the fact that Thailand's Energy Regulatory Commission (ERC) issued a Third-Party Access Regime in 2014, as of November 2019, PTT remains *de facto* the sole LNG importer, transporter and distributor in Thailand, with 100% of reserved pipeline and LNG terminal capacity (Dodge, 2017).

Moreover, while other companies have expressed interest in or attempted to directly import LNG, in practice the Thai authorities did not favour, until recently, further LNG imports other than those by PTT (Dodge, 2017). For instance, state-owned electrical utility EGAT (Electricity Generating Authority of Thailand) agreed with Malaysia's Petronas to import 1.5 million tons of LNG annually for a period from four to eight years. However, the pact was rescinded by the Thai government in September 2019, for fear of increased electricity prices (Bangkok Post, 2019). This cancellation was a major setback in gas market liberalisation.

Nevertheless, other events seem to slowly pave the way toward gas market liberalisation. After the suspension of the EGAT-Petronas agreement, EGAT was allowed to reserve 1.5 mtpa of capacity at the Map Ta Phut terminal. In December 2019, EGAT received its first direct cargo from the spot market, also the first one in Thailand under the third-party access regime. EGAT used PTT's pipeline system to transport the imported volumes to its power stations (EGAT, 2020). More recently, the Ministry of Energy announced its interest in taking advantage of the low Asian spot LNG prices, PTT is building a second LNG receiving terminal and EGAT announced a FSRU to be operational in 2024.

The changing and unstable LNG framework in Thailand has limited the opportunities for further LNG adoption and market liberalisation. This increases the vulnerability inherent in relying solely on the Map Ta Phut terminal and PTT's pipeline system. Clearer regulation may increase investment for regasification and storage infrastructure, enhancing energy security in Thailand. This is particularly relevant given that both Myanmar's gas production (the only source of piped imports) and domestic production have been decreasing in the past few years while demand has been growing steadily.

Viet Nam — unclear policy helps slow LNG terminal investment

Another example in which current institutional frameworks and unclear regulation has led to insufficient LNG receiving infrastructure in the APEC region, is the case of Viet Nam. Following rapid economic growth in the past decade averaging 6.1% annually, Viet Nam's overall energy demand has also grown quickly (APERC, 2019). Viet Nam is a gas producer and is one of the three only APEC member economies that does not trade gas.29 While historically, domestic gas production has been sufficient to meet demand, gas production actually decreased by 5% from 2010 to 2017 (APERC, 2019). Moreover, government expects demand to reach 27 billion cubic metres (bcm) by 2025, more than doubling 2016 levels (Viet Nam News, 2018). This supply gap reflects several factors including the cancellation of a nuclear power plant in 2016 and the relative price dynamics of coal and LNG for power generation. While in neighbouring Thailand, LNG imports have helped to alleviate the gas supply gap, Viet Nam has not managed to build LNG importing infrastructure, owing to challenges including the current legal and policy framework.

The Ministry of Industry and Trade (MOIT) is responsible for energy policy planning. Current policy allows private participation on hydrocarbon exploration and production but is limited and unclear about private sector roles in the rest of the value chain (The Brookings Institution, 2012). Nevertheless, only last year the state-owned corporation Petrovietnam started construction of the Thi Vai terminal, the first LNG importing terminal in Viet Nam (S&P Global Platts, 2019). Moreover, the Vietnamese government authorised AES Corp to build a second terminal, Son My LNG (Oil & Gas Journal, 2019b). While these may reduce the seemingly unavoidable gas supply gap before 2022 when the first terminal is scheduled to be operational, stronger support and a clearer framework from MOIT might have resulted in earlier development of these LNG projects.

More clear regulations needed to support LNG terminal development

While the specific contexts, gas supply and demand dynamics and energy systems have evident differences in Korea, Thailand and Viet Nam, it is safe to argue that as gas demand grows, LNG is poised to play a key role in meeting demand growth. However, this potential is conditioned on further development of LNG receiving infrastructure. Moreover, the fact that for the time being, none of these economies have met an acute gas supply shortage does not mean that it may not happen in the near future. The expansion of LNG importing terminals is not only key for enhancing energy security but also fundamental for reducing greenhouse gas emissions by displacing more polluting fuels like coal and oil products. Regasification capacity in these economies could have grown even more, but further infrastructure development has been hindered by regulatory restrictions on non-state-owned companies, policy shifts or unclear

29 The other two APEC economies that don't trade gas are New Zealand and Philippines. However, the latter had an LNG import terminal under constructions as of 2020.

regulations. Legal and policy frameworks as well as clear regulations that favour investment and partnerships to develop LNG importing infrastructure also contribute to energy security.

Environmental and community opposition challenge LNG terminal development

Another risk for developing LNG infrastructure and, hence, enhancing energy security, is related to projects with negative environmental impacts on local flora and fauna. These impacts may increase opposition from local communities and residents with a 'Not in My Backyard' inclination. While the construction of any major infrastructure project brings with it some negative impacts, governments and regulators are expected to make sure those impacts are minimized, mitigated and even compensated. This type of measures includes environmental impact assessments, social impact assessments and compliance with other legal instruments such as restrictions in protected areas. However, in practice, there are cases that show large room for improvement in the implementation of these measures between governments and LNG project developers. Moreover, the lack of sound engagement and clear communication with local stakeholders, particularly the most affected ones, has translated into project delays and, even, possible cancellations.

Chinese Taipei — insufficient communication caused LNG terminal delays

One example of such challenges is the Taoyuan LNG receiving terminal in Chinese Taipei. With no pipeline interconnections and very small domestic gas production, LNG imports accounted for 99% of total gas supply in 2018 (Bureau of Energy, MOEA, 2019). Moreover, Chinese Taipei has a policy of completely phasing out nuclear reactors by 2025, and raising gas-fuelled power generation to 50%, which was 32% in 2016. Chinese Taipei currently has two LNG receiving terminals: Yung-An Kaohsiung (7.5 million tonnes per annum [mtpa] receiving capacity) and Taichung (4.5 mtpa receiving capacity), amounting to 12 mtpa, which normally operate above their 100% nominal capacity (APERC, 2019). State-controlled oil company CPC owns all of Chinese Taipei's gas terminals, transmission systems, and storage facilities, and is the sole LNG importer. CPC launched a project to build its third importing LNG terminal in Taoyuan in 2016.

However, opposition to the project and pressure from local residents and scientists arose in 2017, claiming that the terminal would create widespread damage to two endemic species of coral reef (Ferry, 2017). In October 2017, the environmental impact assessment (EIA) was postponed by the Environmental Protection Administration (EPA) citing the need for further research; the assessment was denied nine months later and returned to the Ministry and CPC. Nevertheless, this decision was overturned by the EPA's EIA grand assembly in a controversial voting process, which included the EPA Deputy Minister Chan quitting his post under pressure (Taipei Times, 2018a).

CPC stated later that the scale of the Taoyuan terminal has been reduced from 232 hectares to 37 hectares to minimize its effects on the coastal algal and coral reefs and that the terminal's industrial port would be off the coast, which would leave ocean currents undisturbed (Taipei

Times, 2018b). While CPC has reported construction works running as scheduled and expects the Taoyuan terminal to be operational by 2024, opposition from environmental groups and local communities has resulted so far in at least a year of delay and undisclosed additional costs due to changes in the project (CPC, 2019). Further delays on the construction of the Taoyuan terminal could put additional pressure on the already tight power system with the nuclear reactor phase-out by 2025, since most of the substituted generation is expected to come from natural gas and renewables. This experience in Chinese Taipei illustrates the need for improving project planning and minimising adverse environmental and social impacts on local communities, as well as for sufficient communication with local communities and stakeholders.

Chile — environmental concerns and oppositions to the delays of Penco terminal

Another example of environmental concerns and local opposition to the development of LNG terminals is the Penco terminal in Chile. LNG imports have been the predominant source (80%) of gas supply since 2009, when Chile's first LNG terminal became operational (Ministerio de Energia, 2019). Before this, most gas supply was imported piped gas from Argentina. However, sudden curtailment of the Argentinean piped gas imports starting in 2004, led to a fall in the use of gas, and a later construction of LNG importing terminals. To face the shortage of natural gas, coal and oil product demand rose, particularly for power generation.

Chile currently has two LNG regasification terminals, which are regionally disconnected with no integrated gas pipeline network across Chile. While LNG imports have increased since 2014, Chile's share of gas out of total primary energy stood at only 12% in 2017, compared with 24% in 2005; leaving room for unsatisfied gas demand.

A third LNG terminal was proposed in 2013 near Chile's second largest city, Concepción. The Penco terminal (originally known as Octopus LNG) was announced as a FSRU that would feed a power plant and connect to the *del Pacífico* gas pipeline (GNL Penco, 2018). Since 2013, members of local communities spoke against the project arguing it would damage the ecosystem, and the fishing and tourism industries (Ochoa, 2019). In 2014, the project developers submitted an Impact Assessment Study to the Environmental Evaluation Service (SEA, in Spanish), while the opposition groups started to protest the project. Since then, the impact assessment study was modified and resubmitted to 'include the concerns of the local communities," according to the company; meanwhile, protests continued (Ochoa, 2019). In 2016, the project was authorised by the SEA but in 2017, Chile's Supreme Court returned the case to SEA asking for a new free, prior and informed consent (FPIC) of the local indigenous population. After more than six years, the project finally obtained all regulatory permits in August 2019. However, as of February 2020, it is not clear whether Penco LNG will move forward, as strong opposition persists. There are at least two rival projects in the same region and low-cost solar and wind energy put additional pressure on LNG-fuelled power generation (Generadoras de Chile, 2019).

The Taouyan LNG terminal in Chinese Taipei and the Chilean Penco LNG terminal are examples of LNG importing terminals designed to increase the share of gas supply in the energy mix and enhance energy security. In both cases, environmental concerns and local opposition to the projects resulted in tense discussions among the regulators, project developers and local communities. The controversies resulted ultimately in lengthy delays and, possibly (in the case of Penco LNG) in cancelation of the project. While both cases vary in the impact on their energy systems and supply alternatives, these two examples underscore the importance of improving the scope and quality of both the environmental impact assessments and the engagement with local communities to develop LNG importing infrastructure. This is particularly important in the APEC region, as developing LNG importing terminals is fundamental not only to support energy security but also to substitute for more polluting fossil fuels like coal and oil products.

The importance of gas storage facilities

Another key element to enhance energy security in general is increasing storage capacity. For instance, storage of crude oil, petroleum products and other commodities provides flexibility and security by reducing—and even eliminating—the need for immediate consumption after production or procurement. However, gas storage infrastructure faces challenges including long-term planning, unattractive market pricing structures for utilities, and lack of investment. This has resulted in insufficient gas storage capacity in some regions, despite the flexibility and resiliency it provides to gas systems when facing strong variation in demand or supply.

Gas storage facilities

Natural gas is commonly stored in underground storage (UGS) facilities, which are mostly depleted oil and gas fields, aquifers, and salt cavern formations. Each of them has different characteristics related to its geology, permeability, and the relatively ease of withdrawing gas, normally called the "deliverability rate." It is at the very least interesting to note that UGS is not globally developed; in fact, UGS facilities have been built in less than 40 economies around the globe. Most of such facilities are in Europe, with a handful of notable exceptions including, the US, Canada, Russia, China and Australia.

Other than UGS facilities, natural gas is also stored in above-ground tanks, in either gaseous or liquid states. Virtually all LNG importing facilities use this type of storage tanks, with LNG import terminals in the Asia Pacific traditionally having larger storage capacity. Finally, another option is Floating Storage Units (FSU), which are vessels adapted for this specific purpose, with small volumes but with more flexibility. As of 2019, there were five operating FSUs globally (IGU, 2019).

Gas storage benefits

In the case of LNG and, more broadly, natural gas, storage brings multiple benefits not only to the gas value chain but in most cases, also to power grids. Most of these benefits are related to an increased flexibility of the energy system to meet demand peaks, which could be seasonal (e.g. heating in winter), daily (e.g. fuelling power plants in case of disruptions) and even hourly (e.g.- meeting peak demands) (Roques & Mann, 2018). Moreover, increased gas storage capacity entails positive externalities to the energy system making it more resilient and operating as a sort of insurance for unexpected supply disruptions or sharp rises in demand. An example of this could be the cost of additional gas production or procurement in case of disruption or, else, the cost of using an alternative fuel like coal or oil products.

However, the contribution of gas storage to energy security is not always fully captured through purely market-based mechanisms, traditionally based on seasonal spreads. In other words, gas prices tend to be lower in summer (injection period) than in winter (withdrawal period), and this price difference compensates gas storage operators. However, regional gas price convergence, an increasing number of global LNG suppliers and warmer winters than in previous years, among other reasons, have reduced significantly the income of gas operators based mostly in seasonal spreads. For example, the Rough gas storage facility,30 the then largest in the United Kingdom (4.5 bcm), was closed in 2017 because of low seasonal spreads and increasing maintenance costs (IEA, 2018). While these challenges vary across regions, the need for enhanced support from key stakeholders and innovative mechanisms for storage expansion seems to have common features that can benefit gas consumers across regions.

As the geographical condition and gas demand vary, each economy has a different way of dealing with gas storage and associated facilities. This section selects four examples showing different approaches to gas storage. The first two cases, the United States and Italy, are examples with high coverage of gas storage; the third case, China, is an example of how essential gas storage is to energy security. The last one is a collection of examples that shows how gas importers in APEC region deal with gas storage.

The United States — Widespread gas storage and pipeline networks contribute to security

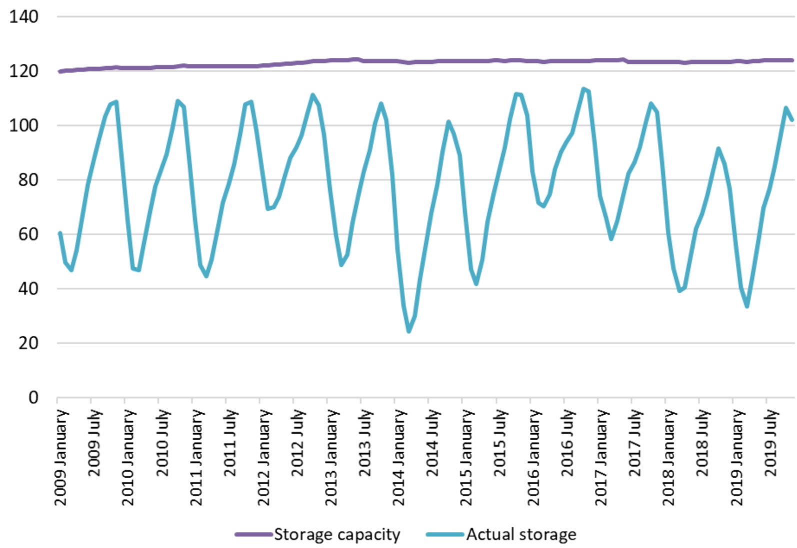
In the United States, most natural gas storage takes place in UGS facilities, most of them in oil and gas depleted fields (EIA, 2015). Existing infrastructure such as gathering systems and pipeline connections reduces conversion costs. There are currently nearly 385 active UGS facilities in the United States owned by 120 entities, varying from pipelines companies, local distribution companies and independent storage service providers (EIA, 2015). Because of regulatory measures, UGS facilities in the US are required to have “open access,” meaning that they have to leave the major portion of their capacity available for leasing to third parties on a non-discriminatory basis (EIA, 2015).

The US has a nominal UGS capacity of around 135 bcm (about 14% of total demand). However, in the past 10 years actual storage volumes have oscillated seasonally from 113 bcm to a minimum of 24 bcm, as seen in Figure 4.1 (EIA, 2020). The graph shows that gas demand for heating peaks in winter, and as production and imports are not enough to cope with the seasonal demand surge, stored gas volumes are withdrawn. This great variability in stored

[30] The Rough gas storage facility, located in the East coast of England, accounted for approximately 70% of the UK’s gas storage capacity. It was closed in 2017 because required maintenance to the site was no longer economic.

volumes increases the resiliency of the gas pipeline systems in the US and demonstrates the value added of robust UGS capacity.

Figure 4.1 • US gas storage capacity and volumes, 2009-2019, (bcm)



Source: (EIA, 2020).

If gas storage capacity was substantially lower, in the winter US gas suppliers would be forced to choose costlier alternatives such as diverting production destined to other markets or importing additional LNG cargoes. In such a scenario pipeline networks might suffer from higher congestion rates and, even, gas shortages. In general terms, existing US gas storage provides flexibility and resilience to consumers and enhances overall gas supply security, but some US regions could still have larger storage volumes or better interconnections to pipeline networks to further strengthen the gas supply network.

Italy — World's fifth largest USG capacity: An example for gas import dependent economies

While the gas pipeline and storage network in Europe is generally well connected and interdependent, Italy seems to stand out in terms of gas imports and storage. While Italy's gas demand was around 72 bcm in 2018, not even in the top 10 largest global gas consumers in 2019, it has the fifth largest USG capacity globally (IEA, 2019c). Italy has 10 USG facilities with 16 bcm of capacity, 22% of annual gas demand, a share considerably higher than that of any APEC member economy (IEA, 2019c). Unlike the US case, 8 of the 10 storage facilities are owned by Snam, a regulated utility partly owned by the Italian state, while the rest by another Italian utility.

Some of the factors that help explaining this are that most of its gas supply is imported, its peninsular geography and geology, and its weather diversity. Take for instance colder winters (hence, more gas demand for heating) in the Northern cities like Milan than in the Southern ones like in Naples. This storage capacity allows gas consumers and electricity generators to be more flexible in the face of changes in demand and supply such as seasonal changes, demand peak shaving and disruptions from gas exporters.

In December 2017, an explosion in a gas facility in Austria interrupted one of the pipelines that supplies gas to Italy. During the disruption, gas withdrawals from the storage facilities were key to secure stability and bridge the gas supply (IEA, 2018). The Italian gas storage case provides an interesting example for other economies dependent on gas imports, with limited pipeline connections, exposed to seasonal demand variations. Investing in similar USG facilities may contribute to energy security and systems flexibility in the APEC region.

China — A lesson learned the hard way

UGS capacity only accounts 3% of gas demand

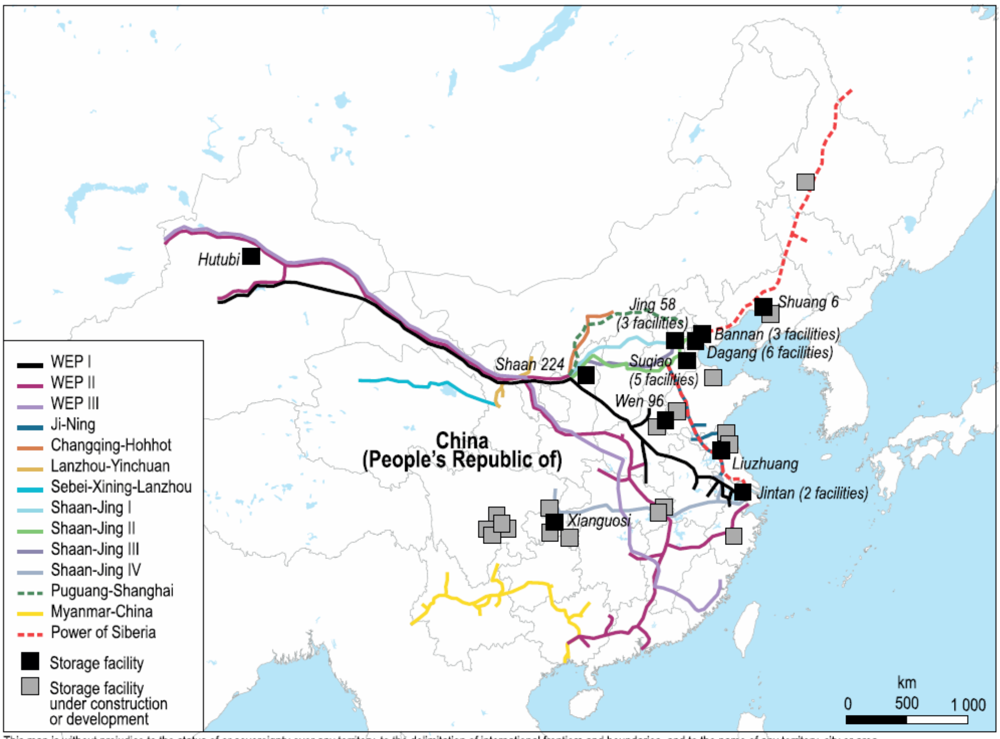
In China, gas demand grew more than eight-fold from 2000 to 2017 driven by a government-mandated coal-to-gas switch aimed at improving air quality (IEA, 2019b). This meant an increase from all its gas supply sources: domestic production, piped imports and LNG imports. With domestic production unable to ramp up as fast as demand, most of demand growth has been covered by imports, particularly LNG.

However, despite this demand growth, China's UGS capacity has not grown at the same pace, accounting for only 10 bcm in 2018, about 3% of total annual demand. This is a low share compared with the 20% average in the European Union (IEA, 2018).

Lack of pipelines transporting gas from south to north, the most needed region

In December 2017 and January 2018, temperatures were colder than normal, increasing gas demand for heating purposes in the north. Additionally, Turkmenistan and Uzbekistan, traditional pipeline gas exporters to China, decreased their exports to China in 2018 because of falling production and increased domestic demand, respectively. Although LNG regasification terminals worked over capacity in northern China and utilities withdrew gas from UGS facilities, there were still gas shortages in several regions, mostly in northern China (IEA, 2018).

Figure 4.2 • China's gas storage and trunk pipelines, 2018



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Note: WEP = West-East Gas Pipeline.

Source: (IEA, 2018).

While LNG importing terminals were even used above nameplate capacity, terminals in the south worked at an average 47% of capacity in 2017. However, since China has limited North-South pipeline capacity, LNG imports from terminals in the South could not reach regions with freezing temperatures like the Hebei and Shandong provinces. The 2017-18 gas shortages in China highlighted the importance for energy security not only of a diversity of LNG portfolio suppliers and importing terminals but also of a robust infrastructure in transportation (mostly, pipelines) and storage.

Lesson learned from the 2017-18 gas shortage

While the 2017-18 lack of gas supply to China showed the importance of infrastructure development and energy security beyond the immediate short-term needs, it also served as a trigger for reinvigorated efforts on energy security and gas supply in China. Since then, three new regasification terminals with a combined capacity of around 10 mtpa have been commissioned in China while nine more terminals are under construction, accounting for an additional capacity of 20 mtpa (IGU, 2019). In December 2019, China set up a new state-owned company, the China Oil & Gas Piping Network Corporation, in charge of building and interconnecting the main oil and gas pipelines to form a unified network (Xinhua, 2019). Meanwhile the government announced natural gas liberalisation reforms, including pipeline interconnection and expanded gas storage capacity. However, gas storage projects by the newly created company have been slowed because of the COVID-19 pandemic and no storage facilities are projected to come online for at least two years (S&P Global Platts, 2020b).

The role of gas storage in gas importing economies in APEC region

As explained before, UGS facilities are concentrated in Europe and about a dozen of other jurisdictions. Out of the 21 APEC members, only Australia, China, Japan, New Zealand, Russia and the US have USG facilities, primarily because of the geological differences. In places without UGS, traditional LNG importers like Korea and Chinese Taipei have instead built large above ground gas storage facilities at their LNG receiving facilities. In fact, Korea has the largest above ground gas storage capacity in the world, Pyeoung-Taek LNG receiving terminal, with 3.3 million cubic meters (mcm) of gas, while worldwide storage capacity in receiving terminals averaged 528,000 cubic meters (IGU, 2019).

Nevertheless, there are some APEC economies that have limited gas storage capacity but have recently increased their gas imports and are projected to continue to do so in future years. Investment in gas storage capacity in these economies could yield positive results not only as their energy security increases but also as their energy systems become more flexible and resilient. This may be particularly beneficial to places like Chile, Thailand or Mexico, when considering substantial intermittent renewable electricity generation additions.

Chile — more storage capacity needed for growing gas demand

For instance, Chile is a net gas importer, highly dependent on LNG imports. Domestic gas production in the southern Chile is not connected to the main demand areas in central and northern Chile, while Argentina's piped exports to Chile have remained almost negligible since 2012. Although Chile's two receiving LNG terminals are responsible for the vast majority of gas supply, storage capacity in Chile is restricted to the tanks located at these two terminals, totalling 312 cubic meters (IEA, 2018). These volumes are lower than the global average per terminal in 2019. While developing UGS facilities may not be feasible because of Chile's geological conditions, increasing storage capacity could enhance the Chilean energy system's flexibility and security, especially considering that there are no pipelines linking both terminals.

Mexico — should utilise depleted gas fields for UGS facilities

Mexico provides another interesting example. While domestic production has decreased every year since 2008, demand has grown by 16% since 2010, reaching 81 bcm in 2018 (IEA, 2019c). The fast-growing supply gap has been covered mostly by US piped exports (accounting for 60% of total demand in 2018), while the rest by LNG imports.

However, gas storage does not follow this trend at all, with the only the LNG storage tanks located at the three LNG receiving terminals in Mexico. Further, one of the terminals is not connected to Mexico's main gas pipeline network. Altogether, Mexico's storage capacity accounts for less than 1% of total demand, despite having plenty of depleted oil and gas fields, the most common way of developing UGS (IEA, 2019c). While, consumers benefit from the competitive prices of US shale production, the lack of storage infrastructure and limited pipeline redundancy erodes energy security. Moreover, gas-power generation accounted for around 60% of total generation in 2018 (IEA, 2020). Consequently, some areas like the Yucatan peninsula faced gas shortages and electricity blackouts during 2019 peak demand season (Reuters, 2019e).

Thailand — more storage capacity needed for growing gas demand

Gas storage in Thailand is similar to that of Mexico. While there is an increasing supply gap resulting from fast growing demand and decreasing domestic production, gas imports have absorbed most of that gap in past years. As mentioned above, Thailand imports gas via pipeline from Myanmar's decreasing production and via LNG to its Map Ta Phut terminal. The three tanks at this terminal are Thailand's total gas storage capacity, accounting for 0.48 mcm, only above 1% of total gas demand. As in the previous two cases, the lack of gas storage infrastructure does not contribute to Thailand's energy security. This creates an opportunity to increase storage and even develop UGS at some depleted oil and gas fields, particularly in a context where gas demand is projected to grow.

FSRU could be a solution but not entirely

Additionally, there seem to be two conflicting trends in gas storage globally. While storage capacity is growing in onshore terminals in mature markets like Korea, Japan and Chinese Taipei, developing markets tend to prefer building FSRU's (with less storage capacity) or onshore smaller tanks (IGU, 2019). FSRUs have generally lower initial investment costs and faster construction times but also substantially less storage capacity than traditional onshore terminals. On average, onshore terminals have between 0.26 and 0.7 bcm, while FSRUs rarely surpass 0.17 bcm of storage capacity (IGU, 2019).

While FSRUs offer flexibility and LNG access at a lower cost, in principle, they entail risks and may require additional storage capacity so as not to compromise gas supply security, particularly in emerging markets. This is especially relevant to the Philippines and Viet Nam. These two APEC member economies do not trade LNG currently, but they are both building LNG receiving terminals. As they join the global LNG market, it is important for their supply security to develop sufficient gas storage capacity alongside importing infrastructure. As these emerging gas markets are still in an early stage of development, there is an opportunity for setting regulation and frameworks that incentivize investment in gas storage and downstream infrastructure, in general. While investments in gas storage may seem too expensive, emerging APEC gas importers might benefit from the experiences and lessons learned in China and Italy.

5 Implications of the dynamics and challenges

As described in the previous chapters, the LNG market is experiencing changes and challenges in every aspect of the LNG supply chain, starting from LNG project construction, to shipping to LNG receiving terminals and storage facilities. Table 5.1 lists the implications of each of the dynamics and challenges that were already mentioned in each chapter. As these implications seems to be independent of one another, this chapter summarises these implications from three main perspectives, helping the reader to grasp the conclusion from a bigger picture.

Portfolio model injects robustness to market and ultimately strengthens LNG supply security

Among the dynamics that have emerged, the rise of portfolio players is certainly a significant trend that led to the shift of LNG business model – evolving from the traditional point-to-point business model to a portfolio business model that encompasses flexibility on supply sources and efficient cargo delivery. The shift of business model also changes the way LNG carriers operate. They are required to operate in a more complex and flexible manner, such as short notice of shipping service, uncertain routes to various buyers, shorter contract commitment, ability to divert cargoes, etc.

The shift of business model bridges between sellers and buyers by enhancing their faith in trade amid various market risks through the portfolio players' wealth of capital and LNG assets, promoting FID of progressing LNG projects and facilitating more trades in a more flexible manner. This makes the market more robust and liquid, which ultimately strengthens LNG supply security.

Technological advancement contributes to cost efficiency and IMO rules compliance in LNG shipping

Technological advancement also plays an essential role in the evolving LNG market, especially in the LNG project development and shipping sectors. The adoption of a modular construction approach in LNG project construction significantly drives down construction costs and time by streamlining the manufacturing process. The Yamal LNG project is the best successful example, where the construction was completed before the scheduled time even under extreme weather conditions.

The technological improvement in propulsion systems of LNG carriers, ME-GI and X-DF, significantly reduced the natural BOG rate and improved fuel efficiency, and more importantly, allowed LNG carriers to comply with IMO rules limiting sulphur and NOx emissions. The stricter rules also imply growing demand for LNG as a fuel for LNG carriers, as it is nearly sulphur-free and has lower NOx emissions.

Government's role is required for LNG terminal and gas storage development

LNG terminals and gas storage are indispensable facilities to maintain gas supply and demand security. However, these facilities are usually capital intensive and thus cannot be easily developed without meeting certain conditions, such as enough demand, stable supply sources, clear legal framework, etc. It is a great challenge to meet all the conditions, which is why the trend of LNG terminal and gas storage development does not follow the fast-increasing demand for gas in the past few years.

Among the required conditions for LNG-related facilities development, legal framework is /identified as one of the main challenges. Unclear or restrictive regulations can hinder gas supply and demand security if the market is not liberalised enough and only allows a few stakeholders to build LNG terminals and gas storage or import LNG. This hindrance could further restrict potential gas demand growth.

Market participants will not invest in infrastructure unless there are appropriate incentives and a stable regulatory framework. Therefore, government must take a lead by providing a more investor-friendly regulatory framework and offering a transparent investment environment to ensure investment safety, and thus facilitate investment. This can be done through various instruments such as tax reduction incentives, subsidisation of infrastructure development, government financing, special office to infrastructure project approval, etc. As the LNG market is evolving quickly internationally, government is also required to take more actions domestically to keep up with the trend.

Table 5.1 • Summary of LNG market's dynamics, challenges and implications

		Dynamics	Challenges	Implications
LNG project development	LNG contracts	· Contract duration is changing · Oil-indexation is weakening · More destination-free contracts signed		· While long-term contract is still the backbone of LNG development, short-term and spot market trade are seeing larger share as the oil price declines. · The future of long-term contract still depends on the price competitiveness and demand.
	Increasing share of portfolio players	Number of contracts signed by portfolio players is increasing.	LNG market may be dominated by a small number of LNG portfolio players.	· More flexibility on supply sources and more efficient cargo delivery · Responding quickly to fluctuating market demand · Promoting FID of progressing LNG projects. · Bridging between sellers and buyers in a market transition period
	LNG project construction		· Cost of LNG production projects is ballooning, · Several factors contribute to ballooning: construction difficulties, rising labour costs and increasing size of LNG projects.	· Project developers should be more realistic about costs · Adopt modular construction approach to minimise costs and streamline construction process

Shipping	Technology evolution	· Propulsion systems evolved. ME-GI and X-DF are the most efficient and advanced LNG systems. · Improvements in containment and propulsion systems reduced the natural BOG rate.		· Increased use of ME-GI or X-DF leads to higher usage of BOG. · Improvements in technology could increase the demand for on-call storage services from LNG carriers.
	Stricter IMO regulations	· IMO's stricter regulations push LNG carriers to use · Vessel obsolescence increases because of non-compliance with environmental regulations, poor economics, and lack of flexibility.		· IMO's regulations expected to increase LNG carrier global demand for LNG by 6%. · Obsolete vessels could be converted into FPSO, FSRU, and FSU.
	Business model changed to accommodate emergence of portfolio model	· LNG carriers are required to operate in more complex and flexible conditions because of the emergence of portfolio model, such as uncertain carrier routes, shorter contract commitment, ability to divert cargoes, etc. · Daily charter rates paid to carriers depend on the flexibility that the carrier offers.		The portfolio model gives LNG carriers an opportunity to optimise their operations via advanced trading algorithms in real-time while increasing flexibilities to accommodate complex services required.
Infrastructure	LNG terminal		· Unclear and restrictive regulatory framework · Environmental and community opposition concerns delay terminal construction.	· More clear and supportive regulatory framework and guidance are needed. · More multi-lateral communications between stakeholders are needed.

	Gas storage		· Gas storage capacity does not expand as gas production and demand grow · Lack of pipeline network connecting production or import region to demand region	· Utilise depleted gas fields for storage if available · Financial support for storage construction, such as tax incentives · FSRU may be a solution but capacity may not suffice.

Source: APERC analysis.

REFERENCES

AGDC. (2019). *AGDC SIGNS ALASKA LNG COLLABORATION AGREEMENT WITH BP & EXXONMOBIL*. Retrieved from http://agdc.us/wp-content/uploads/2019/03/030819-Alaska-LNG-Collaboration-Agreement.pdf

Alten. (2019). *Yamal LNG: a titanic gas project in Arctic Siberia*. Retrieved from https://www.alten.com/yamal-lng-project-gas-arctic-anotech-energy/#:~:text=Yamal%20LNG%2C%20the%20world's%20largest%20modular%20construction&text=That%20is%20why%20the%20engineers,liquefied%20natural%20gas%20per%20year.

Angola LNG. (2020). *OUR HISTORY & OVERVIEW*. Retrieved from https://www.angolalng.com/en/about-angola-lng/our-history-overview/

APERC. (2019). *APEC Energy Demand and Supply Outlook 7th Edition*. Retrieved from https://aperc.or.jp/publications/reports/outlook.php

Argus. (2019a). *Global LNG fleet in excess until 2022: Howe Robinson*. Retrieved from https://www.argusmedia.com/en/news/1976142-global-lng-fleet-in-excess-until-2022-howe-robinson

Argus. (2019b). *Government key to boosting Korean LNG imports: S-Oil*. Retrieved from https://www.argusmedia.com/en/news/1878093-government-key-to-boosting-korean-lng-imports-soil

Atlantic LNG. (2020). *Our Trains*. Retrieved from https://www.atlanticlng.com/our-business/our-trains

Australia Pacific LNG. (2020). *Liquefied natural gas*. Retrieved from https://www.aplng.com.au/topics/liquefied-natural-gas.html

Bangkok Post. (2019). *Panel puts Egat's LNG import plan on hold*. Retrieved from https://www.bangkokpost.com/business/1681212/panel-puts-egats-lng-import-plan-on-hold

Bloomberg. (2018). *Shell, Partners Announce $31 Billion LNG Canada Investment*. Retrieved from https://www.bloomberg.com/news/articles/2018-10-02/shell-partners-announce-31-billion-lng-canada-investment

Bloomberg. (2019). *Long-term charter for FSU underpins LNG-to-power project*. Retrieved from https://www.bloomberg.com/news/articles/2019-10-24/floating-storage-surges-in-lng-market-with-more-ships-from-qatar

BP. (2018a). *Alaska*. Retrieved from https://www.bp.com/content/dam/bp/country-sites/en_us/united-states/home/documents/eir-2018/alaska-factsheet.pdf

BP. (2018b). *Innovative cross-border development offshore Mauritania and Senegal*. Retrieved from https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-announces-final-investment-decision-for-phase-1-of-the-greater-tortue-ahmeyim-lng-development.html

BP. (2018c). *BP announces Final Investment Decision for Phase 1 of the Greater Tortue Ahmeyim LNG development*. Retrieved from https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-announces-final-investment-decision-for-phase-1-of-the-greater-tortue-ahmeyim-lng-development.html

BP. (2020). *BP Annual Report 2019*. Retrieved from https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/investors/bp-annual-report-and-form-20f-2019.pdf

Bureau of Energy, MOEA. (2019). *Energy Statistics Handbook 2018*. Retrieved from https://www.moeaboe.gov.tw/ECW_WEBPAGE/FlipBook/2018EnergyStaHandBook/index.html#p=

Cameron LNG. (2020). *A small local company with a large global impact*. Retrieved from https://cameronlng.com/lng-facility/

Cheniere. (2019a). *Sabine Pass LNG Terminal-Liquefaction Facilities: Trains 1-6*. Retrieved from https://www.cheniere.com/terminals/sabine-pass/trains-1-6/

Cheniere. (2019b). *Corpus Christi LNG*. Retrieved from https://www.cheniere.com/terminals/corpus-christi-project/liquefactions-facilities-trains-1-3/

Chevron. (2009). *Chevron Makes Final Investment Decision to Construct Gorgon Natural Gas Project.* Retrieved from Chevron Press Release: https://www.chevron.com/stories/chevron-makes-final-investment-decisionto-construct-gorgon-natural-gas-project

Chevron. (2013). *Chevron Announces $39.8 Billion Capital and Exploratory Budget for 2014.* Retrieved from Chevron Press Release: https://www.chevron.com/stories/chevron-announces-39-8-billion-capital-and-exploratory-budget-for-2014

Chevron. (2020a). *gorgon project*. Retrieved from https://australia.chevron.com/our-businesses/gorgon-project

Chevron. (2020b). *Wheatstone project*. Retrieved from https://australia.chevron.com/our-businesses/wheatstone-project

Chiyoda Corporation. (2017). *Tangguh LNG Expansion Project (Train 3)*. Retrieved from https://www.chiyodacorp.com/en/projects/tangguh-lng.html.html

Chiyoda Corporation. (2018). *Yamal LNG Project (Train 1, 2, 3)*. Retrieved from https://www.chiyodacorp.com/en/projects/yamal-nenets.html

Chiyoda Corporation. (2019). *Notice of Revisions to the Forecast of Consolidated Results*. Retrieved from Chiyoda Corporation Earnings Release: https://www.chiyodacorp.com/ir/9f13190fb0d162887b7e370fd9b08ed8.pdf

ConocoPhilips. (2020). *The Darwin LNG Project*. Retrieved from http://static.conocophillips.com/files/resources/smid_016_darwin.pdf

Construction Dive. (2018). *Contractors to LNG developers: Be more realistic about costs*. Retrieved from https://www.constructiondive.com/news/contractors-to-lng-developers-be-more-realistic-about-costs/532934/

Dodge. (2017). *Thailand's LNG sector*. Retrieved from http://norway-connect.com/wp-content/uploads/2018/02/Thailand-LNG-Report-170626-Final.pdf

DOE. (2017). *Global LNG Fundamentals.* Retrieved from https://www.energy.gov/sites/prod/files/2017/10/f37/Global%20LNG%20Fundamentals_0.pdf

Dominion Energy . (2020). *Cove Point Terminal*. Retrieved from https://www.dominionenergy.com/company/moving-energy/dominion-energy-transmission-inc/facilities-projects-and-programs/cove-point/cove-point-terminal

Donggi Senoro. (2020). *Tentang Kami Overview*. Retrieved from https://www.donggisenorolng.co.id/about-us/overview/eng

EG LNG. (2020). *Our History*. Retrieved from https://www.eglng.com/about

EGAT. (2020). *EGAT celebrates the first LNG cargo slot*. Retrieved from https://www.egat.co.th/en/news-announcement/news-release/egat-celebrates-the-first-lng-cargo-slot

Egyptian LNG. (2020). *Historical Background*. Retrieved from https://www.egyptianlng.com/Pages/About/History.aspx

EIA. (2015). *The Basics of Underground Natural Gas Storage* . Retrieved from https://www.eia.gov/naturalgas/storage/basics/

EIA. (2019). Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=73&t=11

EIA. (2020). *Natural gas*. Retrieved from https://www.eia.gov/naturalgas/

EMA. (2014). *Appointment of new liquefied natural gas importer(s) for Singapore*. Retrieved from https://www.ema.gov.sg/cmsmedia/Gas/Post-3_Mtpa_RFP_Document_Stage_One_30Jun2014.pdf

Eni. (2020). *Coral South*. Retrieved from https://www.eni.com/en-IT/operations/mozambique-coral-south.html

Equinor. (2020). *Hammerfest LNG*. Retrieved from https://www.equinor.com/en/what-we-do/natural-gas/melkoya.html

Exmar. (2020). *FLNG to be deployed in Argentina for 10 years*. Retrieved from http://www.exmar.be/en/company/about-exmar/history/flng-be-deployed-argentina-10-years

ExxonMobil. (2019a). *ExxonMobil, Qatar Petroleum to Proceed with Golden Pass LNG Export Project*. Retrieved from https://corporate.exxonmobil.com/News/Newsroom/News-releases/2019/0205_ExxonMobil-Qatar-Petroleum-to-Proceed-with-Golden-Pass-LNG-Export-Project

ExxonMobil. (2019b). *ExxonMobil 2019 Summery Annual Report*. Retrieved from https://corporate.exxonmobil.com/-/media/Global/Files/investor-relations/annual-meeting-materials/annual-report-summaries/2019-Summary-Annual-Report.pdf

FERC. (2019). *FERC Reorganizes to Create New LNG Division, Open Houston Regional Office*. Retrieved from FERC News Release: https://www.ferc.gov/media/news-releases/2019/2019-3/07-23-19.asp#.XlzYX6j7TRY

Finizio, S. (2019). *The Guide to Energy Arbitrations*. Retrieved from https://globalarbitrationreview.com/edition/1001292/the-guide-to-energy-arbitrations-third-edition

Flex LNG. (2018). *Market for seaborne LNG transport is maturing*. Retrieved from https://www.flexlng.com/wp-content/uploads/2018/10/Flex_LNG-DNB-2018.pdf

Freeport LNG. (2020). *History of Freeport LNG in Brief*. Retrieved from http://freeportlng.com/about/corporate-history/

Gas Strategies. (2019). *NLNG signs five SPAs for LNG Train 7*. Retrieved from https://www.gasstrategies.com/information-services/gas-matters-today/nlng-signs-five-spas-lng-train-7-0

Gaslog. (2018). *Investor Presentation*. Retrieved from https://www.gaslogltd.com/assets/files/presentations/2018/201812-GLOG-Investor-Presentation.pdf

Gazprom. (2020). *Sakhalin II*. Retrieved from https://www.gazprom.com/projects/sakhalin2/

Generadoras de Chile. (2019). *Reporte Anual 2018.* Retrieved from http://generadoras.cl/media/page-files/909/Reporte%20Anual%202018%20final.pdf

GIIGNL. (2014). *LNG Shipping at 50*. Retrieved from https://giignl.org/sites/default/files/PUBLIC_AREA/Publications/lng-shipping-at-50compressed.pdf

GIIGNL. (2015). *Retail LNG Handbook*. Retrieved from https://giignl.org/sites/default/files/PUBLIC_AREA/Publications/giignl_retail_lng_handbook_0.pdf

GIIGNL. (2019). *2019 Annual report*. Retrieved from https://giignl.org/sites/default/files/PUBLIC_AREA/Publications/giignl_annual_report_2019-compressed.pdf

GIIGNL. (2020). *GIIGNL Annual Report 2020*. Retrieved from https://giignl.org/sites/default/files/PUBLIC_AREA/Publications/giignl_-_2020_annual_report_-_04082020.pdf

Global Construction Review. (2018). *Expensive Louisiana labour costs Japan's Chiyoda almost $1bn on Hackberry LNG contract*. Retrieved from http://www.globalconstructionreview.com/news/expensive-louisiana-labour-costs-japans-chiyoda-al/

GNL Penco. (2018). *Nuesto terminal.* Retrieved from http://gnlpenco.cl/nuestro-terminal/

Golar LNG. (2019). *Golar LNG 2018 Annual Report*. Retrieved from https://www.golarlng.com/~/media/Files/G/Golar-Lng/documents/annual-reports/golar-lng-limited-2018-annual-report-form-20f.pdf

Golar LNG. (2020). *Floating liquefaction vessels (FLNGVs)*. Retrieved from https://www.golarlng.com/our-fleet/floating-liquefaction-vessels

Golden Pass LNG. (2020). *Overview*. Retrieved from http://www.goldenpassproducts.com/index.cfm/page/69

GTT. (2018). *The March of the GTT Membrane*. Retrieved from https://www.gtt.fr/sites/gtt/files/lng_may18_containment_systems.pdf

GTT. (2019). *Investor Presentation*. Retrieved from https://www.gtt.fr/sites/gtt/files/ir-investor_presentation_-_28_may_2019.pdf

Howard Rogers. (2017). *Does the Portfolio Business Model Spell the End of Long-Term Oil-Indexed LNG Contracts?* Retrieved from https://www.oxfordenergy.org/publications/portfolio-business-model-spell-end-long-term-oil-indexed-lng-contracts/?v=24d22e03afb2

Howard Rogers. (2018). *The LNG shipping forecast: costs rebounding, outlook uncertain*. Retrieved from https://www.oxfordenergy.org/publications/lng-shipping-forecast-costs-rebounding-outlook-uncertain/?v=24d22e03afb2

Hydrocarbons. (2020a). *Sonatrach Skikda LNG Project*. Retrieved from https://www.hydrocarbons-technology.com/projects/sonatrach/

Hydrocarbons. (2020b). *Gladstone Liquefied Natural Gas Project*. Retrieved from https://www.hydrocarbons-technology.com/projects/gladstone-project/

Hydrocarbons. (2020c). *Australia Pacific LNG Project, Gladstone, Queensland*. Retrieved from https://www.hydrocarbons-technology.com/projects/australia-pacific-lng-queensland/

Hyundai. (2005). *Comparison of Spherical and Membrane Large LNG Carriers in Terms of Cargo Handling*. Retrieved from http://www.ivt.ntnu.no/ept/fag/tep4215/innhold/LNG%20Conferences/2005/SDS_TIF/050207PR.pdf

IEA. (1995). *The IEA Gas Security Study.* OECD.

IEA. (2017). *Global Gas Security Review 2017*. Retrieved from https://webstore.iea.org/download/direct/275?fileName=GlobalGasSecurityReview2017.pdf

IEA. (2018). *Global Gas Security Review 2018.*

IEA. (2019a). *Energy Security*. Retrieved from https://www.iea.org/topics/energy-security

IEA. (2019b). *Global Gas Security Review 2019.*

IEA. (2019c). *Natual Gas Information 2019.*

IEA. (2020). *Data browser Mexico*. Retrieved from https://www.iea.org/countries/mexico

IEEJ. (2003). *LNG:Falling Prices and Increasing Flexibility of Supply-Risk Redistribution Creates Contract Diversity*. Retrieved from https://eneken.ieej.or.jp/en/data/pdf/191.pdf

IEEJ. (2018). *Emergence of LNG portfolio players*. Retrieved from https://eneken.ieej.or.jp/data/7814.pdf

IEEJ. (2019). *IEEJ Outlook 2020*. Retrieved from https://eneken.ieej.or.jp/data/8650.pdf

IGU. (2015). *IGU World LNG Report 2015*. Retrieved from https://www.igu.org/sites/default/files/node-page-field_file/IGU-World%20LNG%20Report-2015%20Edition.pdf

IGU. (2017). *IGU World LNG Report 2017*. Retrieved from https://www.igu.org/sites/default/files/103419-World_IGU_Report_no%20crops.pdf

IGU. (2019). *IGU World LNG Report 2019*. Retrieved from https://www.igu.org/sites/default/files/node-news_item-field_file/IGU%20Annual%20Report%202019_23%20loresfinal.pdf

IMO. (2014). *Ships face lower sulphur fuel requirements in emission control areas from 1 January 2015*. Retrieved from http://www.imo.org/en/MediaCentre/PressBriefings/Pages/44-ECA-sulphur.aspx

IMO. (2019a). *Nitrogen Oxides (NOx) - Regulations 13*. Retrieved from http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx

IMO. (2019b). *The 2020 global sulphur limit: Frequently Asked Questions*. Retrieved from http://www.imo.org/en/MediaCentre/HotTopics/GHG/Documents/2020%20sulphur%20limit%20FAQ%202019.pdf

Inpex. (2019). *Abadi LNG Project*. Retrieved from https://www.inpex.co.jp/english/business/indonesia.html

Inpex. (2020). *Hisory*. Retrieved from https://www.inpex.co.jp/english/company/history.html

JERA. (2019). Retrieved from https://www.jera.co.jp/english/information/20190513_348

JERA. (2019). *Darwin LNG Project*. Retrieved from https://www.jera.co.jp/english/business/projects/darwin

JOGMEC. (2020). *天然ガスリファレンスブック 2020.*

JXTG. (2004). *Establishment of LNG Supply Chain in Malaysia*. Retrieved from https://www.noe.jxtg-group.co.jp/english/newsrelease/noc/2004/pdf/040906.pdf#page=2

Kinder Morgan . (2015). *Elba Liquefaction Project & EEC Modification Project*. Retrieved from https://www.kindermorgan.com/pages/business/gas_pipelines/projects/elbaLNG

KOGAS. (2020). *Business System*. Retrieved from http://www.kogas.or.kr/eng/contents.do?key=1524

LNG Canada. (2020). *About LNG Canada*. Retrieved from https://www.lngcanada.ca/about-lng-canada/

LNG Industry. (2020). *Kosmos signs Greater Tortue Ahmeyim SPA with BP Gas Marketing*. Retrieved from https://www.lngindustry.com/liquid-natural-gas/12022020/kosmos-signs-greater-tortue-ahmeyim-spa-with-bp-gas-marketing/

Maran Gas Maritime Inc. (2016). *An update on LNG propulsion and peripheral systems*. Retrieved from https://higherlogicdownload.s3.amazonaws.com/SNAME/a09ed13c-b8c0-4897-9e87-eb86f500359b/UploadedImages/2015-2016%20TM%20Photos/hatzigrigoris.an_update_on_LNG_pr.2016.SECP.pdf

McDermott. (2018a). *Q2 2018 SUPPLEMENTAL INFORMATION*. Retrieved from http://s22.q4cdn.com/787409078/files/doc_financials/2018/Q218-MDR-Supplemental-Presentation.pdf

McDermott. (2018b). *Q3 2018 SUPPLEMENTAL INFORMATION*. Retrieved from http://s22.q4cdn.com/787409078/files/doc_presentations/2018/Q318-MDR-Supplemental-Presentation_Final_v4.pdf

McDermott. (2019). *Q4 2018 SUPPLEMENTAL INFORMATION*. Retrieved from http://s22.q4cdn.com/787409078/files/doc_financials/2018/q4/Q4'18-MDR-Supplemental-Presentation_Final_5.pdf

McKinsey. (2019). *Forced boil-off gas: The future of LNG as a fuel for LNG carriers*. Retrieved from https://www.mckinsey.com/industries/oil-and-gas/our-insights/forced-boil-off-gas-the-future-of-lng-as-a-fuel-for-lng-carriers

Mechademy. (2019). *Snøhvit LNG Plant*. Retrieved from https://www.mechademy.com/lng_plant/snohvit-lng-plant/

MHIMME. (2014). *First ultra steam turbine (UST) plant to go into service this autumn*. Retrieved from https://www.mhi-mme.com/cms_docs/meetnews_5_e.pdf

Ministerio de Energia. (2019). *Balance de Energía Nacional 2018*. Retrieved from http://energiaabierta.cl/visualizaciones/balance-de-energia/

Mozambique LNG. (2019). *Progress & Milestones*. Retrieved from http://www.mzlng.com/The-Project/The-Resource-/

Natural Gas Intelligence. (2018). *Cheniere's Sabine Pass LNG Train 6 Near FID as Petronas Contracts for 20-Year Supply*. Retrieved from https://www.naturalgasintel.com/articles/116827-chenieres-sabine-pass-lng-train-6-near-fid-as-petronas-contracts-for-20-year-supply

NLNG. (2020). *Nigeria LNG*. Retrieved from http://nlng.com/Our-Company/Pages/The-Plants.aspx

North West Shelf Gas. (2020). *North West Shelf Gas*. Retrieved from http://www.nwsg.com.au/

NTNU. (1998). *THE MLNG TIGA PROJECT*. Retrieved from http://www.ivt.ntnu.no/ept/fag/tep4215/innhold/LNG%20Conferences/1998/Papers/2-7-Grootjans.PDF

Ochoa, J. (2019). *Tras 6 años aprueban proyecto gasífero Terminal GNL Penco.* Diario Concepción. Retrieved from https://www.diarioconcepcion.cl/economia-y-negocios/2019/08/30/tras-6-anos-aprueban-proyecto-gasifero-terminal-gnl-penco.html

Offshore Energy. (2018). *Toho Gas inks LNG Canada supply deal*. Retrieved from https://www.offshore-energy.biz/toho-gas-inks-lng-canada-supply-deal/

Oil & Gas Journal. (2019a). *Venture Global makes Calcasieu Pass LNG FID*. Retrieved from https://www.ogj.com/pipelines-transportation/lng/article/14038675/venture-global-makes-calcasieu-pass-lng-fid

Oil & Gas Journal. (2019b). *PetroVietnam begins work on first LNG terminal*. Retrieved from https://www.ogj.com/pipelines-transportation/article/14072493/petrovietnam-begins-work-on-first-lng-terminal

Oman LNG. (2020). *Oman LNG*. Retrieved from http://omanlng.co.om/en/TheCompany/Pages/AboutUs.aspx

Pacific Maritime Magazine. (2017). *Gas Carriers: They've Come a Long Way*. Retrieved from https://www.pacmar.com/story/2017/01/01/features/gas-carriers-theyve-come-a-long-way/481.html

Peru LNG. (2020). *Our History*. Retrieved from https://perulng.com/en/nuestra-empresa/historia/

Petronas. (2017). *PETRONAS' First Floating LNG Facility, PFLNG SATU Achieves First Cargo*. Retrieved from https://www.petronas.com/media/press-release/petronas-first-floating-lng-facility-pflng-satu-achieves-first-cargo

Petronas. (2019a). *PETRONAS Names Its Second Floating LNG Facility*. Retrieved from https://www.petronas.com/media/press-release/petronas-names-its-second-floating-lng-facility

Petronas. (2019b). *PETRONAS Names Its Second Floating LNG Facility*. Retrieved from https://www.petronas.com/media/press-release/petronas-names-its-second-floating-lng-facility

PNG LNG. (2020). *PNG LNG*. Retrieved from https://pnglng.com/About

Poten & Partners. (2018). *LNG Shipping: How long will the good times last?* Retrieved from https://www.marinemoney.com/system/files/media/2018-11/4.%20Session%20One%20-%20Jefferson%20Clarke.pdf

PwC. (2006). *LNG-A glossary of terms*. Retrieved from https://www.pwc.com/gx/en/energy-utilities-mining/pdf/lng_glossary_final.pdf

Qatar Petroleum. (2020). *Ras Gas*. Retrieved from https://www.qp.com.qa/en/QPActivities/pages/subsidiariesandjointventuresdetails.aspx?aid=52

Reuters. (2015). *BRIEF-Flex reaches agreement with Samsung to convert two LNG carriers from DFDE to MEGI*. Retrieved from https://www.reuters.com/article/flex-lng-brief/brief-flex-reaches-agreement-with-samsung-to-convert-two-lng-carriers-from-dfde-to-megi-idUSFWN0V903920150202

Reuters. (2016). *Chevron Wheatstone LNG cost blowout to $34 billion hits Woodside*. Retrieved from Reuters: https://www.reuters.com/article/us-chevron-lng-australia-idUSKBN12U0ZZ

Reuters. (2017). *Australia's LNG projects face major delays, benefiting U.S. producers*. Retrieved from Reuters: https://www.reuters.com/article/us-asia-lng-delays-idUSKBN15A24L

Reuters. (2017). *CORRECTED-UPDATE 1-Australia's Ichthys LNG dealt blow as major contractor pulls plug*. Retrieved from Reuters: https://www.reuters.com/article/australia-lng-ichthys-corrected-update-1/corrected-update-1-australias-ichthys-lng-dealt-blow-as-major-contractor-pulls-plug-idUSL4N1FF2PN

Reuters. (2019a). Retrieved from https://www.reuters.com/article/us-japan-lng-conference-tokyo-gas/tokyo-gas-aims-to-renegotiate-lng-contracts-raise-flexibility-idUSKBN1WB10C

Reuters. (2019b). *Japan's Inpex eyes Australia expansion, including via acquisitions*. Retrieved from https://www.reuters.com/article/us-inpex-c-australia/japans-inpex-eyes-australia-expansion-including-via-acquisitions-idUSKCN1VY0L8

Reuters. (2019c). *Shipping industry must act to meet emissions targets, path unclear - IRENA*. Retrieved from https://www.reuters.com/article/us-climatechange-shipping-oil/shipping-industry-must-act-to-meet-emissions-targets-path-unclear-irena-idUSKBN1XA0DR

Reuters. (2019d). *S.Korea to raise coal tax; lower LNG tax for power generation*. Retrieved from https://www.reuters.com/article/southkorea-power-tax-idAFL4N1UQ06T

Reuters. (2019e). *Power outages hit Mexico's Yucatan peninsula, including Cancun*. Retrieved from https://www.reuters.com/article/mexico-cancun-blackout/power-outages-hit-mexicos-yucatan-peninsula-including-cancun-idUSL1N21N1X2

Rigzone. (2018). *With CNPC Deal, Cheniere's Train 3 at Corpus Christi Becomes More Likely*. Retrieved from https://www.rigzone.com/news/with_cnpc_deal_chenieres_train_3_at_corpus_christi_becomes_more_likely-09-feb-2018-153477-article/

Riviera. (2018). *Nakilat's role as a key supporter of Qatar's ambition*. Retrieved from https://www.rivieramm.com/opinion/opinion/nakilats-role-as-a-key-supporter-of-qatars-ambition-25459

Riviera. (2019). *Long-term charter for FSU underpins LNG-to-power project*. Retrieved from https://www.reuters.com/article/us-climate-change-shipping-analysis/shippers-shine-torch-in-every-corner-as-pressure-to-cut-co2-grows-idUSKBN1X21II

Roques, F., & Mann, J. (2018). *Measures for a sustainable gas storage market.* Retrieved from https://ec.europa.eu/info/sites/info/files/gie-fti_study_-_measures_for_a_sustainable_gas_storage_market.pdf

Rystad Energy. (2019). *$200+ billion at stake as offshore sanctioning kicks into gear*. Retrieved from Rystad Energy Press Release: https://www.rystadenergy.com/newsevents/news/press-releases/200-billion-at-stake-as-offshore-sanctioning-kicks-into-gear/

S&P Global Platts. (2017). *The move to modular: LNG developers turn to smaller units to lessen risk*. Retrieved from https://www.spglobal.com/marketintelligence/en/news-insights/trending/-PMG6AjGWEqaOsFLAc4TyA2

S&P Global Platts. (2018). *Contractors express caution on bidding for new US LNG export projects*. Retrieved from https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/092018-contractors-express-caution-on-bidding-for-new-us-lng-export-projects

S&P Global Platts. (2019). *PV Gas starts constructing Vietnam's first LNG terminal, secures funding*. Retrieved from https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/102919-pv-gas-starts-constructing-vietnams-first-lng-terminal-secures-funding

S&P Global Platts. (2020a). *Kogas adopts new LNG pricing method to try keep S Korean utilities off imports*. Retrieved from https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/011020-kogas-adopts-new-lng-pricing-method-to-try-keep-s-korean-utilities-off-imports

S&P Global Platts. (2020b). *China likely to miss 2020 gas storage targets amid COVID-19, incomplete reforms*. Retrieved from https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/050520-china-likely-to-miss-2020-gas-storage-targets-amid-covid-19-incomplete-reforms

Santos. (2020). *Our Story*. Retrieved from https://www.santos.com/about-us/our-story/

Shell. (2014). *SHELL BOOSTS ITS LEADERSHIP IN GLOBAL LNG WITH THE COMPLETION OF REPSOL S.A.*

LNG DEAL. Retrieved from https://www.shell.com/media/news-and-media-releases/2014/shell-boosts-leadership-global-lng-completion-repsol-deal.html

Shell. (2016). *BG SHAREHOLDERS VOTE IN FAVOUR OF THE RECOMMENDED COMBINATION BETWEEN SHELL AND BG*. Retrieved from https://www.shell.com/media/news-and-media-releases/2016/bg-shareholders-vote-in-favour-of-recommended-combination-between-shell-and-bg.html

Shell. (2017). *QGC LNG Plant*. Retrieved from https://www.shell.com.au/about-us/projects-and-locations/qgc/about-onshore-natural-gas/_jcr_content/par/textimage_96d0.stream/1494068662671/5d73e86cf47badf31570aa713dea733a04163d31/46524-qgc-factsheet-lng-plant.pdf

Shell. (2018a). *LNG Canada*. Retrieved from https://www.shell.com/about-us/major-projects/lng-canada.html

Shell. (2018b). *LNG Canada*. Retrieved from https://www.shell.com/about-us/major-projects/lng-canada.html

Shell. (2019). *Integrated Gas overview*. Retrieved from https://reports.shell.com/investors-handbook/2019/integrated-gas.html

Shell. (2020a). *LNG SUPPLY PROJECTS AND REGASIFICATION PLANTS*. Retrieved from https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng/lng-supply-projects-and-regasification-plants.html

Shell. (2020b). *Investor's Handbook 2015-2019*. Retrieved from https://reports.shell.com/investors-handbook/2019/integrated-gas/lng.html

Shell. (2020c). *Shell LNG Outlook 2020.* Retrieved from Shell LNG Outlook 2020: https://www.shell.com/promos/overview-shell-lng-2020/_jcr_content.stream/1582216323272/cf1feb79ca4147e1b5d0d534dc8677225517b951/lng-outlook-pack-feb-2020-updated.pdf

Shell. (2020d). *PRELUDE FLNG*. Retrieved from https://www.shell.com/about-us/major-projects/prelude-flng.html

Stern, J. (2002). Retrieved from Security of European natural gas supplies - The impact of import dependence and liberalization: http://www.bgc.bg/upload_files/file/Security_of_Euro_Gas_.pdf

Taipei Times. (2018a). *EPA deputy quits, cites Lai pressure*. Retrieved from http://www.taipeitimes.com/News/front/archives/2018/10/09/2003702006

Taipei Times. (2018b). *CPC renews vow to meet public's hopes for third LNG terminal in Taoyuan*. Retrieved from http://www.taipeitimes.com/News/biz/archives/2018/10/09/2003701985

TechnipFMC. (2019). *Engineering for Extremes*. Retrieved from https://www.technipfmc.com/en/media/Views/engineering-for-extremes

The Brookings Institution. (2012). *Policy Suggestions for the initial development of Viernam's gas industry*. Retrieved from https://www.brookings.edu/wp-content/uploads/2016/06/09-vietnam-gas-industry-hai.pdf

The Economist. (2013). *Algeria: Gassi Touil starts commissioning stage*. Retrieved from https://www.eiu.com/industry/article/1651166349/algeria-gassi-touil-starts-commissioning-stage/20_6

The West Australian. (2017). *Do your homework: Chevron's outgoing chief John Watson learns from Gorgon mistakes*. Retrieved from The West Australian: https://thewest.com.au/business/oil-gas/do-your-homework-chevrons-outgoing-chief-john-watson-learns-from-gorgon-mistakes-ng-b88643593z

Total. (2009). *YEMEN LNG STARTS PRODUCTION*. Retrieved from https://www.total.com/media/news/press-releases/demarrage-de-la-production-de-yemen-lng

Total. (2018). *Total Closes the acquisition of Engie's Upstream LNG Business And Becomes World #2 LNG Player*. Retrieved from https://www.total.com/en/media/news/press-releases/total-closes-acquisition-engies-upstream-lng-business-and-becomes-world-2-lng-player

Total. (2019a). *Total Closes the Acquisition of Anadarko's Shareholding in Mozambique LNG*. Retrieved from https://www.total.com/en/media/news/press-releases/total-closes-acquisition-anadarkos-shareholding-mozambique-lng

Total. (2019b). *LNG: TOTAL IS INVESTING IN AN ENERGY OF TOMORROW*. Retrieved from https://www.total.com/dossiers/lng-total-investing-energy-tomorrow

Total. (2019c). *TOTAL CLOSES THE ACQUISITION OF ANADARKO'S SHAREHOLDING IN MOZAMBIQUE LNG*. Retrieved from https://www.total.com/media/news/press-releases/total-closes-acquisition-anadarkos-shareholding-mozambique-lng

Tu, H., Fan, H., Lei, W., & Zhou, G. (2018). *Options and Evaluations on Propulsion Systems of LNG Carriers*. Retrieved from https://www.intechopen.com/books/propulsion-systems/options-and-evaluations-on-propulsion-systems-of-lng-carriers

Tusiani, M., & Shearer, G. (2007). *LNG: A nontechnical guide.* Pennwell Books.

Venture Global LNG. (2019). *Venture Global Announces Final Investment Decision and Financial Close for Calcasieu Pass LNG*. Retrieved from https://venturegloballng.com/press/venture-global-announces-final-investment-decision-and-financial-close-for-calcasieu-pass-lng/

Venture Global LNG. (2020). *Calcasieu Pass*. Retrieved from https://venturegloballng.com/project-calcasieu-pass/facility/

Viet Nam News. (2018). *Viet Nam to face gas shortage in 2020*. Retrieved from https://vietnamnews.vn/economy/480138/viet-nam-to-face-gas-shortage-in-2020-moit.html

Vitol. (2019). *LNG Producer-Consumer Conference*. Retrieved from https://www.lng-conference.org/presen/pdf/Session3_PabloGalanteEscobar.pdf

Wartsila. (2002). *The DF-Electric LNG Carrier Concept*. Retrieved from http://www.ivt.ntnu.no/ept/fag/tep4215/innhold/LNG%20Conferences/2002/Papers/Kosomaa_paper.pdf

Wartsila. (2016). *Back to the future: steam turbine to DFDE conversion for LNG carriers*. Retrieved from https://www.wartsila.com/twentyfour7/in-detail/back-to-the-future-steam-turbine-to-dfde-conversion-for-lng-carriers

Wood Mackenzie. (2019). *Golden Pass crests second wave of US LNG*. Retrieved from https://www.woodmac.com/ja/press-releases/golden-pass-lng-fid/

Woodside. (2020). *Pluto LNG*. Retrieved from https://www.woodside.com.au/our-business/pluto-lng

World Bank. (2018). Retrieved from http://documents.worldbank.org/curated/en/344451553842171106/pdf/Phase-Two-Liquefied-Natural-Gas-LNG-Demand-Projection-Procurement-Strategy-and-Risk-Management-Executive-Summary-Report.pdf

Xinhua. (2019). *China sets up new central SOE to manage oil, gas pipelines*. Retrieved from http://www.xinhuanet.com/english/2019-12/09/c_138617600.htm