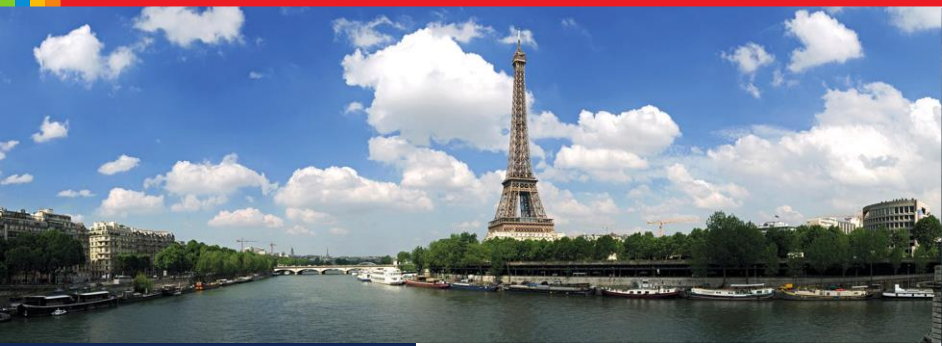
2012-2015 Triennium Work Reports



Remote LNG

International Gas Union

Programme Committee D Study Group 1

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Executive Summary

With natural gas advancing its position in the world energy mix, exploration activity, which has been historically focused on oil, now embraces gas with the same enthusiasm. Today it is the gas discoveries, which are dominating the headlines.

Driven by demand, technological advances and viable economics, LNG is allowing the development of gas discoveries in more and more remote and hostile regions of the globe. As exploration moves into these new frontiers, gas liquefaction projects will similarly be located in increasingly distant and hostile areas. Perhaps considered the most hostile region of all, the Arctic Circle provides some of the most challenging projects for LNG today and looks to be one of the biggest growth areas in the coming 20-30 years of exploration.

The purpose of this IGU report is to review the new and challenging remote and hostile regions where LNG projects are being planned and could be located in the future, and discuss the particular challenges that are faced in the whole chain from site selection through design and construction to the operation and LNG export from these plants. Whilst Floating LNG (FLNG) can be considered as another remote concept, it was decided to exclude FLNG from this discussion due to the very specific nature of the concept and extensive discussion in other publications or working groups.

The term "remote" generally implies a significant distance from a particular place, and it is fair to say that, by definition, the majority of LNG production projects are in geographically isolated areas, as the driving force behind liquefaction projects has always been the need to monetize and transport isolated gas reserves in an economic way to markets, which can be anywhere in the world. However, this report proposes to include other factors into the term "remote" to give a more complete indication of the challenges that are faced by complex projects in complicated areas of the world.

Therefore a Remoteness Index has been developed and presented in this report. The Remoteness Index, quantifies just how remote and hostile a particular project is and, based upon past projects experiences, looks at correlations, which may be useful in predicting outcomes and success rates of future projects. Several case studies are discussed of projects that are in operation or are under the planning/construction phase, and specific lessons learned are highlighted.

The Remoteness Index does not just measure geographical distance. There are other factors that cause severe challenges in any or all of the planning, design, construction, operations, and export phases, and therefore these are incorporated into the concept of the remoteness of a project.

The criteria identifying **REMOTE** are as follows:

- **Geographical Remoteness** – This refers to the site being a significant distance from any infrastructure, any urban centre and any notable logistical availability.
- **Extreme climatic conditions** - This refers to either constant extreme temperature, significant seasonal temperature swings, or other adverse constant or varying extreme conditions.
- **Manpower Problems** - Severe operational challenges caused by lack of skilled affordable manpower, applicable mainly to the construction phase but also relevant to the operational phase.
- **Operational Challenges / infrastructure** - Access to the site, local content problems through lack of local suppliers. This affects both the construction phase as well as the operational phase.
- **Technical hurdles** - The need for a technical solution drives the development of the technical solution. This criterion rates the projects in relation to the technological challenges faced in the design, construction, and operational phases.
- **Environmental Sensitivity -** By default most remote areas of the world are untouched and considered environmentally sensitive. New projects have an effect on the environment and there is an increasing public resistance to such intrusions.

The earliest liquefaction plants were ground-breaking in terms of technology application and provided great leaps forward regarding know-how, and, whilst at the time they were constructed in what were considered out-of-the-way places, today many of the plants are now considered as standard. So, which plants are more remote than others, what makes them more remote and what does the future hold?

In order to address this, and be able to have a quantification of remoteness, the previously mentioned factors can be defined and weighted to provide a numerical indication of remoteness. And when statistically analysing LNG Plants it was concluded that the distribution of the Remoteness Index was quite narrow in a band between 3 and 4, which nicely fitted a Gaussian distribution. However, new projects, especially in the United States do not follow the former trend. This is explained by the fact that these new liquefaction plants use a new production scheme (i.e. conversion of existing LNG receiving terminal into a liquefaction plants), are located close to the source of gas (not stranded gas) and are in an area where infrastructure is fully developed. United States shale gas has triggered a series of new projects with surprisingly low Remoteness Indices. The Remoteness Index can be used as an analytical tool to identify historical and future trends, and allows explanation of the historical trends and potential prediction of future trends. This will also be an indication for the complexity of certain remote projects.

Major conclusions presented in the extended IGU report for the criteria defining the Remoteness Index are:

Geographical and climatic conditions

The Arctic Circle offers perhaps the most prolific potential regarding exploration, but at the same time it presents some of the biggest challenges regarding development and export of gas to market. Cold and harsh conditions present a unique set of technical challenges in all phases of the project, including LNG export in carriers with ice-breaking capability.

Other locations in Asia-Pacific and in East Africa are likely hard to reach due to geographical isolation and lack of well-developed infrastructure. Severe climatic conditions affect the design of the project and can significantly influence construction activities. All planning cycles should be carefully matched with adequate contingencies for the weather cycles.

While infrastructure will develop over the years, adverse climatic conditions cannot be changed by mankind. Thus, this aspect will remain a significant indicator for a competitive sufficient profit generating LNG liquefaction project.

Social and environmental issues

The majority of remote projects, even though initially located in areas of little or no urbanisation, do affect the socio-political landscape, often leading to development of urbanisation and bringing significant social change. In addition, the social implications of large scale investment projects are increasingly an obligation in the design and planning stage. They carry a large social responsibility towards indigenous habitants. Social responsibility programs need to be part of project execution and operation.

Environmental aspect constraints need to be taken into account to minimise impact on marine and wildlife environment, which has not seen industrial development.

While people may assimilate to changes in their social and cultural life within decades, the environment needs much longer periods to recover from imprudent disturbances. Short sighted run for profit may cause tremendous expenses to re-establish fair living conditions. Thus, a high rating in the category Environmental Concern needs to be considered seriously, when new projects approach FID.

Technical and operational challenges

All countries, especially the new LNG players are demanding significant Local Content in projects. Whilst most LNG project shareholders fully support the notion of Local Content, the reality is often a big obstacle in the sanctioning and development of remote projects. Development of these project requirements has a special focus on operation, maintenance, safety, and occupational health.

From a design point of view remote projects have special requirements due to soil conditions, ambient conditions like snow and ice or storms, humidity, floods and sun radiation. This results in selecting optimal liquefaction technology, redundancy of equipment to ensure reliability and sometimes extensive winterisation of structures and equipment.

Proper planning is critical since construction windows may be limited. Standardisation and modularisation to minimise construction work on site is one of the key success factors of constructing remote projects.

However, technology is keeping pace with hostile environment project requirements. No project as yet has been shelved due to purely the lack of technological solutions, but due to the lack of economical sense of the required technological solutions.

Cost impact of Remoteness Index

From an aprioristic approach it could be expected, that the costs for an LNG project directly correlate to the remoteness (and therefore the Remoteness Index). However by evaluating past projects it is not possible to infer such a relationship exists. While certain remoteness criteria clearly do have an impact on a projects overall costs, other factors also have a very large impact on a particular projects costs (such as: raw materials costs, contractors' workload panorama, projects confluence, and many others). A clear view on the correlation between remoteness and cost looks as likely to be as absent for future projects as has been the case up until now.

Usage of Remoteness Index

Nevertheless, the Remoteness Index can be taken as an indication about how challenging a new LNG project can be due to its location; in this sense developers of new remote projects, can find it useful to check their new projects Remoteness Index estimate against other past projects with similarities.

All of those projects, which have been classified as highly remote (Remoteness Index ≥4.0) and have started up already, are located in hot areas of the Asia-Pacific. Future projects including Yamal LNG and Alaska LNG will go further North and will be more in line with the general perception of remote.

Country	Project Name	Start Year	Remoteness Index
Indonesia	Bontang LNG	1977	4.3
Indonesia	Arun LNG	1978	4.1
Indonesia	Tangguh LNG	2009	4.0
Indonesia	Donggi-Senoro LNG	2014	4.0
PNG	PNG LNG	2014	4.2
Russia NW	Yamal LNG	2020	4.1
PNG	Gulf LNG	2021	4.2
Alaska	Alaska LNG	2023	4.4
Indonesia	Natuna D Alpha	2025	4.1

Introduction to Remoteness Index

Natural gas liquefaction dates back to the 19th century and immediately raised the possibility of transportation of natural gas, economically, to distant destinations (beyond certain level of distances, LNG economics can be better than pipeline, for example). In January 1959, the world's first LNG tanker, The Methane Pioneer, a converted World War II liberty freighter carried an LNG cargo from Lake Charles, Louisiana to Canvey Island, United Kingdom. This event demonstrated that large quantities of liquefied natural gas could be transported safely across the ocean. 1964 saw the start-up of the world´s first large-scale (at the time) commercial LNG export plant in Algeria, shipping gas to the UK.

Since then, 19 countries have collectively an LNG exporting capacity of 291 mtpa from a variety of regions, climates and geographies. In addition, global LNG production capacity could reach 397 mtpa by 2018[1]. Many other new projects that are planning to start-up in the 2020 time frame are located in extremely inhospitable and hostile locations.

Gas continues to grow as a principal fuel of choice in the world energy mix, and gas discoveries are now providing some of the most prolific hydrocarbon finds. Some of the biggest headlines in the last few years have been about gas. Driven by demand, sustained prices and the advance of cost-effective technology, gas exploration will continue to push the technological and economically viable boundaries into new frontiers, in regions of the globe previously considered too distant and too hostile.

Two examples of remotely located LNG plants discussed in this report are Alaska LNG and Tangguh LNG.

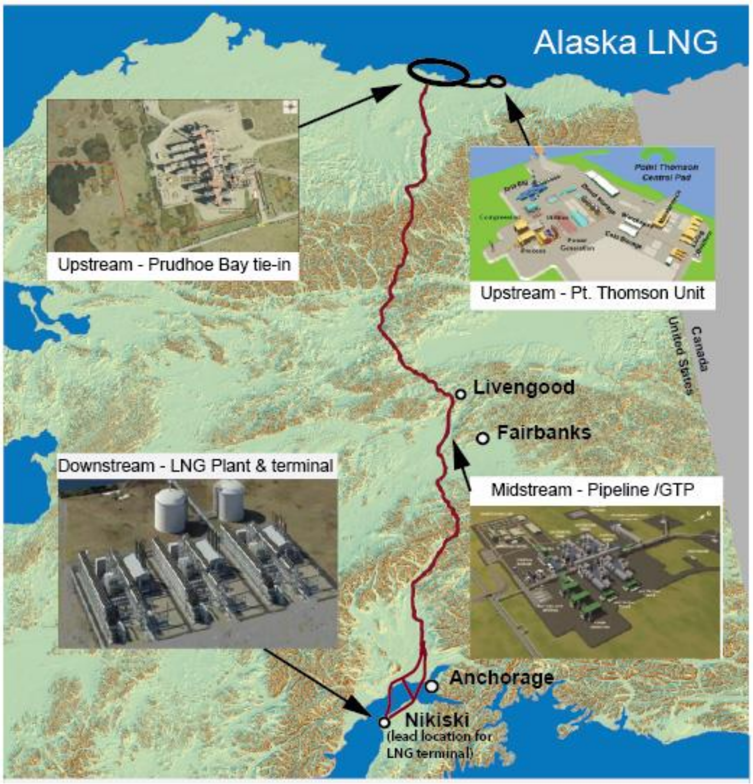


Figure 1 Alaska LNG project

Alaska LNG[2] (see Figure 1)

[1] Source: IGU World LNG Report 2014
[2] Courtesy of Alaska Gas Pipeline Project Office

Figure 2 Tangguh LNG Indonesia

impresses by the ambitious technical concept with the upstream part in an extremely arctic climate and a challenging, 1300 km long natural gas pipeline through highly sensitive vegetation and wildlife.

Tangguh LNG[3] (Figure 2) is an example for severe difficulties to reach the site, which may even be impossible for a certain period, the unavailability of local labour and a formerly untouched environment.

Each and every one of these frontier locations brings new and different challenges in the design, planning, permitting, construction and operation of the plants. Such issues as climatic extremes, logistic complexities and non-existent infrastructure all contribute to lengthier sanctioning, extended project construction times and more complex operation processes.

The purpose of this report is to take a look at the most extreme and isolated LNG projects of today, and discuss the more significant challenges that were faced in execution of the projects. Then, by looking at the future of the exploration frontiers, assess what lessons have been learned from the ongoing projects that can be used to assist and assess future projects.

It is important as a first step to define what is meant by remote. The most common understanding implies a significant geographical distance. However, there are other factors related to these projects that cause severe challenges in any or all of the planning, design, construction, and operation phases, and therefore it's needed to incorporate these issues into the concept of remoteness of a project. These are as follows:

- **Geographical Remoteness** - This refers to the site being a significant distance from any infrastructure, any urban centre and any notable logistical availability. Geographical distance from the market is not considered in this factor. However, distance from the gas source to the LNG Plant is an issue, which can compound significantly the complexity and cost of a project (like Peru LNG). The perceived geographical remoteness may have changed in the past and will change in the future due to developments with respect to infrastructure and technology.
- **Extreme climatic conditions** - This refers to either constant extreme temperature, significant seasonal temperature swings, or, other adverse constant or varying extreme conditions. such adverse constant or varying extreme

[3] Courtesy of BP (http://www.bp.com/en_id/indonesia/bp-in-indonesia/tangguh-lng.html)

conditions like snow, wind, rain and humidity. The Köppen-Geiger climate classification is used and establishes climate zone boundaries based upon the concept of native vegetation. It combines average annual and monthly temperatures and precipitation.

- **Manpower Problems** - Severe operational challenges caused by a lack of skilled manpower, applicable mainly to the Construction phase but also relevant to the Operational phase.
- **Operational Challenges / infrastructure** - Access to the site, local content problems through lack of local suppliers – mainly affects construction phase but has a significant impact on the operational phase as well.
- **Technical hurdles** - As ever in the Oil and Gas business, the need for a technical solution drives the development of the technical solution. Extreme climates are driving innovative solutions both in plant design, plant construction and LNG export technologies. This criterion rates the projects in relation to the technological challenges faced in the design, construction and operational phases. Technical hurdles may have been overcome in the past and will change in the future due to developments with respect to technology and equipment. Therefore this index needs to be understood in context with the year of start-up of the project.
- **Environmental Sensitivity -** By default most remote areas of the world are untouched and considered environmentally sensitive. Any new projects in these areas will inevitably have an effect on the environment and there is an increasing public resistance to such intrusions.

While the most high profile projects are appearing at higher latitudes, the scope of this report is not limited to these projects only as the future will see more developments in other remote geographic areas. Examples are recent developments like Yamal LNG and the recently commissioned Angola LNG both of, which posed unique challenges and required creative solutions due to their remoteness.

Further, an LNG project may include very remote gas production and transport via a technically challenging pipeline, while the liquefaction plant itself is not quite as demanding. Examples for such an installation are Sakhalin LNG, Peru LNG, and Snøhvit LNG.

Initial developments of the earliest liquefaction plants were ground-breaking in terms of technology application and provided great leaps and bounds regarding know-how, and, whilst at the time they were constructed in what were considered out-of-the-way places, today many of the plants are now considered as standard. So, which plants are more remote than the others, what makes them more remote and what does the future hold?

In order to address this, and be able to have a quantification of remoteness, the previously mentioned factors can be defined and weighted to provide a numerical indication of remoteness – The **Remoteness Index.**

Table 1 establishes the criteria of the Remoteness Index. The components of this matrix were selected using group discussions and consensus of the more significant factors of an LNG site´s location. It also considers the complete cycle from visualization to operation (merely economic influences like production and processing cost as well as the LNG price have not been considered).

Geographical Remoteness – This encompasses not only distance from either an urban or industrialized centre, but also accessibility. As examples, Yamal LNG is located in the northern part of Russia, in a tundra environment with virtually no infrastructure and extremely complicated access, including seasonal variance, which dramatically affects scheduling. Peru LNG on the other hand is in a sparsely populated desert coastal plain, some 170 km from Lima, the capital, but has very good road access via the Pan American highway, which runs down the coast of the South American Continent. An additional aspect of remoteness applies to Peru LNG - the distance and complex routing of the feed gas field (Camisea) on the other side of the Andes Mountains.

Table 1 Remoteness Index Criteria and Levels (* letters refer to Köppen-Geiger classification)

Remoteness criteria Weighting	Geographical Remoteness 25%	Extreme climatic conditions 15%	Manpower problems 10%	Operational challenges / infrastructure 20%	Technical hurdles 10%	Environmental sensitivity 20%
	Ease of access to site	Climatic classification	Availability of skilled labor	Complexity of operating a plant	Unproven concepts	Site impact
1 low	Uninterrupted access by land, air and sea	Humid moderate climate without dry seasons (Cf*)	Easy access to local skilled labor	No significant operational challenges	none or one non-critical	abandoned area
2 slight	Good land and sea access, occasion-ally no air access	Humid moderate Mediterranean climate, dry winter (Cw, Cs*)	Good basic local labor pool, training required	Minor operational challenges - easily overcome	several non-critical	industrial area
3 average	Temporary access inconveniences via land and air	Cold moderate climate (D*)	80/20 local/import labor	Some operational challenges	one critical	populated area
4 elevated	Extended land and air access interruptions	Tropical climate (A*)	Limited local labor available, depen-dence on import	Significant challenges	several or critical	recreational area
5 high	Severe difficulties, occasional zero access	Dry climate, desert, polar climate (B, E*)	No local labor available, rotational imports only	Severe operational issues, incl. seasonal	several and critical	nature reserve

Extreme Climatic Conditions – The highest and lowest temperatures ever recorded on Earth are respectively +70.6°C (+159.1°F) in Dasht-e Lut, in the Lut desert in South Eastern Iran and −93.2°C (−135.8°F) in Antarctica. The seasonal temperature variation in the Yamal peninsula ranges from 10-15°C in the summer to as low as -25°C in the winter. Temperature variations, rainfall, snow, surface conditions all impact both the construction phases and the operational phases of LNG plants with particular effect on the shipping in the case of Arctic plants.

The Köppen-Geiger climate classification is one of the most widely used climate classification systems. It was first published by Russian German climatologist Wladimir Köppen in 1884, with several later modifications by Köppen himself, notably in 1918 and 1936. Later, German climatologist Rudolf Geiger collaborated with Köppen on changes to the classification system, which is thus sometimes referred to as the Köppen–Geiger climate classification system. The system is based on the concept that native vegetation is the best expression of climate. Thus, climate zone boundaries have been selected with vegetation distribution in mind. It combines average annual and monthly temperatures and precipitation, and the seasonality of precipitation.

A simplified subset of the Köppen-Geiger classification (see Table 2) has been used to quantify the extremity of the prevailing climatic conditions. A world map[4] illustrating the climate zones is shown in Figure 3 World Map of Köppen-Geiger Classification

Table 2 Simplified Köppen-Geiger Classification

Code	Type	Description	Remoteness
A	Tropical climate	Monthly average temperature > 18°C No winter season Strong annual precipitations (higher than evaporation)	elevated
B	Dry climate / Desert	Annual evaporation higher than precipitations No permanent rivers	high
C	Hot moderate climate	Cf (low): humid moderate climate without dry seasons Cw (slight): humid moderate climate with dry winter Cs (slight): Mediterranean climate : humid moderate climate with dry summer	low /slight
D	Cold moderate climate	Coldest month average temperature of the coldest month < -3°C Hottest month average temperature > 10°C The seasons summer and winter seasons are well defined	average
E	Polar climate	Average temperature of the hottest month < 10°C The summer season is very little different from the rest of the year	high

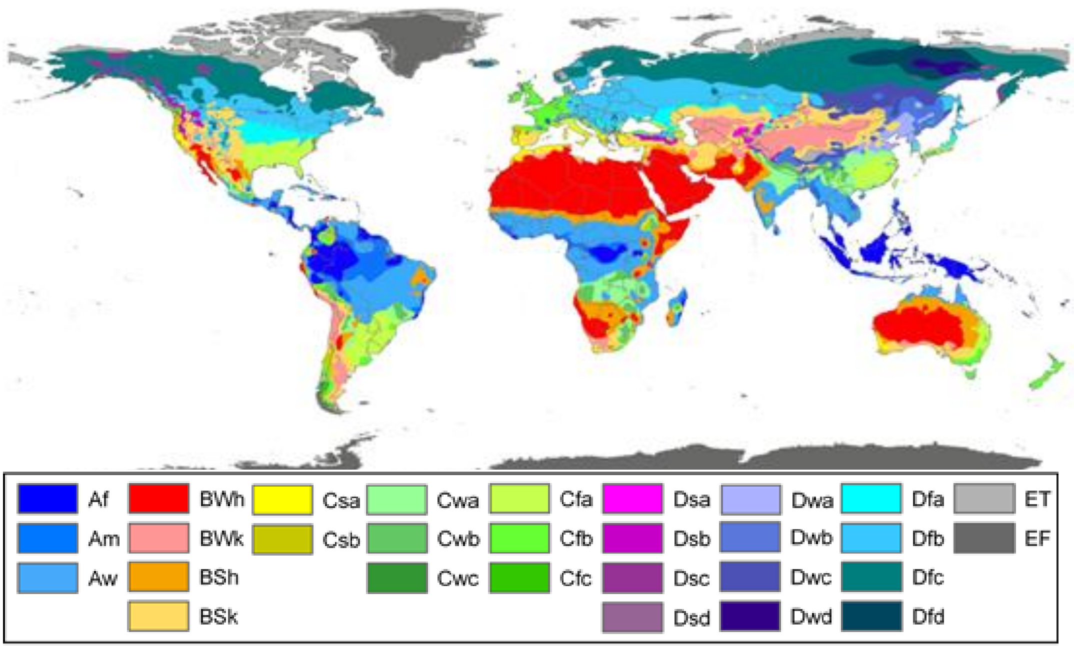


Figure 3 World Map of Köppen-Geiger Classification

[4] Peel MC, Finlayson BL & McMahon TA (2007), Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci., 11, 1633-1644.

Manpower Problems – The majority of LNG plants are using foreign labour which is contracted in. Many times local labour, especially skilled, has been mostly non-existent and is a direct and important implication of the remoteness of a project.

Operational Challenges / Infrastructure – in addition to the isolation and logistics of getting materials and people to the site, it is necessary to consider the unique complexities of constructing and running a complex LNG plant – no two sites are the same. A good example is the distance and topography between the feed gas source and the plant in the case of Peru LNG; the feed gas pipeline had to cross one of the highest mountain ranges in the world.

Technical Hurdles – Different sites, different climates, different feed gas configurations and different export scenarios all present the need for technically viable solutions, and the "technicality" of the project thus is considered a key factor when such challenges are directly due to the remoteness of the site. (Note – it is true that all plants however remote involve ever evolving technological solutions).

Environmental Sensitivity – today there is more focus and concern than ever on the protection of the environment. As projects move into ever-more remote and consequently uninhabited areas of the globe, the fact is that these areas are often deemed environmentally sensitive by default. This is a key factor in the Remoteness Index.

The Remoteness Index serves as an index not only on the geographical isolation of the plant but also on the planning, construction and operational complexities required for such a remote site. This Remoteness Index provides a single and weighted remoteness figure that can be compared from one project to another and which takes into account, not only the "classical" geographical remoteness, but five additional and relevant parameters. A separate criterion based only on installation cost of the plant has not been considered as not enough consistent information is available for this matter.

1 LNG Plants of Today and Tomorrow – How remote are they?

This chapter classifies operational plants, projects under construction and conceptual or non-sanctioned projects and applies the remoteness criteria previously discussed. Analysing the data produced, trends are observed and discussed later in the paper. An up-to-date list (status 2013) of land based LNG plants with a nameplate capacity of at least 1 mtpa of LNG has been compiled and assessed according to the six remoteness criteria, which have been explained in the introduction above.

1.1 Currently operational plants

The first group of LNG plants (Table 3) lists all facilities, which are presently in operation. Mothballed plants (status 2013) are not included.

Table 3 Currently Operational Plants ordered by Remoteness Index

Country	Operational Plants Project Name	Start Year	Geographical Remoteness	Extreme climatic conditions	Manpower problems	Operational challenges	Technical hurdles	Environmental concerns	Remoteness Index
Indonesia	**Bontang LNG**	1977	4	4	5	4	4	5	**4.3**
PNG	**PNG LNG**	2014	5	4	5	3	2	5	**4.2**
Indonesia	**Arun LNG**	1978	4	4	5	4	4	4	**4.1**
Indonesia	**Tangguh LNG**	2009	5	4	5	2	2	5	**4.0**
Brunei	Brunei LNG	1972	4	4	4	3	3	5	**3.9**
Malaysia	MLNG	1983	4	4	4	3	2	5	**3.8**
Equ. Guinea	EG LNG	2007	4	4	5	3	2	4	**3.7**
Norway	Snøhvit LNG	2007	5	3	3	4	3	3	**3.7**
Oman	Oman LNG	2000	4	5	5	3	2	3	**3.7**
Oman	Qalhat LNG	2006	4	5	5	3	2	3	**3.7**
Nigeria	NLNG	1999	4	4	5	2	2	4	**3.5**
Alaska	Kenai LNG	1969	4	3	4	3	3	3	**3.4**
Australia	Darwin LNG	2006	3	4	4	2	2	5	**3.4**
Australia	North West Shelf	1989	3	5	4	2	2	4	**3.3**
Australia	Pluto LNG	2012	3	5	4	2	2	4	**3.3**
Russia	Sakhalin	2009	4	3	3	3	3	3	**3.3**
Peru	Peru LNG	2010	4	5	4	2	1	3	**3.3**
Yemen	Yemen LNG	2009	4	5	5	2	2	2	**3.3**
Trinidad	ALNG	1999	3	4	4	4	3	2	**3.3**
Egypt	SEGAS	2005	3	5	4	2	2	3	**3.1**
Egypt	ELNG	2005	3	5	4	2	2	2	**2.9**
Qatar	Qatargas	1997	3	5	4	2	2	2	**2.9**
Qatar	RasGas	1999	3	5	4	2	2	2	**2.9**
UAE	ADGAS LNG	1977	3	5	4	2	2	2	**2.9**
Algeria	Arzew	1978	2	2	3	4	5	2	**2.8**

Algeria	Skikda	1972	2	2	3	4	5	2	**2.8**

1.2 Plants under construction

The second group (Table 4) includes all LNG export projects, where FID has been taken, but which are not yet in operation at the time of writing the report (2013).

Table 4 Plants under construction ordered by Remoteness Index

Country	Plants under Construction Project Name	Start Year	Geographical Remoteness	Extreme climatic conditions	Manpower problems	Operational challenges	Technical hurdles	Environmental concerns	Remoteness Index
Russia NW	**Yamal LNG**	2020	5	5	4	4	3	3	**4.1**
Indonesia	**Donggi-Senoro LNG**	2014	5	4	5	2	2	5	**4.0**
Australia	Gorgon LNG	2015	3	5	4	3	3	5	**3.8**
Australia	Wheatstone LNG	2016	3	5	4	3	3	5	**3.8**
Angola	Angola LNG T1	2013	4	4	4	3	3	4	**3.7**
Australia	Ichthys LNG	2017	3	4	4	3	3	5	**3.7**
Australia	AP LNG	2015	3	2	4	4	3	5	**3.6**
Australia	Gladstone LNG	2015	3	2	4	4	3	5	**3.6**
Australia	Queensland Curtis	2014	3	2	4	4	3	5	**3.6**
Algeria	Arzew GL3Z	2014	2	2	3	2	1	2	**2.0**
Algeria	Skikda Rebuild	2013	2	2	3	2	1	2	**2.0**
US	Sabine Pass	2015	1	2	1	2	1	2	**1.6**

1.3 Proposed plants

The last group (Table 5) shows LNG export projects that are planned with various levels of maturity. Projects with an estimated start-up date later than 2020 are often considered speculative.

Table 5 Proposed plants ordered by Remoteness Index

Country	Proposed Plants Project Name	Start Year	Geographical Remoteness	Extreme climatic conditions	Manpower problems	Operational challenges	Technical hurdles	Environmental concerns	Remoteness Index
Alaska	**Alaska LNG**	2023	4	5	4	4	4	5	**4.4**
PNG	**Gulf LNG**	2021	5	4	5	3	2	5	**4.2**
Indonesia	**Natuna D Alpha**	2025	3	4	4	4	5	5	**4.1**
Mozambique	Mozambique LNG	2019	5	4	5	2	2	3	**3.6**
Tanzania	Tanzania LNG	2021	5	4	5	2	2	3	**3.6**
Australia	Arrow LNG	2020	3	2	4	4	3	5	**3.6**

Cameroon	Cameroon LNG	2020	4	4	5	2	2	4	**3.5**
Nigeria	Brass LNG	2020	4	4	5	2	2	4	**3.5**
Australia	Browse	2020	3	5	4	2	2	4	**3.3**
Russia E	Vladivostok LNG	2022	4	3	3	3	3	3	**3.3**
Iraq	Iraq LNG	2030	3	5	3	3	2	3	**3.2**
Canada W	Kitimat LNG	2020	4	2	4	2	3	4	**3.2**
Canada W	LNG Canada	2020	4	2	4	2	3	4	**3.2**
Canada W	Pacific NW LNG	2020	4	2	4	2	3	4	**3.2**
Canada W	Prince Rupert LNG	2021	4	2	4	2	3	4	**3.2**
Libya	Marsa El Brega	2022	2	2	4	2	2	2	**2.2**
US East	Cove Point Export	2019	1	3	1	1	1	3	**1.7**
US East	Corpus Christi LNG	2021	1	2	1	1	2	2	**1.5**
US East	Cameron LNG	2018	1	2	1	1	1	2	**1.4**
US East	Freeport Export	2018	1	2	1	1	1	2	**1.4**
US East	Golden Pass LNG	2019	1	2	1	1	1	2	**1.4**
US East	Gulf Coast LNG	2022	1	2	1	1	1	2	**1.4**
US East	Gulf LNG Energy	2020	1	2	1	1	1	2	**1.4**
US East	Lake Charles	2019	1	2	1	1	1	2	**1.4**
US East	Southern LNG	2017	1	2	1	1	1	2	**1.4**

1.4 Highly remote plants

In the last table (Table 6) all LNG plants with a Remoteness Index equal to or higher than 4.0 are jointly listed. This gives a first impression of really remote locations, which can be found in South-East Asia and in the Arctic regions of the US and Russia.

Table 6 Highly Remote Plants ordered by Remoteness Index

Country	**Highly Remote Plants** **Project Name**	**Start Year**	**Geographical Remoteness**	**Extreme climatic conditions**	**Manpower problems**	**Operational challenges**	**Technical hurdles**	**Environmental concerns**	**Remoteness Index**
Alaska	**Alaska LNG**	2023	4	5	4	4	4	5	**4.4**
Indonesia	**Bontang LNG**	1977	4	4	5	4	4	5	**4.3**
PNG	**PNG LNG**	2014	5	4	5	3	2	5	**4.2**
PNG	**Gulf LNG**	2021	5	4	5	3	2	5	**4.2**
Indonesia	**Arun LNG**	1978	4	4	5	4	4	4	**4.1**
Russia NW	**Yamal LNG**	2020	5	5	4	4	3	3	**4.1**
Indonesia	**Natuna D Alpha**	2025	3	4	4	4	5	5	**4.1**
Indonesia	**Tangguh LNG**	2009	5	4	5	2	2	5	**4.0**
Indonesia	**Donggi-Senoro LNG**	2014	5	4	5	2	2	5	**4.0**

Using all data from the tables above, an average ranking of the countries and regions can be extracted (see Figure 4). Low Remoteness Indices (<3.5) can be found mostly in North America and in Mediterranean countries. Moderate Remoteness Indices (<3.7) prevail in countries close to the Equator except for South-East Asia, where significant environmental concerns add to manpower problems.

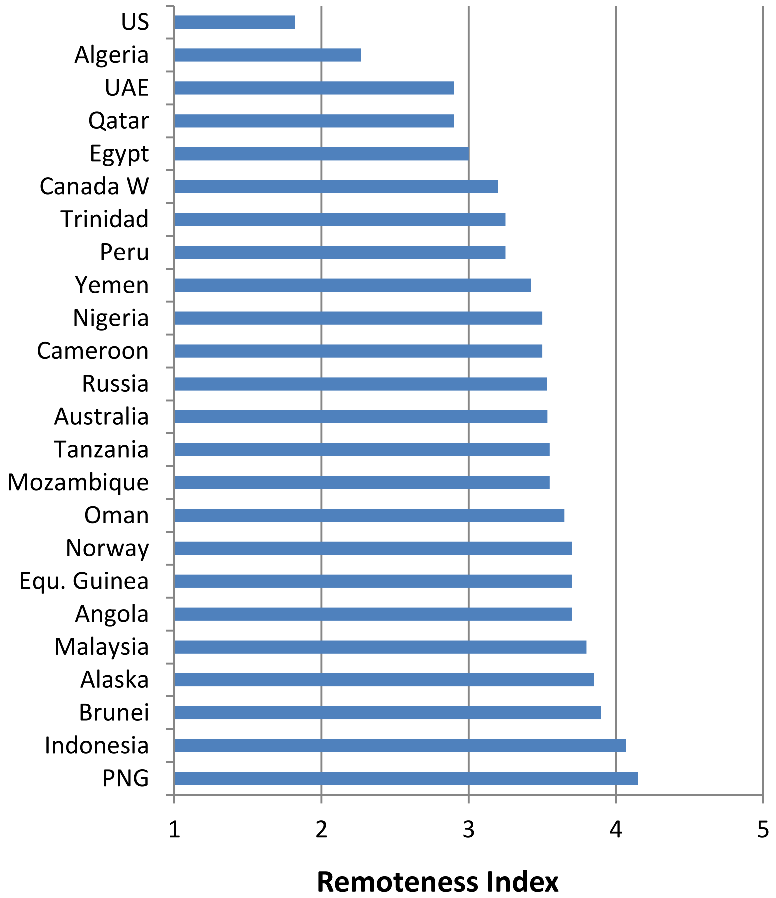


Figure 4 Average Remoteness Index for Different Countries

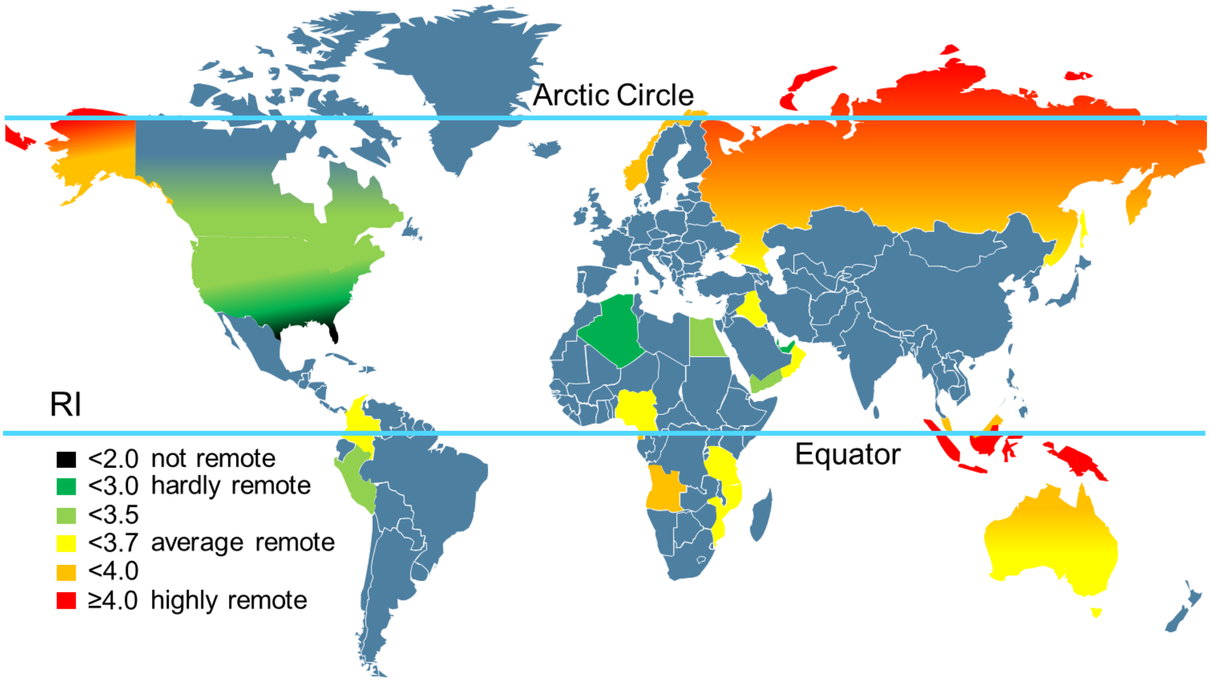


Figure 5 Remoteness Index World Map

1.5 Statistical analysis of Remoteness Index

One might expect to see a clear dependence of the Remoteness Index from the start-up year as easy gas may have been produced earlier leaving difficult gas for newer sites. This assumption is not supported by the analysis of the data shown in Figure 6. Obviously a Final Investment Decision (FID) had been taken over the decades as soon as the project was technically and commercially viable. Extremely expensive or risky projects (like e.g. Shtokman LNG) are not considered as viable today. A detailed analysis of the Remoteness Index versus LNG plant or train size did not disclose a statistically meaningful correlation.

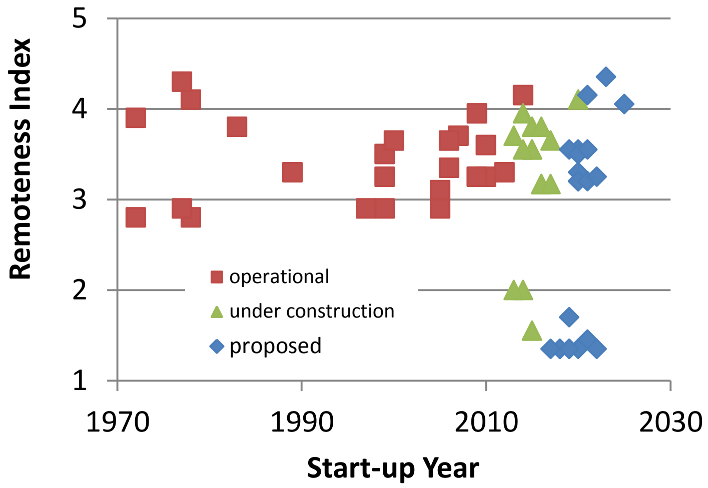


Figure 6 Correlation between Start-up Year and Remoteness Index

However, when plotting the number of sites with a certain Remoteness Index (Figure 7) a clear trend can be observed. While the distribution of the Remoteness Index was quite narrow in a band between 3 and 4, which can be nicely fitted with a Gaussian distribution, some new projects, especially in the US do not follow the former trend. After successfully refining production methods like fracking and gas collection from many wells, low cost US shale gas has triggered a series of new projects with surprisingly low Remoteness Indices. It should be noted that a 50% percentile of the Remoteness Index has a value of 3.1 not 3.0 due to the uneven statistical distribution of the Remoteness Index for the overall data set of LNG projects.

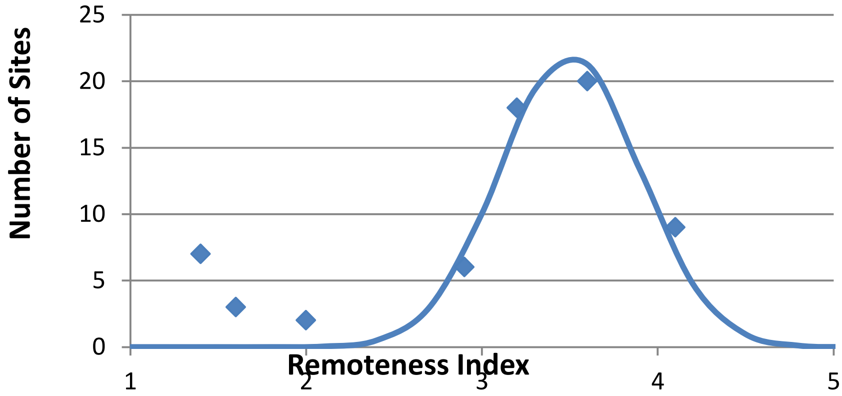


Figure 7 Statistical Distribution of the Remoteness Index

2 LNG Outlook/New Frontiers/Future Trends

As discussed in chapter 1, future LNG projects will have a wide distribution for their Remoteness Indices. At the lower end of the range are a number of proposed US Gulf LNG export projects with a Remoteness Index in a band between 1-2. This chapter will focus on the LNG outlook and its impact on future LNG projects with a look into some of the new frontiers. At the end it will discuss trends appearing in Remoteness Index.

2.1 LNG Outlook

Like any commodity, technology plays a big part in the LNG market. Over the past decade it can be observed that the industry geared up to supply the expected shortfall of gas to come in the U.S. with around 390 mtpa of import capacity proposed in 2007. Fast forward to three years later when the first US export application was filed in 2010 as the success of shale gas and the technology to unlock this resource at a low cost started to become apparent. Now, the US is no longer expected to be one of the major importers of LNG by 2020 (see Figure 8) but instead a major exporter of LNG by 2020 (see Figure 9).

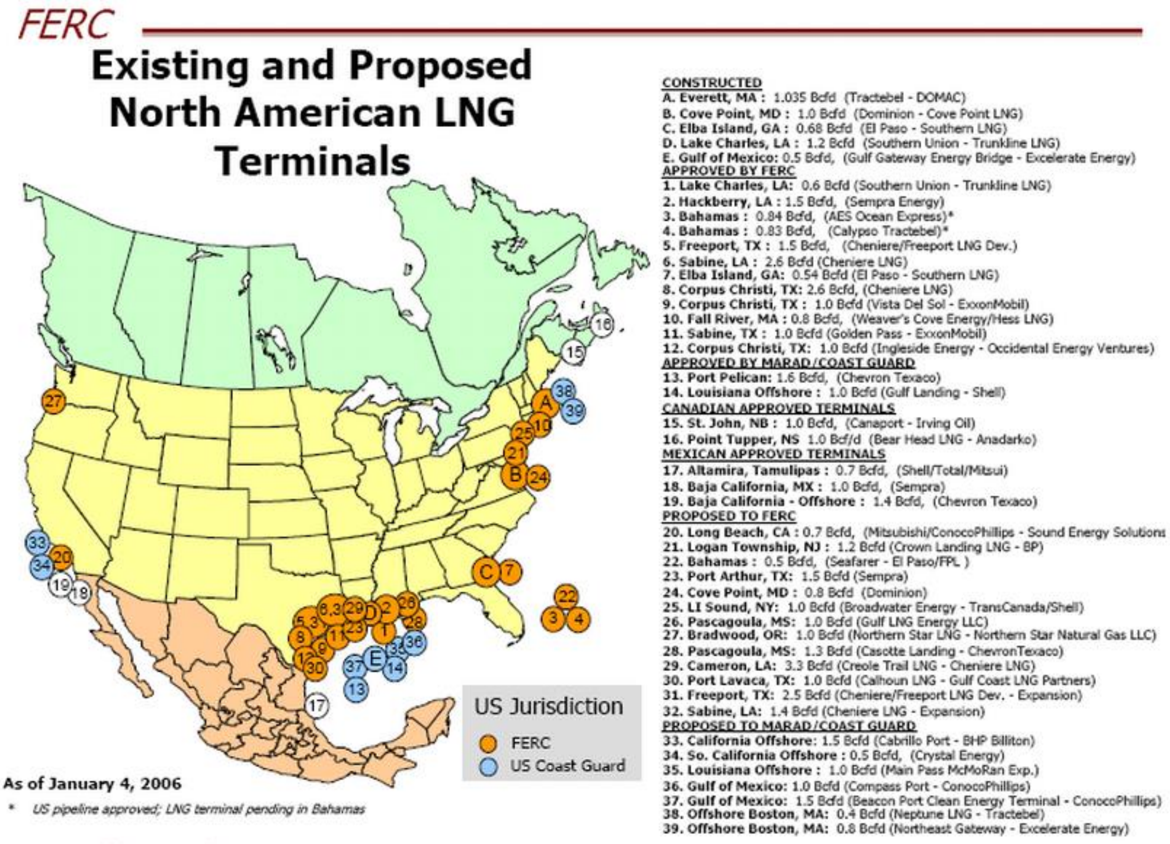


Figure 8 Existing and Proposed North American Receiving LNG Terminals

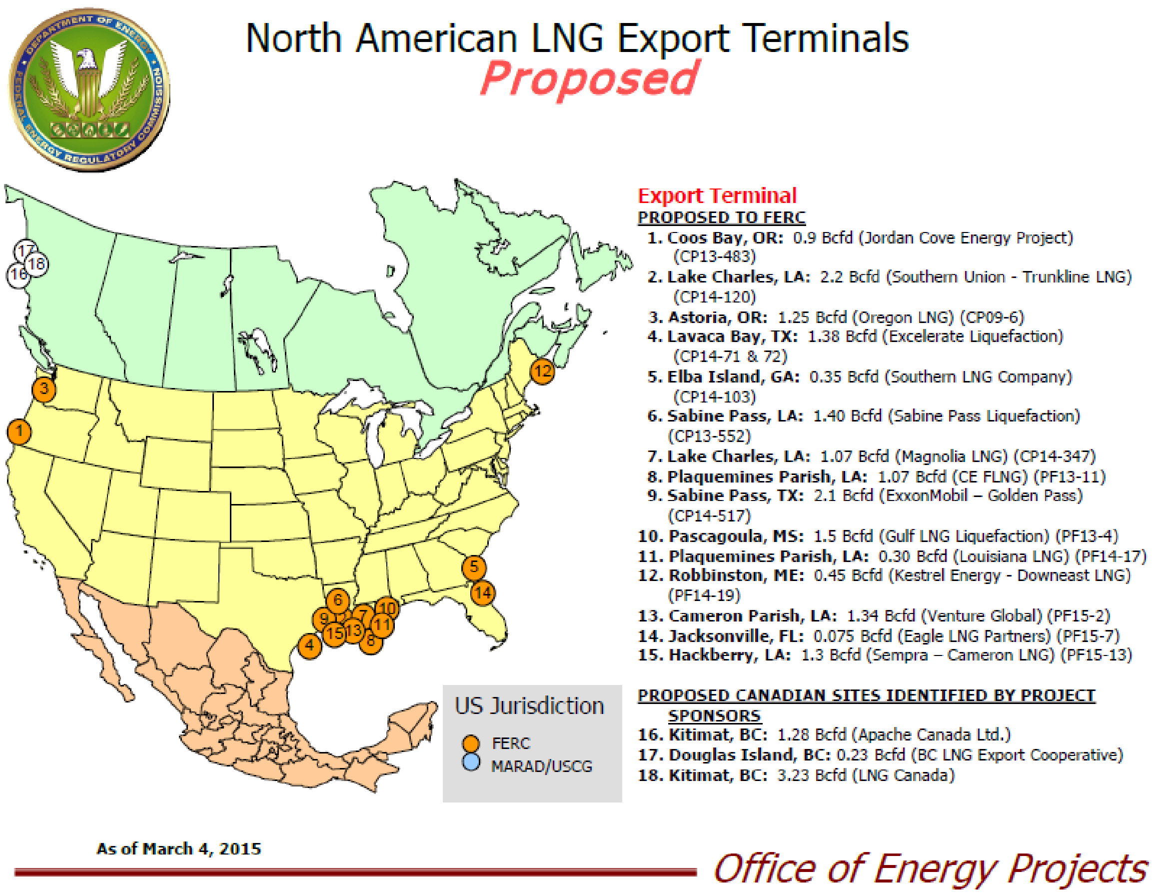


Figure 9 Proposed North American Export LNG Terminals

The US is not the only resource being unlocked with new technology (E&P, midstream to downstream). Other examples are Arctic Russia, West Coast Canada, East Africa, and deep-water Australia. Improvements in technology are allowing companies to consider LNG production in areas previously thought to be too challenging and too costly. However, while technology makes a project feasible, it's the price markets are willing to pay which makes a project actually happen (come to fruition). Over the past few years the industry has seen an ever growing appetite for LNG in Asia, the Middle East and Latin America. (Figure 10). In some markets this is due to domestic decline in gas production, in others its due to demand as they look to switch from more expensive fuels such as diesel, and in others its due to demand growth as policy forces a switch to cleaner fuels that are better for the environment. It's the price the markets are willing to pay that allow for these new frontier projects to become a reality.

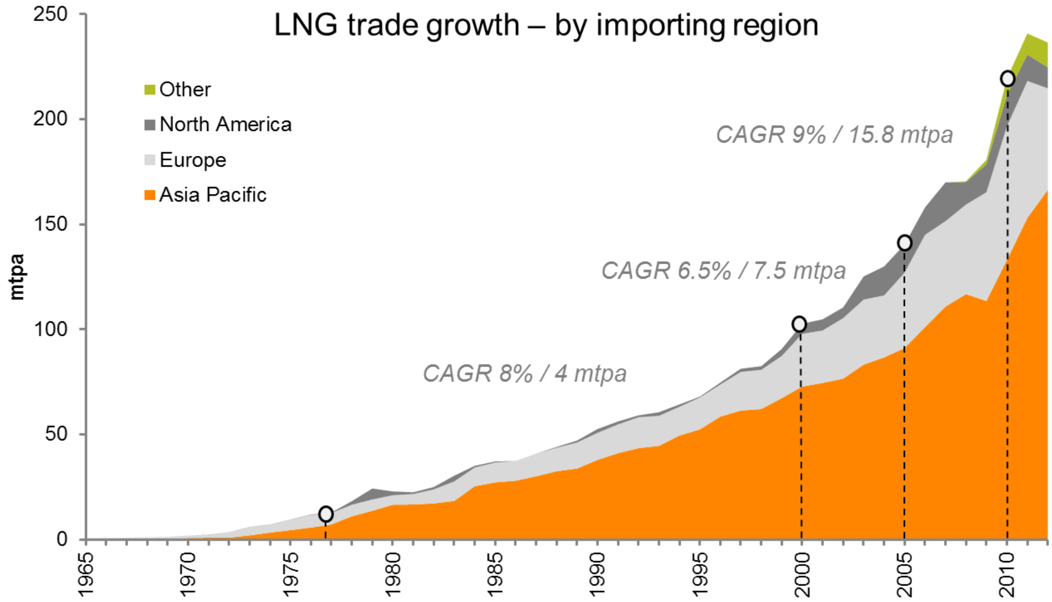


Figure 10 LNG Trade Growth by Import Region[5]

What drives the LNG industry to such remote areas?

LNG has traditionally been an industry that takes stranded gas to the markets that need it. Looking forward over the next decade there is a supply gap of approximately 150 mtpa that needs to be filled with new supply yet to be identified. Refer to Figure 11. One area that's expected to fill some of this gap is the US – the same country once expected to be a major importer in the same time frame. The US is a less traditional LNG play where gas is being taken from a well-developed market -- and responsible for most of the outlier future projects on our Remoteness Index. However, buyers want diversity of supply and sellers will do a project with the proper amount of return so therefore projects in other countries have an opportunity to come on-stream. The areas that are currently at the forefront are the remote areas of Canada and East Africa, with Alaska further off in the distance.

[5] Source: Wood Mackenzie

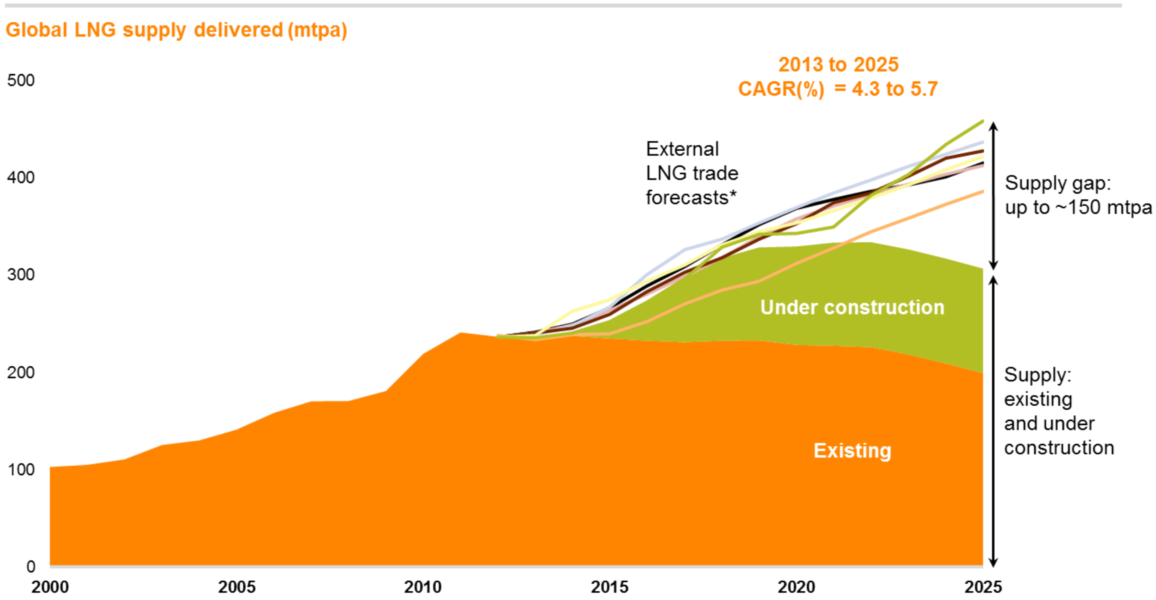


Figure 11 Global LNG Supply Delivered (mtpa) [6]

LNG prices have been on the rise over the past few years along with other commodity prices as the marginal cost of supply increases and there is enough demand for energy to support the prices needed to develop these more costly resources. Refer to Figure 12. Areas that have options for cheaper LNG based on low cost gas from associated oil production and no significant construction or operational issues can have other hurdles that to date have kept LNG suppliers hesitant to build new or expansion projects there. LNG suppliers then seek out other options and those left tend to be the more challenging, more remote options because most of the easier options have already been done.

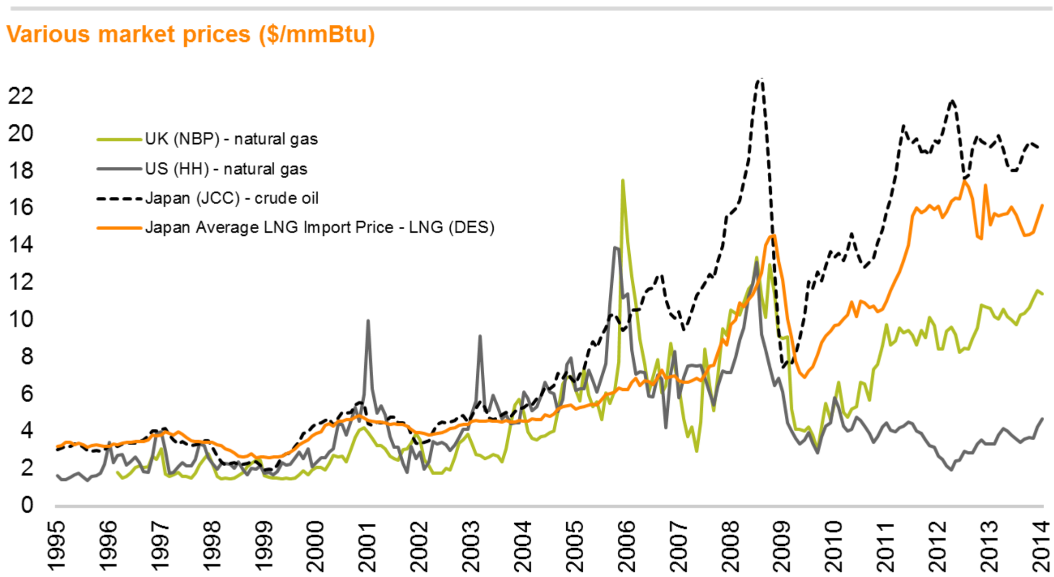


Figure 12 Various Market Prices [7]

[6] Source: Wood Mackenzie

These remote areas are not without their (higher) costs, but over the past decade there was a rise in LNG prices that can support projects previously considered uneconomic. Chevron kept Gorgon for a number of years before taking FID on September 2009 after signing several oil indexed contracts. The technology behind shale gas has made Canadian gas at the field relatively cheap; however the long pipelines and associated liquefaction plants are a far bigger cost item in the chain than the production costs at the wellhead. Although Alaska gas is associated gas produced at a low cost it still requires a very costly pipeline crossing around 1300 kilometres. These multi-billion dollar projects will not go forward if buyers do not have the demand for the LNG at the required price. If the demand at that price is not there as currently the industry expects, it could happen that another decade goes by before some of these projects are sanctioned. The president of Chevron's Canadian arm was quoted saying 'Chevron requires a stable price and long-term contracts that provide an acceptable return on investment' – highlighting that these future projects will require the right return on investment before sanctioning. In the current low oil price environment, with costs of construction yet to respond, this adds more uncertainty to future LNG projects and when they will be able to take a final investment decision.

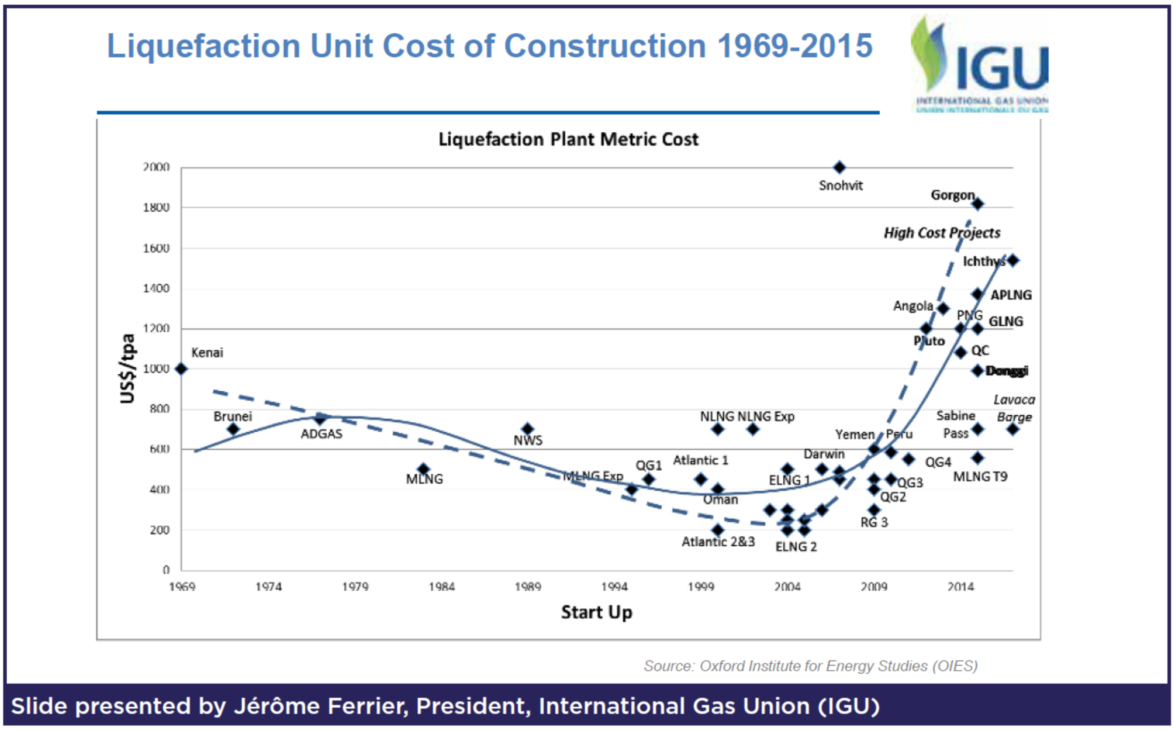


Figure 13 Liquefaction Unit Cost of Construction

Figure 13, previously presented by the president of the IGU Jérôme Ferrier, shows how the liquefaction unit cost of construction has evolved over the years. As described in chapter 1 there is a low correlation between the Remoteness Index and Start-up year of the LNG project. However, it is interesting to note that between the first LNG plant (starting up in 1964) and plants commissioned up to 2010, with the exception of Snøhvit, the unit costs per mtpa were in a relatively narrow band. Since 2010, there

[7] Source: Wood Mackenzie

has been a significant escalation of unit costs for certain proposed projects, particularly those nearing start-up in Australia, while at the same time US projects under construction such as Sabine Pass have managed to remain within the historical unit cost band. While the US export projects rank very low on the Remoteness Index (1.4), the more expensive Australian projects have a RI of only 3.6. Nevertheless this is significantly less than some projects that have preceded them. While certain remoteness criteria clearly do have an impact on a projects overall costs, other factors also have a very large impact on a particular projects costs. With reference to chapter 1 and above Figure 13 clear correlation between remoteness and cost looks as likely to be as absent for future projects as has been the case up until now.

2.2 New Frontier Alaska LNG

Over the past 40 years, several attempts have been made to monetize the stranded gas reserves of the Alaska North Slope gas fields. Several pipeline projects to the L48 US market have been proposed, as well as earlier LNG export initiatives. However, the cost of each of these proposals always continued to be a stumbling block, at a time when there were cheaper alternatives for consuming markets. As discussed above in the LNG outlook a new global gas demand gap coupled with higher gas prices have prompted the major stakeholders to pursue a new initiative; the Alaska LNG project.

The Alaska LNG export project would be among the world's largest and most expensive natural gas-development projects. At 4.4 on the Remoteness Index, the project also ranks as the most remote LNG project ever undertaken. The size, scope and location of this project will present the project partners with a wide range of challenges. Refer to Figure 1 of this report.

Project Overview: The sponsors are North Slope producers ExxonMobil, ConocoPhillips and BP, as well as pipeline company TransCanada and the state of Alaska. The companies estimate a cost of $45 billion to more than $65 billion (2012 dollars) for a project that includes a massive plant to cleanse produced gas of carbon dioxide and other impurities; an approximately 800-mile pipeline from Alaska's North Slope to the liquefaction plant; and an LNG plant, storage and shipping terminal at Nikiski, 60 air miles southwest of Anchorage along Cook Inlet.

Gas Production and LNG Treatment Plant: Despite its geographic remote location, the Alaska North Slope already benefits from existing infrastructure from current oil production facilities. However, due to its size, the construction of the huge gas treatment plant will pose challenges to the project, and may require certain aspects of the facility to be pre-fabricated and shipped to its final location. Located on a 200 acre site on the North Slope and requiring more than 250,000 tons of steel, this part of the project will be constructed in the harshest environment as measured by the Köppen-Geiger climate classification, and the project has been ranked a 5 on the Extreme Climactic Conditions RI criteria as a result.

Gas Pipeline: The proposed pipeline would run 1300 km from Point Thompson to Nikiski. However, it is not just the length that will make construction of the pipeline difficult. The partners will face similar challenges to the ones faced when building the existing Trans-Alaska Pipeline System oil pipeline along a similar route. Extreme cold, difficult terrain, remote locations and permafrost will require particular construction techniques to be used. Construction may also not be possible year round, with access restricted in the winter months in some locations. However, proven technologies and experience of constructing pipelines in this region mean that the pipeline construction contributed to an overall ranking of 4 on both the Operational Challenges and Technical Hurdles RI criteria.

The Liquefaction Plant: The liquefaction plant is likely to be the most expensive part of the project. Consisting of three LNG trains, the plant will have a capacity of up to 22 mtpa. While climatic conditions may be less of an issue than on the North Slope itself, a majority of the resources including people required to construct the plant and docks will need to be shipped in from a significant distance. Indeed, the project will require the construction of the equivalent of a new town nearby just to support the construction work force. This contributed to a ranking of 4 on the Manpower Problems RI criteria.

Figure 14 Alaska Liquefaction Plant – Artist Impression

Conclusion: A combination of technical, climatic, and geographic challenges mean Alaska LNG would be one of the most complex and remote LNG projects ever undertaken. The length and terrain of the required pipeline adds to the complexity, and there will be significant environmental concerns that will arise, resulting in a ranking of 5 on the Environmental Concerns RI criteria. Together these remoteness criteria provide an overall Remoteness Index ranking of 4.4. Combine this with the current price tag of $45-$65B, and it will set a new benchmark for remote LNG.

2.3 New Frontier Western Canada LNG

The huge gas resources in Western Canada are attracting several companies into the region to explore a range of LNG export projects. Several proposed projects include Kitimat LNG, LNG Canada, Prince Rupert, and Pacific NorthWest LNG. Proven project sponsors such as Shell and BG have joined forces with major buyers in Asia, including China and Japan, setting Western Canada up as a potential major player in future LNG supply.

Projects Overview: A majority of the 15 currently proposed projects along Canada's West Coast are looking at sourcing their gas from either the Horn River basin or the Montney basin. Both of these shale resources are over 800 km from the coast and behind the Rocky Mountains. Once the gas gets to the coast there are limited locations where it is suitable to build a standard size LNG plant, which is why a majority of the large projects are located in two areas – Kitimat and Prince Rupert. (Refer to Figure 15). Aside from the pipeline and liquefaction site the projects will face other challenges like getting First Nations agreements in place and sourcing the appropriate skilled labour.

Figure 15 Proposed Canada West Coast LNG Sites

Remoteness Assessment: While there are several challenges to these projects linked to remoteness, the overall remoteness index for these projects is lower than one might expect at 3.2 This includes an assessment of the challenge of transporting the gas 800 km across extreme terrain, including the Rocky Mountain range where the pipelines will go up to 3000 m, giving the projects a ranking of 4 on the Geographical Remoteness RI criteria.

Climatic conditions at the proposed sites for the liquefaction plants however are moderate, and no major operational challenges are expected once the plants are operating, giving a ranking of 2 on both the Extreme Climatic Conditions and Operational Challenge RI criteria. Of more concern will be the environmental considerations. The pipeline projects are acutely aware of the need to work with the First Nations groups to proactively manage and mitigate various environmental concerns. There is wildlife including caribou, moose and grizzly bears in many of the areas that the pipeline (Figure 16) will run through. Work is already underway to identify sensitive areas and plan conservation measures. Given that the pipeline stretches over 800 km, this will be a major undertaking. Due to these challenges, the Western Canada projects have a ranking of 4 on the Environmental Concerns RI criteria.

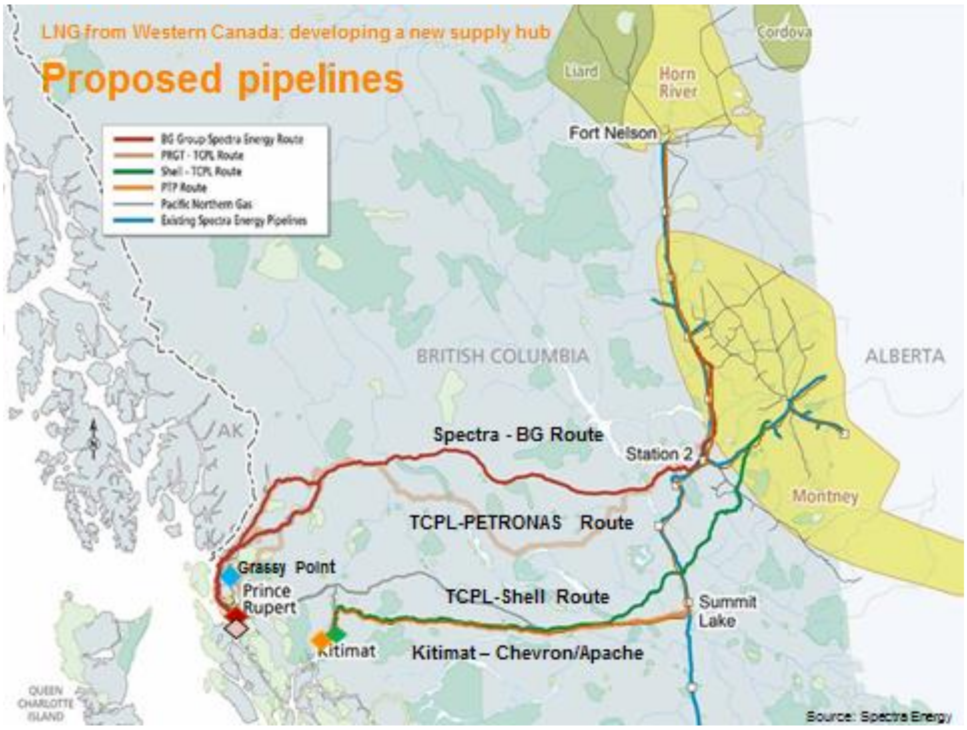


Figure 16 Western Canada Proposed Pipelines

The other significant challenge the projects will face in the context of remoteness is Manpower Problems, which ranks 4 on the RI criteria. As with the LNG liquefaction plant for the Alaska LNG project, there is not a large local population from which to draw labour and expertise. The area is serviced by a small airport, with links to the International airport at Vancouver. However, the Pacific NorthWest project estimates that it will require 4,500 construction jobs alone. The logistical challenge of importing and accommodating this volume of workers, while not a unique problem faced by major projects, should not be underestimated.

Conclusion: While there are some significant remoteness challenges that will need to be addressed, including the Geographical Remoteness of the pipeline and the Manpower Problems, the Western Canada LNG projects generally rank among the less remote LNG projects undertaken. However, with several projects all targeting the same small region for their export plants, competition for scarce resources could make the remoteness challenges more acute. Problems can arise when multiple LNG projects try to proceed in relatively close proximity, as in the case of other locations such as East Australia. However there could be an advantage to those projects which reach FID first.

2.4 Future trends

LNG plants over the past half century have been based on stranded gas, with ever increasing train sizes for economies of scale, and located in coastal locations since the key to LNG is putting it on a ship for transportation. However, recently, some new models are emerging: the US export projects are based off a deep existing gas market whose gas is anything but stranded; small scale technology is improving making the economics of smaller trains more competitive with large trains; technology and an interest to monetize gas stranded long distances from the coast has LNG projects linking up with mega pipeline projects. Over the years improvements in technology has the industry moving to fit for purpose plants.

New LNG projects are looking at more remote locations than ever before. However the Remoteness Index has shown that LNG has always been remote for its time – it is an industry that seeks to monetize stranded gas, which on average tends to be in remote locations.

The US has offered an anomaly where there is a large gas market with even larger gas resources; it is valuable to export gas. Is this the future for LNG or will LNG return to its trend of stranded gas in remote locations?

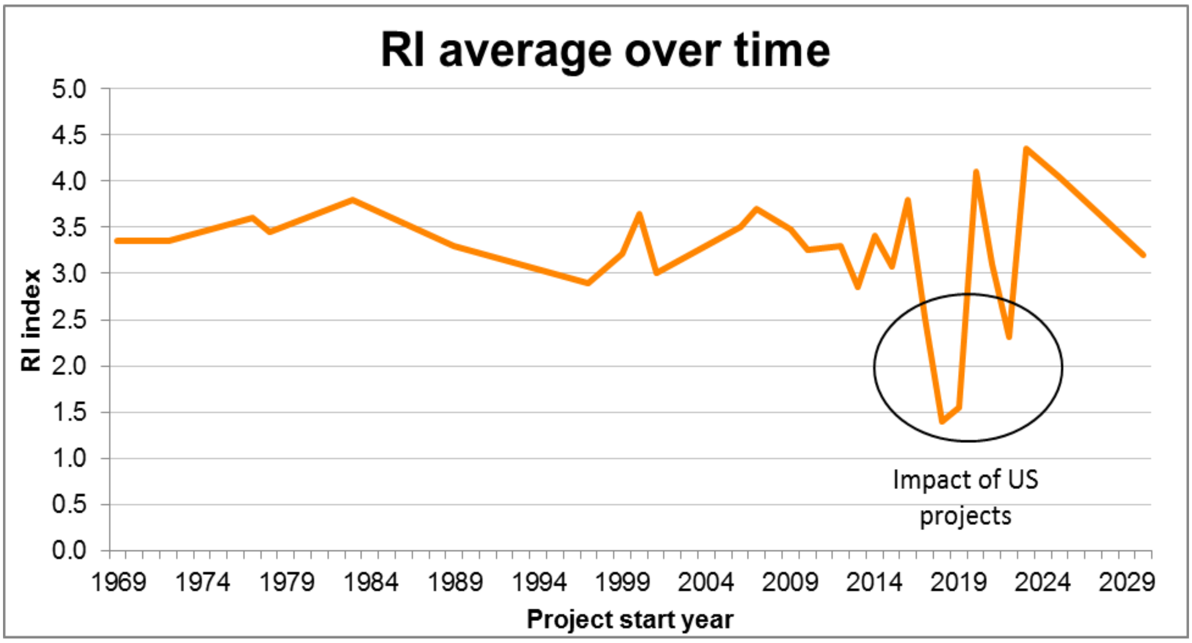


Figure 17 Remoteness Index Average over Time

As can be seen in the chart above (Figure 17) LNG projects have on average been high on the Remoteness Index. Stranded gas is generally in remote areas and that is why the projects have been monetized via LNG instead of pipe gas or domestic gas.

The US has pulled down the average of the RI over the period 2015 to 2022, however with many of the other new projects currently being proposed outside of the US – Canada, East Africa, Alaska – the Remoteness Index is pulled back up post 2022. This suggests that the US has not altered the trend for the average new developments, and LNG projects of the future will be much like those of the past – remote. And as new technology arises and more resources are found LNG will continue to push into the remote regions of the world as long as the demand for LNG is there.

Across the various components of the Remoteness Index there are varying trends. The geography indicator has largely remained in the same range with a jump down (Figure 18) being attributable to the US export projects and a return to trend with the Canada and East Africa projects to follow. As mentioned earlier, LNG has traditionally been about monetization of a stranded resource which tends to be at a distance from urban centres and infrastructure, so it makes sense that the index would remain much the same over time with the US being an outlier.

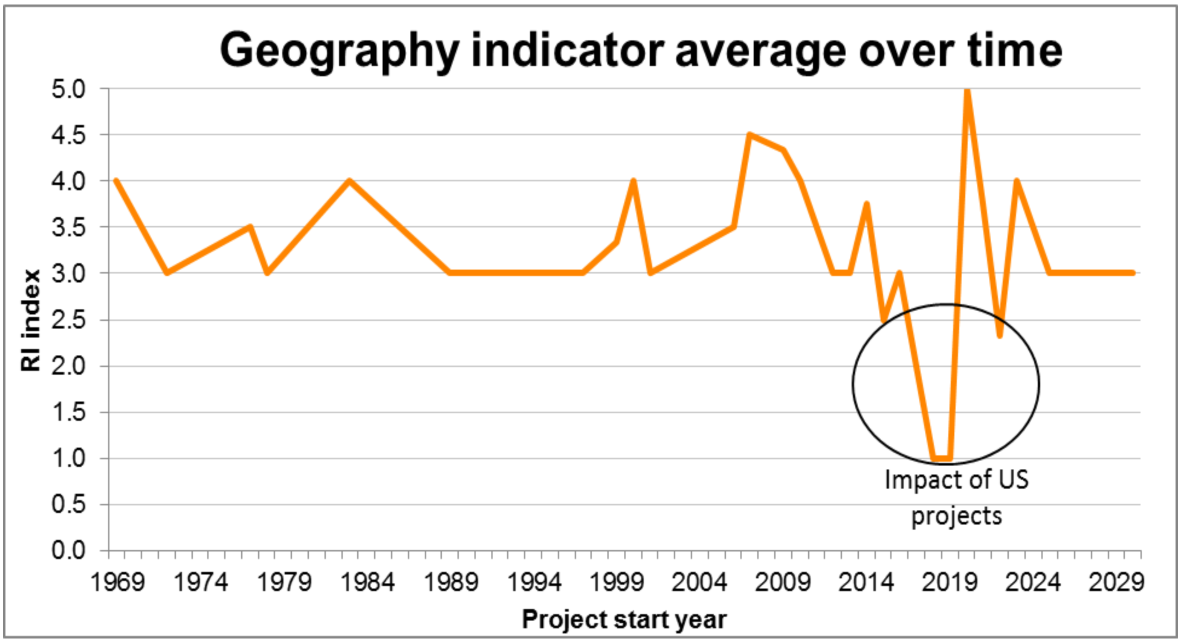


Figure 18 Geography Indicator Average over Time

Manpower is the only indicator that has a noticeable trend down (Figure 19) – possibly as it gets better in general at adding skilled labour to the industry and thereby improving the overall skilled resource as a whole.

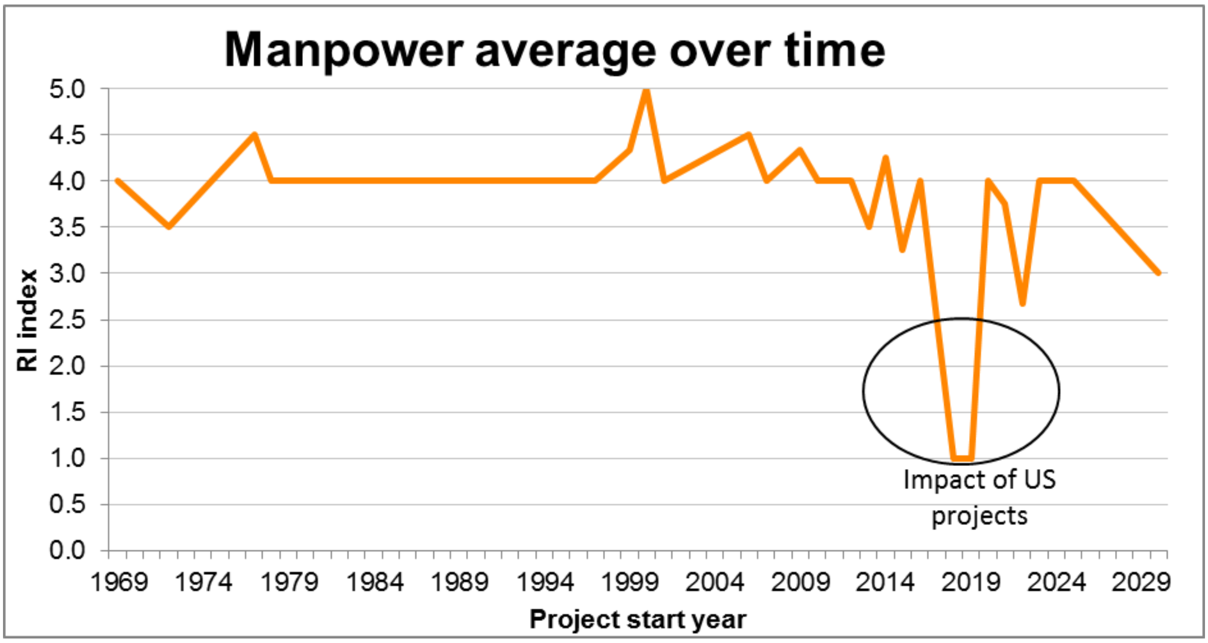


Figure 19 Manpower Average over Time

Meanwhile, in terms of operational challenges and technical challenges (Figures 20, 21), the gains made in the RI seem to be taken away as those resources are produced and the industry moves on to ever more challenging opportunities. It's a cycle where the easily recoverable assets tend to be done first, then as the technology and operational capability are improved new frontiers are found and become viable. And as new improvements are done at these frontiers and exhaust these frontiers then next new frontiers can be opened.

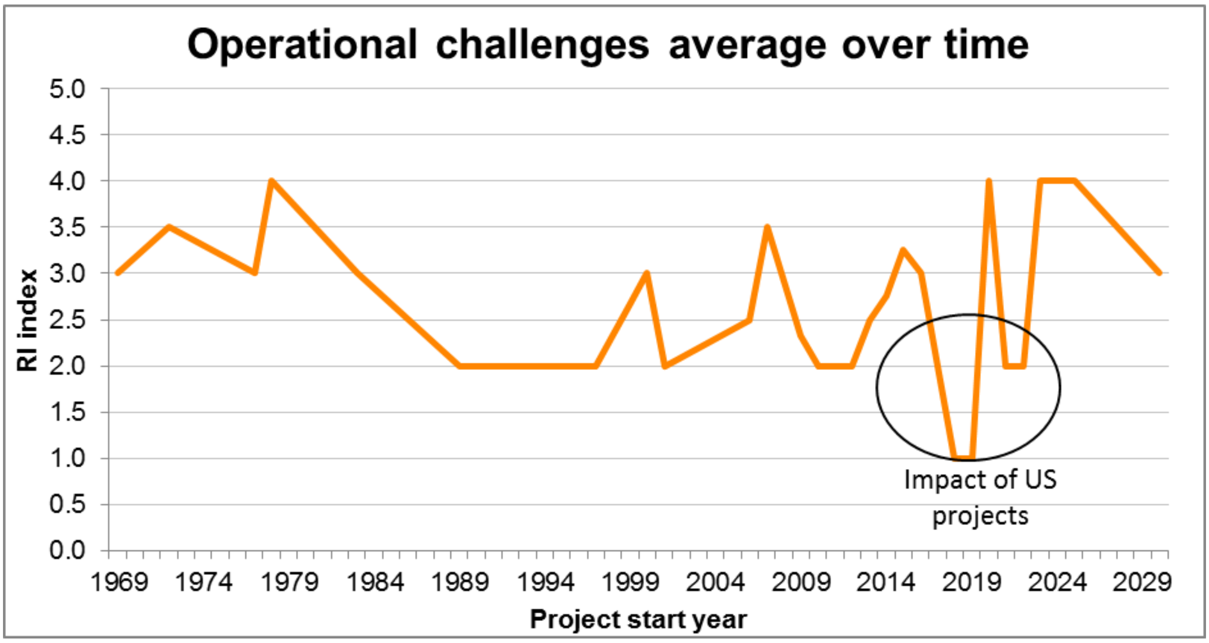


Figure 20 Operational Challenges Average over Time

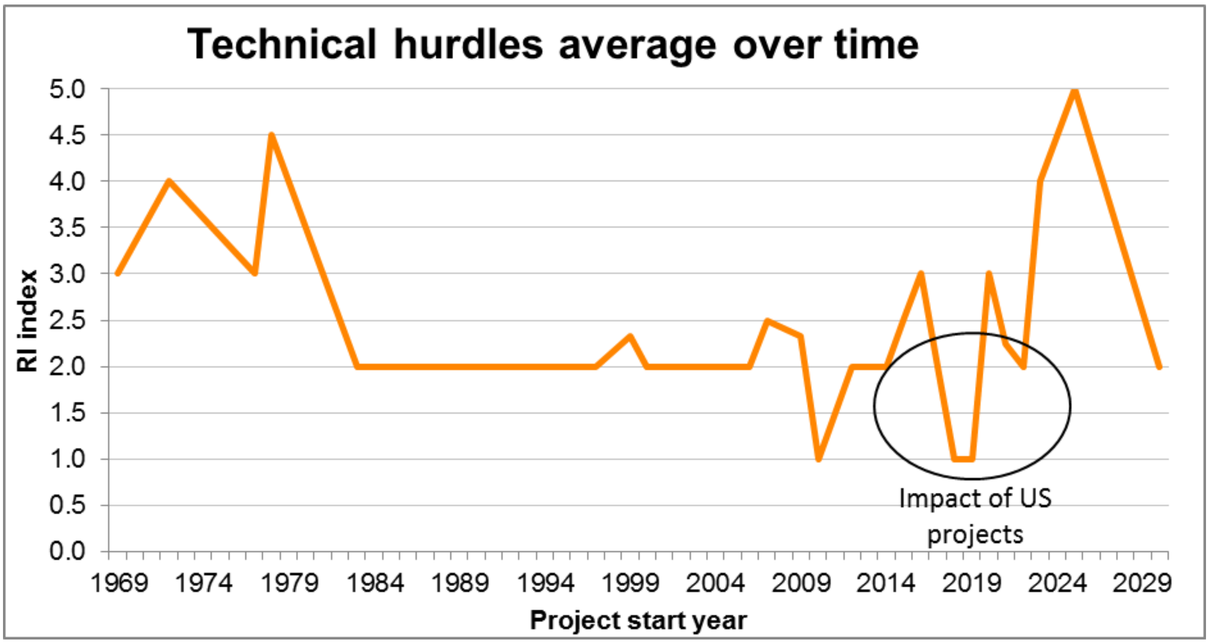


Figure 21 Technical Hurdles Average over Time

Where will LNG plants of the future be located?

It will depend on various factors: location of yet to find resources; technological developments; and most importantly the economics of the project. More than likely the yet to find resources will largely be where the current resources are (see Figure 22).

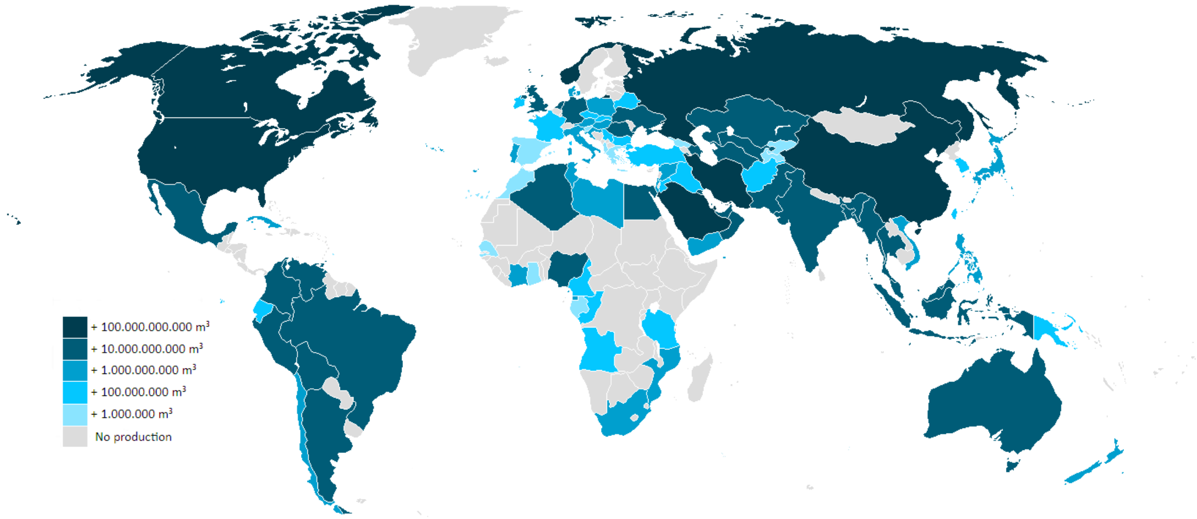


Figure 22 Location of World Gas Resources

However with technology improvements anything is possible for the future and those plants will come with their own challenges. Japan is looking at methane hydrates and Figure 23 gives an indication of where technological success around methane hydrate recovery could take future LNG plants – Antarctica, the middle of the Pacific Ocean, or further into the Arctic than Yamal.

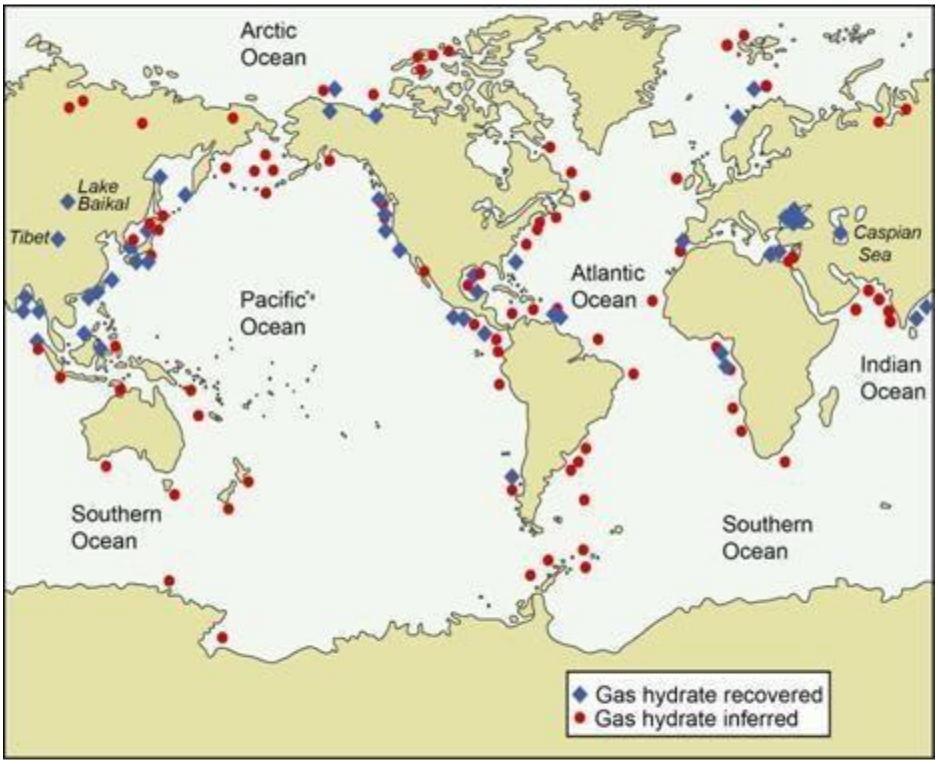


Figure 23 Location of Gas Hydrates

3 New Frontier Technical Aspects - Arctic Projects

3.1 Definition of Arctic and cold continental climate

LNG projects above the Arctic circle and in cold continental climates (refer to Köppen-Geiger) face enormous challenges, principally related to the hostile & harsh environment, extreme temperatures, hostile wind, poor soil conditions, with snow and ice. These challenges are common to these projects.

Up until now, the majority of base-load LNG facilities have been either in tropical or desert regions of the world, with only two LNG projects having been completed in Arctic and cold climatic conditions in the past decade, i.e.: Snøhvit and Sakhalin.

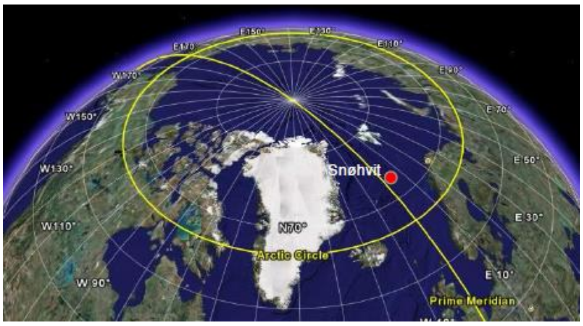


Figure 24 The Arctic Region

This chapter is not project specific, but based on the current operational projects mentioned above and future projects like Yamal, Alaska LNG, and Western Canada LNG. Some of the shared challenges are:

- Extensive planning phase
- Arctic project requirements
- Engineering and design considerations for Arctic conditions
- Liquefaction technology selection for Arctic conditions
- Logistics
- Construction
- Operations and maintenance
- Environmental impact and social responsibility

The following table summarizes the LNG projects to be discussed:

Project	Location	Status	Latitude
Shtokman	NA	Proposed	74°
Yamal LNG	Yamal Peninsula	Construction	72°
Snøhvit LNG	Hammerfest	Operational	70°
Alaska LNG	Nikiski	Proposed	61°
Sakhalin LNG	Sakhalin	Operational	51°
Canada LNG	Multiple	Proposed	54°

Note: Arctic Circle latitude 67°

Table 7 Arctic and Cold Continental Climate projects

3.2 Arctic and cold continental climate project requirements

Development of these project requirements has a special focus on operation, maintenance, safety, environment and occupational health. The conditions in which these projects need to be constructed, operated, and maintained require more from the initial planning phase than projects developed in a less remote location.

These projects are similar in many ways but also differ. The following is a listing of design specifications and requirements generally implemented[8].

- Construction methods to minimize exposure to the Arctic conditions
- Modularization construction
- Structural integrity buildings and structures to withstand snow and ice load
- Foundations for tanks and structural buildings for Arctic soil conditions
- Equipment protection heat tracing, precipitation shielding, HVAC requirements, etc...
- Working environment and personnel protection
    - wind/snow shielding, protection from falling ice, etc…
    - Personal Protection Equipment (PPE) and operator clothing for Arctic conditions, and localisation of personnel
    - Flare radiation zones need protection to avoid melting permafrost soil
- Plant design solutions
    - (redundancy, equipment and material selection, definition of requirements towards suppliers)
    - Power supply back-up solutions
- Operational procedures specific to Arctic conditions

Differences in these projects can be found in their environmental and social responsibility characteristics. This depends largely on any local inhabitant, wildlife, and environment being impacted by the development.

The above has the following impact on the Remoteness Index of these projects, due to similar geographical remoteness, manpower problems, and technical challenges they all score above 3.2 on the Remoteness Index.

3.3 Engineering and design considerations

During feasibility study, permitting phase and basic engineering design typical studies will need to be prepared, many of them are not specific to these project conditions, like Quantitative Risk Assessments etc… however, these projects do have some site specific weather studies and surveys, including but not limited to:

- Winterization engineering study
- Model study of wind conditions
- Icing and snow drift study
- Sea spray icing modelling

[8] Statoil, LNG Seminar, Murmansk, 15 May 2012

- Wind-Chill index simulations
- Study of comparable installations
- Met-ocean data studies, including ice movement studies
- Full mission ship simulations for project conditions

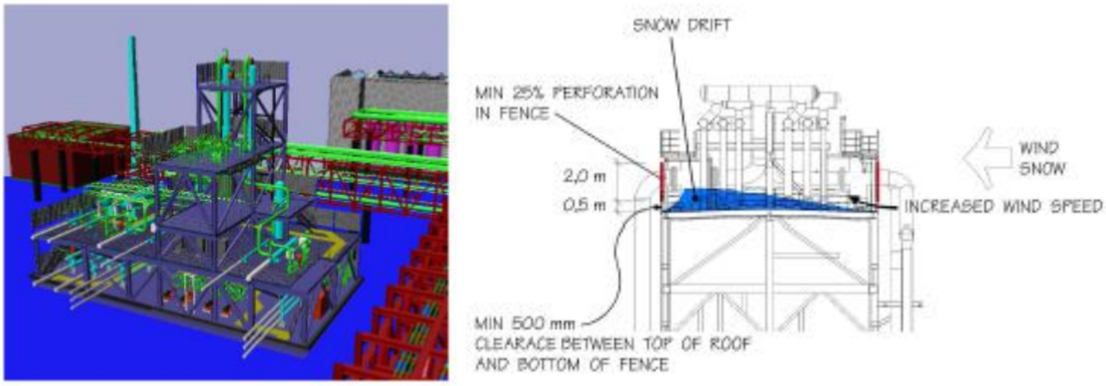


Figure 25 Winterisation Engineering Study

3.3.1 Equipment design features and winterization

To ensure continuous operation in cold and harsh conditions, key equipment, will need to be located in heated shelters and buildings. Other examples of winterization features are anti-icing facilities for the gas turbine inlets, electrical heating for piping and rotating equipment, winterization for water system, and or application of dry risers and heating coils for intermittent start and stop operations[9] This to ensure that equipment like gas turbines, other rotating equipment, and diesel engines for vehicles and machinery need to be designed such that they are able to start under the extreme cold temperatures.

Winterization is primarily defined in terms of the minimum temperature which the modules, buildings, equipment & pipes need to be maintained at in order to prevent damage, allow operation of equipment and allow for operation and maintenance activities during winter at ambient temperature.

This also includes consideration of all aspects affected by cold conditions, snow, ice build-up, freezing winds, blizzard conditions and extended darkness like working environment & personal protection, structural integrity, equipment & material protection, process design, redundancy, equipment & material selection, and operations procedures.

The following list summarizes some examples of design for these cold and harsh conditions:

- Minimization of stagnant sections of piping
- Piping to be installed above ground due to permafrost soil conditions
- Heat tracing to be installed with possibility for isolation.

[9] Meiring W., Shell, Case Study The Sakhalin LNG plant LNG in Arctic conditions, October 2010

- Insulation on piping shall minimize necessity to screw and drill and shall be based on easy to open/close cover boxes
- Air intake of gas turbines shall consider snow and wind direction
- Usage of heated shelters for equipment
- Air coolers louvers installation and winterized air coolers, to be able to restart quickly after shut-down
- Fire and gas detectors installation to take snow conditions into account

3.3.2 Onshore design features

In addition to this there may be requirements for cold weather protection for civil foundation stability, for snow loadings on structures, and requirements for available and accessible snow clearing equipment.

Soil conditions pose a design challenge when the remote location has to be built on permafrost. Piled foundations are subject to frozen soil conditions, then potentially molten soil conditions. Design of foundations should have minimal thermal and mechanical impact on frozen soil. All this requires more from the structural designer when building in Arctic conditions.

For the building designs one should consider the following:

- Provide sufficient gates, doors, removable panels, lifting gears for maintenance, avoiding scaffolding in order to limit maintenance time in cold or windy conditions at elevated places like pipe racks and stacks
- Avoid underground cables/piping due to permafrost conditions
- Build to support snow load e.g. structural design of roof slope and shape
- Build to withstand wind exposure in combination with snow conditions
- Heating systems to be based on water/glycol mixtures and to be redundant, but avoiding heating of the ground which results in melting of the permafrost
- Allow for sufficient space between buildings and process modules to allow for snow removal

3.4 Liquefaction technology selection for cold and harsh conditions

There are several liquefaction processes available, varying from C3-Mixed Refrigerant, Dual Mixed Refrigerant, pure cascade processes, and Single Mixed Refrigerant processes. A comparison was made between the C3-MR and DMR[10]

As an example the Sakhalin liquefaction plant is DMR based, the Snøhvit liquefaction plant is Mixed Fluid Cascade (MFC) based. With the same power input, these processes produce essentially the same LNG flow with essentially the same specific power, except in very specific circumstances, like Arctic conditions. The following graph demonstrates the importance of selecting the most efficient process for Arctic

[10] Schmidt. William P., et al., Arctic Plant Design: Taking Advantage of the Cold Climate, Air Products and Chemicals Inc.

conditions. The graph is based on a nominal 6 mtpa at the yearly average ambient of 4°C.

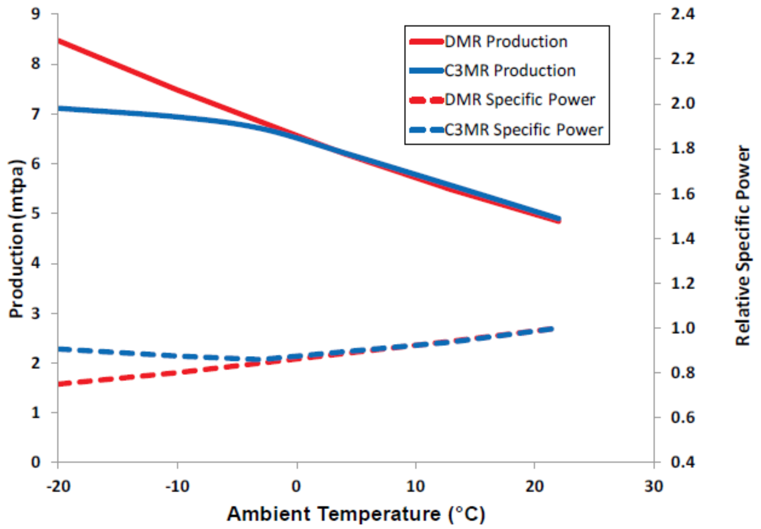


Figure 26 Liquefaction technology comparison

As shown in the graph the DMR process will produce more LNG in cold and harsh conditions, provided that sufficient feed is available. This is caused by the fact that the propane pre-cooling loop in the C3-MR process cannot be fully utilized under these conditions. The production and specific power differences are shown in Figure 26. To achieve higher production, the compositions in the pre-cooling loop of the DMR process will need to be continually or periodically adjusted. A thorough evaluation and selection for ambient conditions that vary from extremely cold to relatively warm conditions is therefore key to the economic viability of the project.

3.5 Offshore design features and shipping (Logistics)

In addition to the above mentioned onshore design features, the cold and harsh conditions also impact the offshore development of the Port and LNG shipping requirements. As an example the Yamal LNG development has an ice cover, and ice encroachment into the Port area for more than 80% of the time of the year and therefore LNG carriers with ice-breaking capacities are required. The proposed LNG carriers with ice-breaking capacities may require other ice-breakers to enable year round navigation and shipping capabilities. In addition to the LNG carrier and the supporting ice-breakers the tugboats and mooing boats will also have to be provided with ice-breaking capabilities. The following figure depicts the Yamal LNG shipping concept.

Figure 27 Yamal LNG Shipping Concept[11]

3.6 Construction

3.6.1 Environmental challenges

Due to extreme environmental conditions there will be challenges during the construction phase. The following list summarizes some of these challenges:

- Snow ingress & snowdrift built-up caused by blizzards
- Persisting snow covers preventing works
- Foggy conditions, night frosts
- Strong winds
  - During Winter high wind conditions combined with low temperature induce intensive equipment surface heat losses & re-distribution of snow cover at open areas
- Construction access limitation, caused for example by iced-up roads resulting in limited road capacity
- Ambient temperatures below water freezing point (could be 9 months per year)

This results in harsh working conditions, generally in a remote location away from any infrastructure and residential areas in which snow/ice management is one of the means to ensure construction can still take place.

3.6.2 Modularization

For construction of LNG projects in cold and harsh conditions, modular design and construction of pre-assembled units (at milder ambient conditions) to be either transported to site by ship or road will reduce construction cost associated with traditional construction in situ. Examples of this construction strategy have been applied at Snøhvit, and remote projects in Canada[12].

[11] YLNG Presentation – September 2012
[12] Fluor, Barcelona LNG Summit, October 2013

Figure 28 Module transport by road

Many project developments and execution approaches are “traditional” with still a significant level of site construction required. This adds cost to projects and puts more risk on predictability of results.
The future of construction of LNG projects in cold and harsh conditions will rely on modular designs and construction approaches, maximizing construction hours away from the remote location. This largely reduces the construction risks at the remote site. During the design it has to be realized that the modularization construction approach drives the design and the design does not drive the modular construction approach. Designs will have to become more and more standardized to enable this.

An example of modularization and shipping a complete module by barge to site was used on the Snøhvit LNG project. The LNG processing facilities of this project are installed on a purpose-built barge. The barge was built in Spain and completed in 2005 and towed to the site with the top-sides LNG plant facilities already installed. The barge concept was selected due to cost efficiencies, modular construction and reduced need for works under cold and harsh conditions.

Figure 29 The barge concept

3.6.3 Standardization

For development of LNG facilities in remote location standardization is an enabler to the success of the project. LNG facilities can be standardized for arranges of feed-gas compositions and other process units can be modularized and added to the overall facility. Modules can be added and or deleted like building blocks.

To be able to utilize the modularized and standardized LNG facility at different location an envelope of civil, soil, and seismic conditions needs to be assumed if the design will go to several locations. The main advantages of standardization are a reduction in costs of equipment and bulk, and reduction in project schedule.

3.7 Operations and maintenance

Operations in cold and harsh conditions are hard and personnel-on-site has to be minimized, since prolonged exposure to these conditions has a negative effect on mental & physical health. To minimize personnel, there is a requirement for multi-skilled personnel.

Although outdoor work shall be minimized personnel shall be provided with personnel protective equipment (PPE) suitable for the conditions. Part of the PPE is personnel GPS positioning to be able to localize each and every employee. Any outdoor work shall be performed as much as possible in protected work places e.g. heated shelters.

An elaborate cold health & safety risks management shall be in place which considered:

- Frostbite and hypothermia
- Cold induced health problems and diseases
- Psychological & physiological issues have to be considered

Operations will spend a significant amount of time on snow and ice management. This required dedicated snow removal equipment and the site lay-out should be such that snow can be removed and stored. Other activities of snow management are:

- Avoidance of snow accumulation. E.g. roof snow removal and maintenance
- Regular maintenance and inspections at locations where snow can build-up
- Management of snow melting and water accumulation during spring season
- Disposal of standing water. E.g. via drainage gutters and sump pumps to a drainage area
- Ice falling management to prevent damage and or injuries

Operations shall seek for a high level of automation, certainly for repetitive routine tasks and shall have remote process control and monitoring. Equipment shall be able to be started and stopped remotely.

To avoid equipment having a single point of exposure, which in case of breakdown will cause in loss of the facility, there shall be a proper sparing philosophy with sufficient redundant equipment to ensure high availability. To reduce operational and maintenance complexity equipment shall be standardized as much as possible.

Shut-down for maintenance shall be properly planned in the summer or least severe conditions. For the maintenance activities accessibility is of key importance and a detailed plan or campaign is required to minimize time required for the activities. For example the lifting schedule is drastically influenced by low ambient temperature and wind conditions.

Enough storage space within warehouse and/or reparation (increased preservation works to limit site delivery should be envisaged in order to store critical equipment and avoid long shut-down periods, in case of equipment failure, and limitation of navigation window during plant construction.

3.8 Environmental aspects and social responsibility

Remote LNG projects in cold and harsh conditions are most likely to be in a pristine and untouched environment with unique marine environment, biodiversity, and protected wildlife[13]. During the permitting phase the permitting authorities will therefore impose environmental conditions and environmental impact constraints on these projects.

Examples of these environmental aspects are:

- Minimization of exhausts from boilers, and gas turbines
- Strict conditions on water quality that can be discharged to the sea
- Strict and extensive environmental monitoring of air, water, and soil conditions

In addition to purely environmental impact constraints remote projects in these conditions potentially also impact the lives of indigenous people with conventional lifestyles and economic activities, like deer breeding , fishing, fish spawning, and hunting. To minimize the impact of these projects they implement programs with the objective of protection of wildlife habitat, archaeological sites, ceremonial and cultural sites, and monuments. In addition compensation programs are implemented as well.

Figure 30 Yamal Environment

3.9 Conclusions

On the basis of the discussion on LNG projects located in the Arctic or cold continental climates, the following conclusions can be drawn:

- Development of these projects require a special focus on operation, maintenance, safety, the environment and occupational health, since they have

[13] Verburg R., Shell, From simulation to reality, Start-up and initial operation of the Sakhalin LNG plant, March 2011

to be constructed and operated in cold and harsh conditions. This requires a longer planning phase for project execution.

- From a design point of view these projects have special requirements due to soil conditions, ambient temperature, and snow & ice conditions. This results in dedicated studies and selecting optimal liquefaction technology, redundancy of equipment to ensure reliability and extensive winterization of structures and equipment, as well as power generation back-up.
- From a shipping point of view a dedicated special fleet of LNG carriers, tugboats and mooring boats might be required to ensure adequate availability of the Port and shipping movements.
- From a construction point of view planning is critical since construction windows are limited. Standardization and modularization to minimize construction work on site is one of the key success factors of constructing these projects.
- These projects ask for special requirements with respect to operations and maintenance. Exposure and impact to personnel from the harsh conditions need to be minimized.
- Environmental aspects need to be taken into account to minimize impact on marine and wildlife environment which has not seen industrial development.
- These projects carry a large social responsibility towards indigenous habitants, and social responsibility programs need to be part of project execution, and operation.

4 New Frontier Asia-Pacific Projects

4.1 Asia-Pacific LNG Panorama

The Asia-Pacific Region has a strong relevance in the global LNG industry, both from a consumption and production stand point:

- The Asia-Pacific region is, by far, the largest LNG consuming region in the world.
- Although the Middle East and North Africa is now the most important producing area in the world, Asia-Pacific is a close second.

Since the 70's, spudded by the strong regional demand, many liquefaction projects have been installed in the Asia-Pacific region, starting in south-east Asia (Brunei, Malaysia and Indonesia) in a first "wave" from 70's to 2000's and then with the incorporation of Australia's new Liquefaction projects from the 90's onwards. In addition, a new LNG producing country has recently been incorporated in 2014: Papua-New Guinea.

The region is expected to continue to increase its LNG producing capacity in the future, largely underpinned by growth in Australia.

4.2 Remote projects in the Area

In the context of remoteness, recalling on the Remoteness Index discussed in chapter 1 above, there are many Asia-Pacific projects near the top of index**,** for all of the categories of projects:

- Plants on stream: there are a significant number of Asia-Pacific projects that had a high (RI>4) Remoteness Index: Bontang LNG, Arun LNG and Tangguh LNG (Indonesia); PNG LNG (Papua-New Guinea). With a slightly lower Remoteness Index: Brunei LNG (3.9) and Malaysia LNG (3.8)
- Plants under construction: Donggi Senoro LNG (Indonesia) with RI>4; and Gorgon LNG and Wheatstone LNG (Australia) with RI=3.8
- Proposed plants: Gulf LNG (PNG) and Natuna D Alpha (Indonesia) with RI>4

For all the projects referenced, the indices for Geographical Remoteness, Extreme Climatic Conditions and Manpower problems are 4 or more. Clearly, the "physical" conditions of the area coupled with long distances from fields to LNG sites (for example, Australia and PNG) or with producing sites spread into multi-island countries/areas (for example, Indonesia), together with the climatic conditions lead to a high proportion of remote developments.

Therefore remoteness is an issue that many Asia-Pacific projects now on stream had to overcome and that will need to be overcome for many fore coming projects in the area.

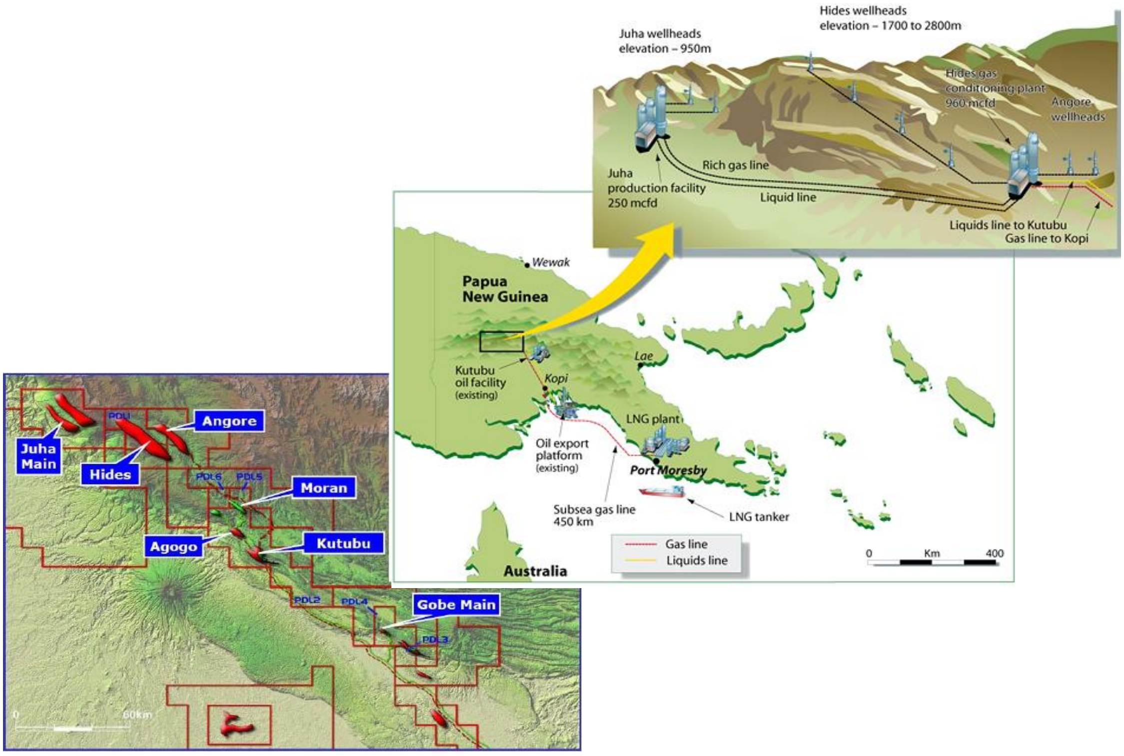
4.3 Asia-Pacific remote LNG project example: PNG LNG

To illustrate the issues related to a remote project in the Asia-Pacific area it's been chosen the case of Papua-New Guinea LNG as it is the first LNG project in this country, a new entrant in the LNG export "club" from Asia, that had all the remoteness issues in a country with no past experience in LNG Projects and with geographical hurdles for the development of such extensive infrastructure. The PNG LNG project completed its construction phase in 2014, and the plant loaded its first LNG cargo at the end of May 2014.

4.3.1 Project overview

The PNG LNG project is an integrated LNG project. The gas will be treated at a gas conditioning plant at Hides, then transported via an onshore and offshore pipeline to a 6.9 mtpa LNG liquefaction (two liquefaction trains) and storage facility located 20 km north-west of Port Moresby on the Gulf of Papua (close to an existing refinery). PNG LNG is also expected to produce more than 200+ million barrels of associated liquids during its operating life.

PNG LNG is a phased development underpinned by the Hides field. The initial phase, which includes the majority of new facilities, is now complete.



Source: www.arcticgas.gov

Figure 31 PNG LNG Fields and Gas Treatment

The shareholders of the project are: Exxon (operator); Oil Search; Santos Limited; National Petroleum Company of PNG Government (Landowners) ; Nippon Papua New Guinea LNG LLC; MRDC, Mineral Resources Development Company (Landowners);

Petromin PNG Holdings Limited. It’s important to notice that as per Papuan law, the Papua New Guinea government has a right to hold up to a 20% stake (in this case, executed through the entities of: National Petroleum Company of PNG Government and MRDC (Mineral Resources Development Company). In addition the local “landowners” have a right up to 2%.

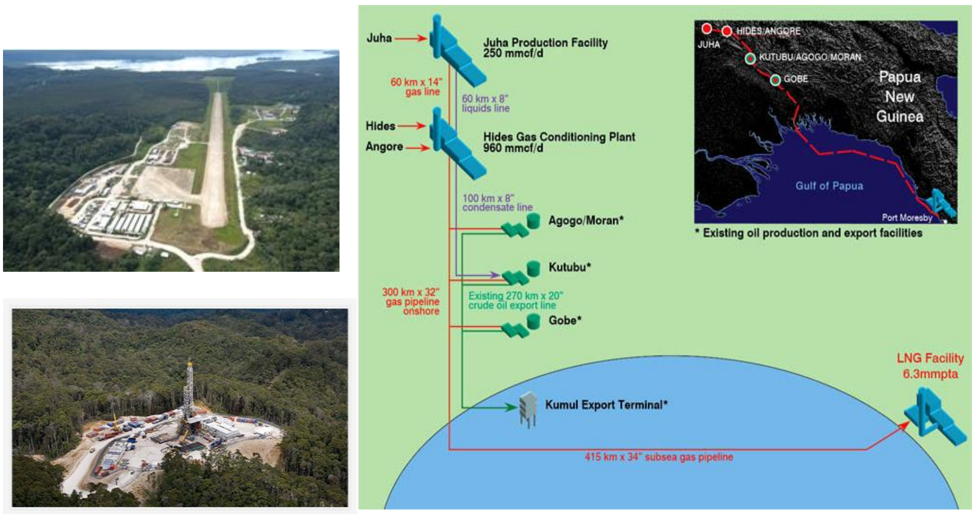
The estimated cost for this development is $19 billion (including upstream development costs and 435-mile pipeline to the LNG plant and the LNG facilities).

The offtake of the LNG project is almost fully contracted (through long term contracts) for Japanese, Chinese and Taiwanese consumers.

4.3.2 Gas production and gas treatment plant

The feedgas comes from gas resources from the Southern Highlands and Western provinces of PNG:

- Gas from *Hide*, *Angore* and *Juha* fields
- Associated gas from the already oil producing fields of *Agogo*, *Gobe* and *Moran*



Source: www.oilsearch.com

Figure 32 Gas Production, Treatment Plant, and Pipelines

The gas producing fields are located in a forest/undulated area far away from the seashore; the gas is treated in Hides gas conditioning plant (960 mmscfd capacity) where the condensates/liquids are extracted. Due to PNG’s extreme undulating terrain, an airport has been constructed to ensure materials are delivered to the site on time: a joint venture between McConnell Dowell and Consolidated Contractors was awarded the contract to procure and construct the Komo Airfield in PNG, located 10 km southeast of the Hides Gas Conditioning Plant, which received air freight for the project; the runway is 3.2 km long.

4.3.3 Gas Pipeline

One of the most challenging issues, in terms of Geographical Remoteness, for the development of PNG LNG is the extensive pipeline required to connect the gas fields with the LNG site, taking into account: the orography of the country, the forest and the fact that most of the country has no existing infrastructure; in addition, PNG is a country with multiple tribes living in their territories with their own cultural and social structure, and sacred areas.

This scenario led to the decision made by the project's promoters to have a pipeline from the gas producing fields/treatment plant to the closest point in shore (influenced by the fact of having existing oil exporting facilities to commercialize the liquids) and then to build a long range offshore pipeline to the site (avoiding onshore).

The pipeline's design and construction is governed by the Project's Environmental Impact Statement and is designed to meet all Papua New Guinea regulatory requirements, project design specifications, and industry standards.

Onshore pipeline: The main 292 km gas pipeline was constructed to transport the conditioned gas from the Hides Gas Conditioning Plant (HGCP) to the Omati River where it connects to the offshore pipeline.

Offshore pipeline: The offshore pipeline commences at the Omati River landfall and follows the river for approximately 24 km past Goaribari Island to the open sea. The pipeline then crosses the Gulf of Papua to the Caution Bay landfall at the LNG Plant site near Port Moresby. The length of the offshore pipeline is 407 km and uses over 34,000 joints of pipe. The deeper water sections of the pipeline reach depths of up to 110 metres.

4.3.4 Liquefaction Plant

The LNG plant is located in Port Moresby, close to the existing refinery and consists of:

- The receiving and treatment facilities that take the feedgas from the pipeline
- Two LNG process trains with an overall capacity of 6.9 mtpa of LNG (condensate, a low-density mixture of hydrocarbon liquids recovered through the gas liquefaction process, is also stored and offloaded at the LNG Plant)
- Two 160,000 m^3 LNG storage tanks
- A loading terminal for LNG tankers up to 220,000 m^3

Port Moresby LNG

Figure 33 Port Moresby LNG Site

The project has conducted years of extensive research and developed mitigations to minimise its impact on the environment. This has included adjusting the facilities and construction methods to limit impacts on existing vegetation and to preserve the estuary of Vaihua River and archaeological sites.

4.3.5 Conclusions

The PNG LNG project had to deal with many aspects related to the remoteness, common in the Asia-Pacific area: the issues for the location and materials supply for the gas treatment plant and the extensive pipeline (avoiding the most direct inland route resulting in a big offshore extension), together with the social structure of the county with sacred areas, earn PNG LNG a rating of 5 for the Geographical Remoteness parameter and also 5 for the Environmental concerns. The climate (as per the Köppen-Geiger climate classification) gets a rating of 4 for the Extreme climatic condition parameter. In addition, the lack of experienced/educated manpower in the country/area, leads to a rating of 5 for the Manpower problems parameter.

The remaining parameters related to the operability of the facilities and the technical challenges were considered less remote: Operational challenges (3) and Technical hurdles (2). The project success will be underpinned by the long term LNG offtake commitments by reliable consumers in the Asian market.

4.4 Conclusions

The Asia-Pacific region has many projects with a high Remoteness Index: on stream, under construction and proposed. Therefore, this region is a clear example of how the LNG projects promoters can overcome the different issues related to the remoteness of their projects, by putting in place creative ways to make such challenging development both technically and economically feasible.

As stated in other parts of this report, from a technical stand point the LNG industry is on a degree of development, knowledge and creativity that almost any known project is now technically feasible and could be developed.

5 New Frontier: East Africa Projects

Historically, the African continent has been dominated by West Africa and Northern African countries, with the Eastern Africa region having considerably less importance on the Oil and Gas global stage. That is until recently. Uganda heralded the way with onshore oil finds, with Kenya, South Sudan, and Ethiopia having subsequent exploration successes. However, offshore, Mozambique, and Tanzania have made the biggest headlines each with world-class gas finds.

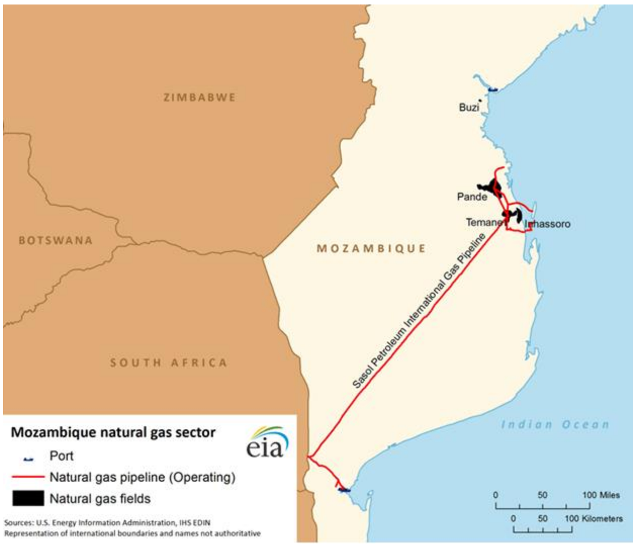
5.1 Gas resources perspective

Since offshore exploration efforts began in earnest in East Africa in 2009, some 180 Tcf of gas have been discovered in the north of Mozambique Rovuma Basin in offshore Areas 1 and 4 (close to 150 Tcf) and the south of Tanzania (>30 Tcf) making this one of the most exciting future LNG regions in the world today.

Such enormous reserves are sufficient to support multiple train LNG developments with the potential to propel the area to the forefront of global LNG producing regions. Large-scale, onshore LNG plants are being proposed for both offshore developments. Domestic gas usage and infrastructure is very limited in both countries.

5.1.1 Mozambique

Onshore gas discoveries were made in Mozambique in the 1960s, and Sasol was awarded licenses to develop the Pande and Temane gas fields (est. 3 Tcf) in 1998, located in the southern/central coastal area of the country. This included the construction of an 865km 26 inch pipeline linking Temane to South Africa. As a result, some gas development and infrastructure expertise does exist in country.

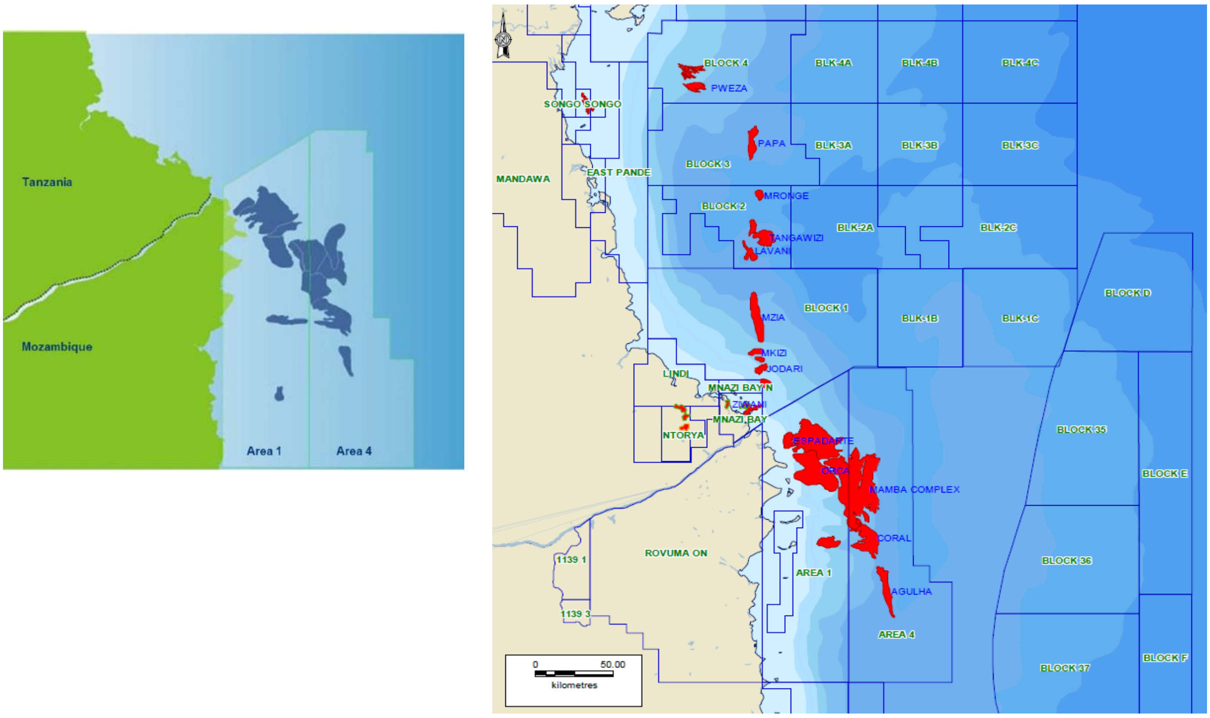


Source: US Energy Information Administration

The 538-mile Sasol pipeline moves Mozambique natural gas to South Africa

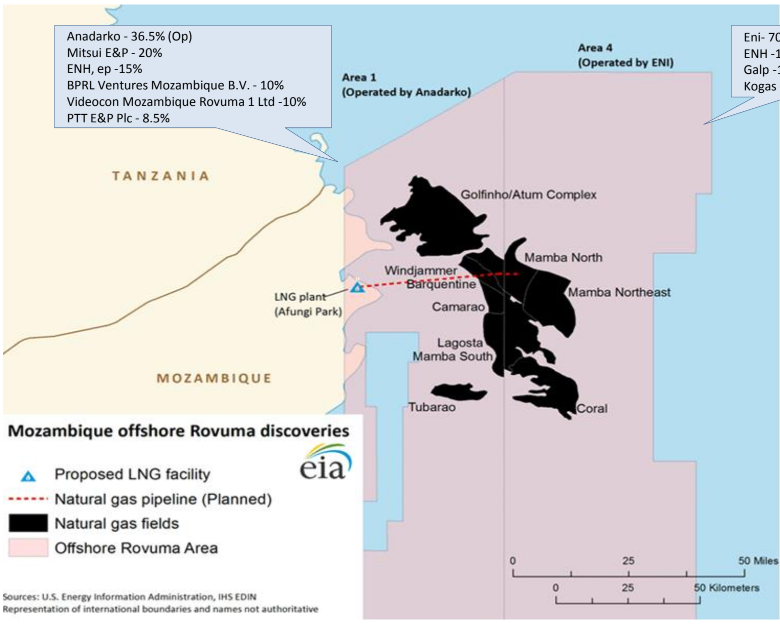
Figure 34 Sasol Petroleum International Gas Pipeline

Since 2009, major gas finds were made in Areas 1 and 4, offshore north Mozambique.



Source: Gaffney, Cline and Associated, Major Gas Projects Development Plans report

Figure 35 Mozambique Offshore Blocks



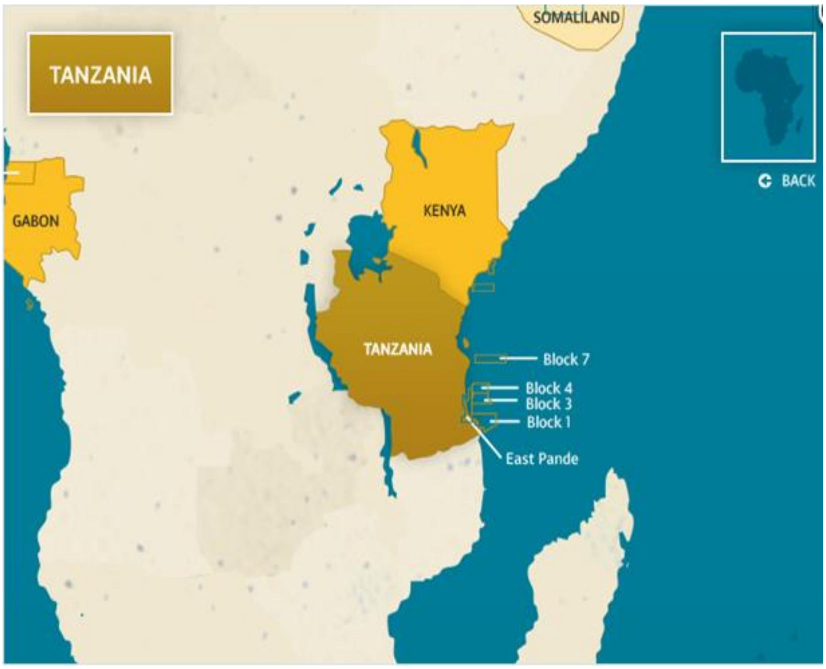
Source: US Energy Information Administration

Figure 36 Mozambique Offshore Area 1 and Area 4

5.1.2 Tanzania

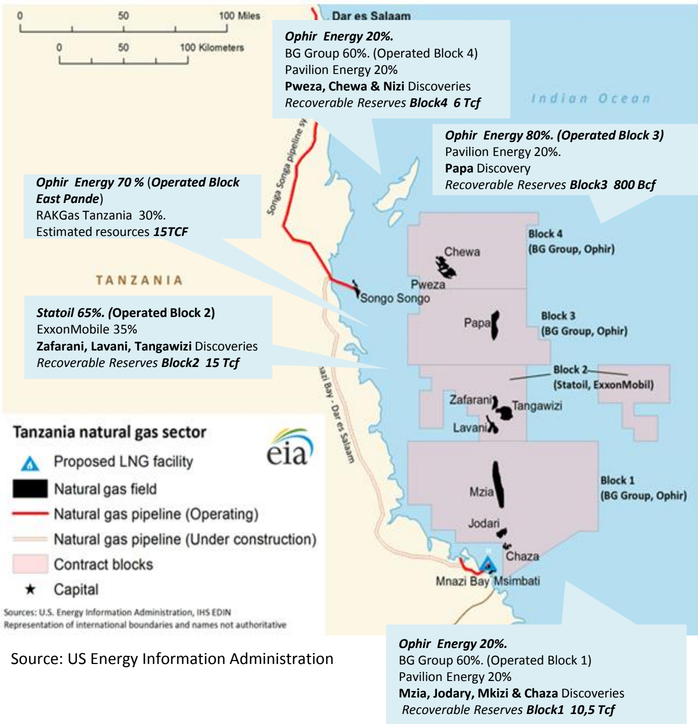
Tanzania has two gas fields (Songo Songo and Mnazi Bay) for exclusive domestic supply, and where domestic demand limitations have limited gas production.

Significant gas reserves have been discovered in 4 offshore blocks in the southern part of the country to the order of >30 Tcf. Blocks 1, 3 and 4 are operated by a BG/Ophir consortium and Block 2 by a Statoil/ExxonMobil JV.



Source: 3w.2b1stconsulting.com/bg-and-ophir-come-closer-to-tanzania-lng-project/

Figure 37 Tanzania Offshore Blocks



Source: US Energy Information Administration

Figure 38 Tanzania Offshore Blocks and Shareholder Composition

5.2 LNG projects

5.2.1 Mozambique's LNG project

Since 2009, major gas finds were made in Areas 1 and 4 offshore north Mozambique. Area 1, led by AMA1 (Anadarko Mozambique Area 1) has two main fields to be developed - the Golfino/Atum fields in the north of the block and the Prosperidade field in the south –some 50 km offshore and with a total area of some 350 km. Further offshore (55 km), the Area 4 discoveries, operated by ENI, consist of the Mamba and Coral gas fields in deeper waters (1200-2300 m). The field´s area coverage is around 1100 km^2.

Anadarko (as Area 1 operator) and ENI (as Area 4 operator), reached a Heads of Agreement (HOA), establishing principles for the coordinated development of the common natural gas reservoirs spanning both Mozambique's Offshore Area 1 and Offshore Area 4

A shared LNG facility with the main partners from Area 1 and Area 4 is being planned on the Afungi Peninsula to receive feed-gas from both areas from a 45 km sub-sea pipeline.

The facility is initially planned for 2 x 5 mtpa trains to then expand to another 2 x 5 mtpa. Future trains may be added. Three LNG storage tanks are planned, with a multi-purpose dock being constructed at the plant site to directly import materials and equipment for the plant construction.

Figure 39 Palma Site

A marine terminal and jetties will be constructed as well as channel dredging in Palma Bay for ship access and turning. For construction, infrastructure for a workforce of between a 7,000 to 10,000 workers will be necessary as well as a 3.5 km long airstrip.

Source: Eni, LNG Mozambico Report

Figure 40 Palma Site LNG Plant Lay-out

CAPEX including offshore wells Blocks 1&4, undersea pipeline, housing, dock, airstrip and four liquefaction trains, each with a capacity of 5 mtpa could total $25-$30 Bn.

The official timeline pegs 2018 as the year of the first LNG delivery, though some analysts believe that 2019 or early 2020s is more likely.

In terms of demographics, Mozambique has an average population density of some 28.7/km^2 (178th in the world), with the majority of the population residing in the middle part of the country, and the capital city, Maputo. Of the 10 provinces in the country, the two northern-most coastal provinces are Nampula and Cabo Delgado. The site for the LNG facility is in Cabo Delgado province, on the Afungi peninsula in the Bay of Palma (See figure above). Palma is a very small town on the coast, whose people live off fishing and such crafts as basket making. No oil and gas activities exit in any of the surrounding region.

The nearest towns of any significant size to the site are Nampula, 500 km away and with a population of 500,000 and Pemba, a small port some 350 km to the south of the site along the coast, with a population in the order of 110,000. Road access between Nampula, Pemba and Palma is very basic.

With a virtual complete absence of local skilled labour and local supplier base, AMA1 (Anadarco Moçambique area 1) has taken the initiative to engage the services of an international economic development NGO (non-governmental organization) to help it develop local content suppliers and labour in advance of Mozambican regulation on local content. As existing villages will be affected by the plant location on the Afungi peninsular, re-settlement plans are being developed in conjunction with local communities and government.

The Afungi site is a greenfield site with no significant challenges beyond the lack of infrastructure and labour shortage.

5.2.2 Tanzania

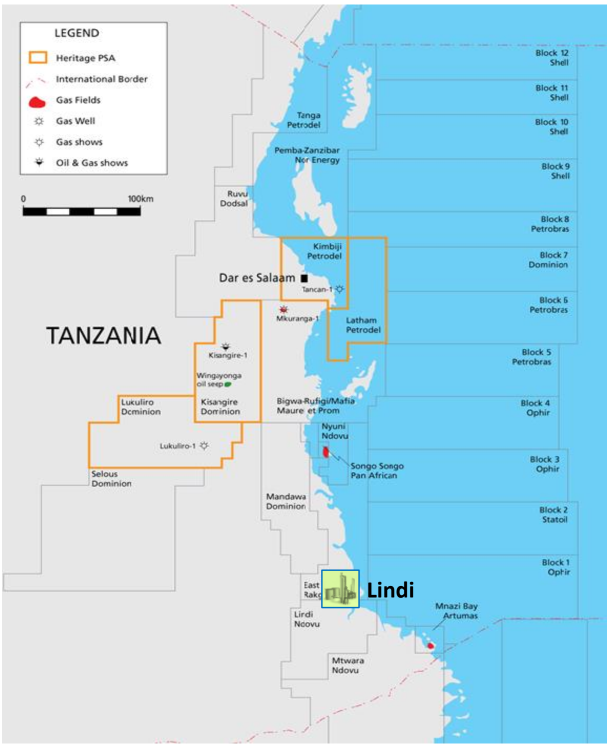
The Songo Songo producing fields are small and took decades to bring to commercial production because of the lack of a local market and the impracticability of export (in view of the limited reserves). The Songo Songo field has been in production since 2004 and provides gas to generate a significant proportion of Tanzania's electricity. Gas is also used by a number of industrial and commercial customers in the Dar es Salaam area.

The significant gas resources expected from blocks 1, 2, 3 and 4 will be mainly developed for LNG. Nevertheless there is an expected rise in the domestic gas consumption, mainly driven by gas-fired power plants growth and fertilizers.

Statoil, BG Group, Ophir Energy, ExxonMobil and Pavilion are teaming up to look at building that country's first LNG export terminal in the southeastern town of Lindi (in 2014, the BG JV signed aHOA" with the Block 2, Statoil JV, to pursue a joint onshore LNG development), the project will be in a joint venture with Tanzania Petroleum Development Corporation (TPDC).

It will be delivered with Blocks 1, 3 & 4 upstream project involving TPDC, BG, Ophir and Pavilion and Block 2 upstream project involving TPDC, Statoil and ExxonMobil.

The Tanzanian government has insisted it wants only one LNG project associated with the more than 30 Tcf of reserves found in BG-operated Blocks 1, 3 and 4 and Statoil-operated Block 2.



Source: http://mergersandacquisitionreviewcom.blogspot.com.es/2011/06/east-africas-tanzania-oil-and-gas.html

Figure 41 Lindi Site Location

- Several locations under study, the most likely is near Lindi.
- Space for up to 6 liquefaction trains.
- Current plans for 4 x 5 mtpa trains (total 20 mtpa), fed by several operator/discoveries.
- Individual trains wholly owned and operated separately by the block operators.
- pre FEED awarded to CB&I in August 2014.
- FEED expected in 2015.
- FID expected in 2017.
- Expected start up early 2021-22.
- Liquefaction plant will operate under a non-integrated tolling structure, charging a fee sufficient to generate a 10% nominal rate of return. Capex estimate around $10 Bn (LNG plant).

5.3 Conclusions

Both Tanzania and Mozambique have planned LNG plants that have high Remoteness Indices at 3.6, mainly due to geographical isolation, almost a complete lack of infrastructure and manpower along with a tropical climate.

Either side of the Rovuma River, both areas are very similar in respect to the challenges that lie ahead.

It’s worth to mention that apart from the pure LNG related construction and operation challenges, these gas project have to put efforts, in parallel, on the development and materialization of the domestic demand requirements.

6 Conclusions

The most common understanding of **REMOTE** implies a significant geographical distance. However, there are other factors related to these projects that cause severe challenges in any or all of the planning, design, construction, operations, and export phases, and therefore these issues have been incorporated into the concept of remoteness of a project.

These are the individual remoteness Criteria within the Remoteness Index.

Remoteness criteria Weighting	**Geographical Remoteness** 25%	**Extreme climatic conditions** 15%	**Manpower problems** 10%	**Operational challenges / infrastructure** 20%	**Technical hurdles** 10%	**Environmental sensitivity** 20%
	Ease of access to site	Climatic classification	Availability of skilled labor	Complexity of operating a plant	Unproven concepts	Site impact
1 low	Uninterrupted access by land, air and sea	Humid moderate climate without dry seasons (Cf*)	Easy access to local skilled labor	No significant operational challenges	none or one non-critical	abandoned area
2 slight	Good land and sea access, occasionally no air access	Humid moderate Mediterranean climate, dry winter (Cw, Cs*)	Good basic local labor pool, training required	Minor operational challenges - easily overcome	several non-critical	industrial area
3 average	Temporary access inconveniences via land and air	Cold moderate climate (D*)	80/20 local/import labor	Some operational challenges	one critical	populated area
4 elevated	Extended land and air access interruptions	Tropical climate (A*)	Limited local labor available, dependence on import	Significant challenges	several or critical	recreational area
5 high	Severe difficulties, occasional zero access	Dry climate, desert, polar climate (B, E*)	No local labor available, rotational imports only	Severe operational issues, incl. seasonal	several and critical	nature reserve

After the creation of the Remoteness Index to assess the difficulties faced by LNG plants of yesterday, today and tomorrow, it can be observed that average LNG plants have always been challenging and remote for their time. Therefore the LNG plants of today and those of the future are very much as challenging and remote as those of the past when they were built.

Detailed findings for the main indicators of the Remoteness Index are summarised below.

Geographical and climatic conditions

The Arctic Circle offers perhaps the most prolific potential regarding exploration, but at the same time it presents some of the biggest challenges regarding development and export of gas to market. Cold and harsh conditions present a unique set of technical challenges in all phases of the project, including the shipping of LNG in tankers with ice-breaking capability.

Other locations in Asia-Pacific and in East Africa do not suffer from access limitation caused by snow and ice, but are likely hard to reach due to geographical isolation and lack of well-developed infrastructure. Severe climatic conditions affect the design of the project and can significantly influence construction activities. All planning cycles should be carefully matched with adequate contingencies to the weather cycles.

While infrastructure will develop over the years, adverse climatic conditions cannot be changed by mankind. Thus, this aspect will remain a significant indicator for a profitable LNG liquefaction project.

Social and environmental issues

The majority of remote projects, even though initially located in areas of little or no urbanisation, do affect the socio-political landscape, often leading to development of urbanisation and bringing significant social change. In addition, the social implications of large scale investment projects are increasingly an obligation in the design and planning stage. They carry a large social responsibility towards indigenous habitants. Social responsibility programs need to be part of project execution and operation.

Environmental aspect constraints need to be taken into account to minimise impact on marine and wildlife environment, which has not seen industrial development.

While people may assimilate to changes in their social and cultural life within decades, the environment needs much longer periods to recover from imprudent disturbances. Short sighted run for profit may cause tremendous expenses to re-establish fair living conditions. Thus, a high rating in the category Environmental Concern needs to be considered seriously, when new projects approach FID.

Technical and operational challenges

All countries, especially the new LNG players are demanding significant Local Content in projects. Whilst most LNG project shareholders fully support the notion of Local Content, the reality is often a big obstacle in the sanctioning and development of remote projects. Development of these project requirements has a special focus on operation, maintenance, safety, and occupational health. Shipping might require a dedicated special fleet of LNG carriers, tugboats and mooring boats to ensure adequate availability of the port and shipping movements.

From a design point of view remote projects have special requirements due to soil conditions, ambient conditions like snow and ice or storms, humidity and sun radiation. This results in selecting optimal liquefaction technology, redundancy of equipment to ensure reliability and sometimes extensive winterisation of structures and equipment.

Proper planning is critical since construction windows may be limited. Standardisation and modularisation to minimise construction work on site is one of the key success factors of constructing remote projects.

However, technology is keeping pace with hostile environment project requirements. No project as yet has been shelved due purely to the lack of technological solutions, but due to the lack of economical sense of the required technological solutions.

From an aprioristic approach it could be expected, somehow, a certain direct correlation between remoteness (and therefore the Remoteness Index) and LNG projects' cost. However, the fact is that it cannot be properly inferred such a relationship looking at the past projects. While certain remoteness criteria clearly do have an impact on a projects overall costs, other factors also have a very large impact on a particular projects costs (as an example: raw materials costs, contractors' workload panorama, projects confluence and many others). A clear correlation between remoteness and cost looks as likely to be as absent for future projects as has been the case up until now.

Nevertheless, the Remoteness Index can be taken as an indication about how challenging can be a new LNG project due to its location; in this sense new remote projects developers, can find useful to check their new projects Remoteness Index estimate against other past projects with similarities.

7 Study group acknowledgment

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