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# Myanmar: Technical Assistance on Liquefied Natural Gas Options for Myanmar Phase 1 (Selection # 1216215)

**Myanmar Final Report (Revised)**

16th June 2017

**MJMEnergy Limited**

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# Abbreviations and acronyms

| Abbreviation | Description |
|---|---|
| bbl | Barrels of oil |
| Bcm | Billion cubic metres |
| Btu | British thermal units |
| C&F | Cost and freight |
| cm | Cubic metres |
| E&P | Exploration and production |
| EL | Exploration licence |
| FRR | Final revenue requirements |
| FSU | Floating storage unit |
| FSRU | Floating storage and regasification unit |
| FY | Financial Year |
| GoM | Government of Myanmar |
| GSA | Gas sales agreements |
| IOC | International Oil Company |
| IPP | Independent power producer |
| IRR | Internal rate of return |
| LNG | Liquefied Natural Gas |
| mmbbl | Million barrels |
| mmbtu | Million British thermal units |
| mmcfd | Million cubic feet per day |
| MOGE | Ministry of Oil and Gas Enterprise |
| scf | Standard cubic feet |
| Tcf | Trillion cubic feet |
| ToR | Terms of Reference |
| TPA | Third Party Access |
| T&D | Transmission and distribution |
| UFG | Unaccounted for gas |
| UGS | Underground Storage |

# Executive Summary

The high-level objectives of this project are to support the Government of Myanmar (GoM) in developing a gas sector development plan by focusing on the near-to-medium term options to meet the gas demand in Myanmar. Specifically, focusing on import options of LNG initially as a bridging fuel while new gas exploration gets underway in Myanmar. In particular, the focus is on the possibilities for LNG receiving facilities in Myanmar, which given the proposed timescales suggest prospects for development of floating regasification LNG terminals. The original terms of reference (TOR) for this project covered three main tasks which are summarized below as follows:

- ***Task 1(a)*** – Siting analysis to assess three potential locations for LNG import facilities in Myanmar.[1]
- ***Task 1(b)*** – Prepare prioritisation framework and accompanying analytical tool for LNG import options and locations.
- ***Task 1(c)*** – Prepare an overview of the LNG markets that Myanmar may access with a view of procuring LNG to be physically swapped with gas export partners. (NB: This Task 1(c), required quite separate analysis from Tasks 1(a) and 1(b) and was therefore delivered in a separate standalone report.)

Towards the end of the original project timeline the Client requested that Task 1(a) be expanded to include two additional potential locations for LNG imports taking the number of locations being examined to five. Since the draft main report had already been completed and delivered to the client it was decided that the results of the analysis for these additional locations would be captured in two separate standalone reports. However, for the sake of clarity the results from the analysis of all five locations have been summarized in the Executive Summary and the Conclusions and Recommendations of this report. Therefore, this report, the standalone reports for locations 4 and 5, and the associated spreadsheets consist of the main deliverables in response to the Tasks 1(a) and 1(b) as set out in the original TOR.

**Section 2 – Introduction to LNG technology**

Choosing a suitable location for an LNG terminal is often a compromise between four key physical factors. An ideal site should not be significantly affected by wind and waves, whilst having access to deep water, gas transmission pipeline and local infrastructure. In addition, international financiers also require assurances that people and the environment are not unduly damaged by the construction and operation of the LNG facility. These physical and environmental factors will also influence, and be influenced by, the choice of LNG technology deployed, whether a land-based terminal, a Floating Storage and Regasification Unit (FSRU), or other approaches to LNG regasification. Therefore, this section of the report examines the following areas: LNG technology, metocean analysis, environmental issues, geography and geology, local infrastructure and pipelines.

***LNG Technology*** – In recent years a range of offshore technologies have been developed for the importation of LNG which essentially involve the modification of LNG Carriers (LNGCs) either through conversion or by including new elements in shipbuilding programmes, which are described as follows:

- ***The onshore LNG terminal*** – Land-based terminals with a marine jetty to provide a mooring for the LNG vessel and tank-based LNG storage which are essentially large conventional

[1] *Use of terminology – For example, Location 1 denotes a general location which the Client has asked the Project Team to consider. Within Location 1 the Project Team have examined a number of specific sites which are referred to as Site 1A, 1B etc.*

metal storage tanks. Whilst costly, they are robust with high levels of security of supply and low operating costs

- ***Gravity Base Structures (GBS)*** - Gravity Base Structures (GBSs) are effectively manmade islands with a LNG import terminal built in. Their design retains most of the advantages of the onshore import terminal and is able to mitigate most of the environmental disadvantages by being able to locate the facility at a preferred location. However, it should be noted that seabed conditions are critical for their implementation.
- ***LNG regasification vessels (LNGRVs)*** - The LNGRV consists of a modified LNGC which has high pressure pumps, seawater vaporisation system and the buoy mooring system in deep water (>50 m) included in the bow of the LNGC. All the LNGRVs are able to operate as LNGCs if LNGRV service is not required. LNGRVs can be built and deployed in less time than it takes to build a land-based LNG terminal, although the capital costs can be high and often similar to onshore terminals.
- ***FSRUs and GasPorts –*** Floating Storage and Regasification Units (FSRUs) and GasPorts are essentially the same technology branded in different ways by competing companies. An FSRU is an LNGC with additional equipment to allow vaporisation and export of gas. Most FSRUs are able to trade as an LNGC if no regasification work is available. This remains essential to their financing, but the increased prevalence of FSRUs is diluting this requirement. FSRUs appear to be the terminal of choice at the present time (mid 2017) but are not suitable to all locations or operating profiles.
- ***FSUs -*** Floating Storage Units are FSRUs without any vaporisers. Vaporisation is carried out onshore or on another floating structure. The premise for this technology option is that an old LNGC can be purchased inexpensively and quickly converted to serve as a floating storage tank resulting in a step change in costs. Vaporisation can be separately contracted, often onshore to reduce costs and schedule.

***Metocean analysis*** - Wind and wave conditions are of vital importance for the safe, secure and continuous operation of LNG facilities, with metocean analysis an important part of assessing the suitability of LNG facility sites (and indeed technologies). As much of Myanmar is between the Tropic of Cancer and the Equator, it is often impacted by a southwesterly monsoon. Therefore for each potential site, coastal waves have been simulated by means of numerical modelling. The simulations have also been used to assess the level of exposure to metocean conditions at each location. However, with Myanmar's coast entirely exposed to the SW Monsoons, locations with natural shelter are preferable to building breakwaters. Suggestions for berth protection are made on a qualitative basis under each site.

***Environmental issues –*** Myanmar has a requirement for environment impact assessment for major projects, although it is currently uncertain whether this applies to LNG projects. However, for financing the project, developers will need to perform an environmental assessment to meet, at least, the IFC Performance Standards and Equator Principles.[2] In the environmental assessment the level of harm depends on the degree of damage as well as the value of the site. Key ways that the project might have an environmental impact include dredging, breakwaters, subsea pipelines, pipeline landfalls, noise and vibration, visual impact, air emissions and water emissions.

***Geography and geology -*** The geography and geology of each site is important in considering its suitability for an LNG facility. On a geological basis, the key concern relates to seismicity and the risk of damage by earthquake, tsunami, volcanic eruption or other geological events. The geography of Myanmar, in particular its mountain ranges and rivers systems will have an impact on the cost and

[2] *See Section 2.4.2.*

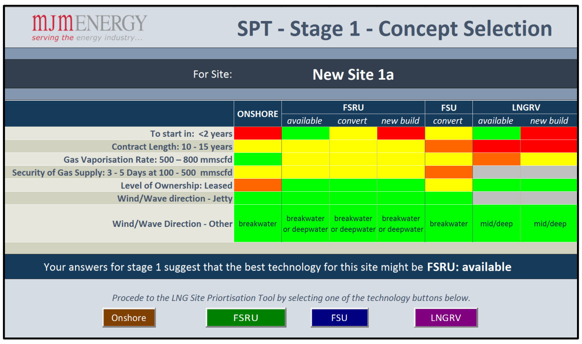
feasibility of building connecting pipelines to each site, while climatic conditions, including the impact of monsoons, have the potential to adversely affect LNG operations. Offshore, sea depth (as measured by bathymetry) and other marine factors, are important for determining suitability for LNG vessels, requirements for dredging and implications for terminal design (breakwaters, jetties etc).

***Local infrastructure –*** Constructing and operating an LNG regasification facility is a major industrial operation, and requires significant local infrastructure in order to manage the safe and orderly docking and unloading of LNGCs (by tugs), the delivery (and removal) of construction and operational materials (by road, rail, port and air links), and operation of the facility by a skilled workforce. The availability of local infrastructure (or the ability to construct/source such infrastructure) is an important consideration in assessing potential LNG facility sites.

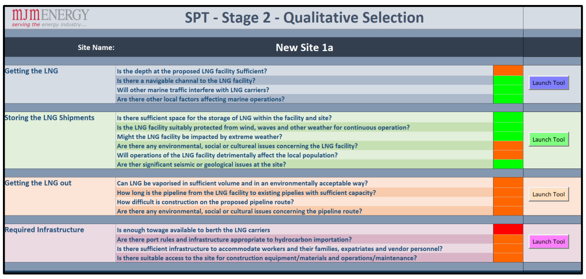
**Section 3 – The Site Prioritisation Tool (SPT)**

This report section provides a brief overview of the SPT in response to the requirement Task 2(b) in the TOR *'Prepare prioritisation framework and accompanying analytical tool for LNG import options and locations',* with a fuller explanation provided in Annex C. The Site Prioritisation Tool consists of three linked spreadsheets that relate to the three stages of the site prioritisation process: (1) Concept selection; (2) Qualitative selection and (3) Discounted expenditure selection stages as follows:

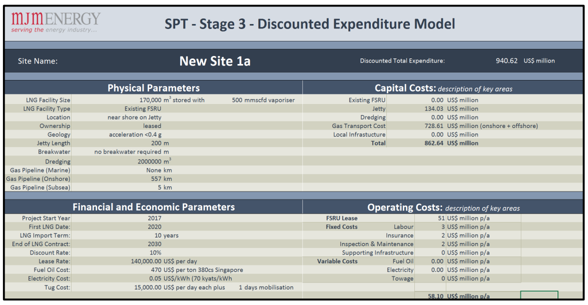
***SPT-Stage 1 (Concept selection***) – This first stage asks a series of generic questions in relation to gas demand, timing, security of supply and ownership, whilst not site specific the answers to these questions will influence site selection. SPT-Stage 1 then uses this data to identify a suggested LNG import technology such as an FRSU or land-based LNG import terminal, although the user can override this with their own preferred choice. The output from SPT-Stage 1 is then summarised in a simple traffic light summary chart as shown on the right.




***SPT-Stage 2 (Qualitative selection)*** – Once a technological choice has been made the user is then asked a series of questions that fall under the following four categories: (1) Getting LNG to the LNG facility; (2) Storing the LNG shipments; (3) Getting LNG out; and (4) Local infrastructure. Responses are analysed and scored using the traffic light methodology. (Red indicates the site has major issues that may not be cost effectively resolved, and green means the site has no substantive issues.)



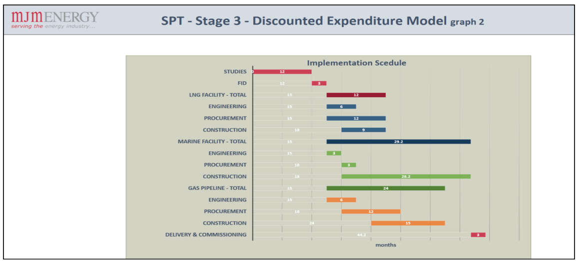
***SPT-Stage 3 (Discounted expenditure selection)*** –SPT-Stage 3 compare the financial, operational and commercial aspects of the different site selection options. The approach used is a simple Net Present Value (NPV) model, which in the absence of income data is based solely on expenditure. The data requirements for STP-Stage 3 analysis includes the following:
***Project data*** (LNG Option, location, ownership, geology, project start year, start of operations and duration, LNG storage, gas demand, vaporisation capacity and utilisation.)
***Marine data*** (Extent and cost of dredging, breakwater, jetty length & subsea pipeline).
***Gas export data*** (subsea and onshore pipelines). In addition to discounted expenditure SPT-Stage 3 also provides a discounted expenditure chart and project implementation plan.


SPT - Stage 3 - Discounted Expenditure Model

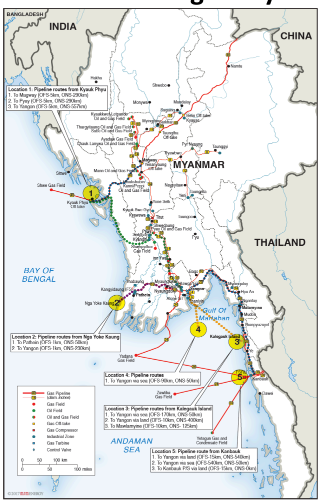
Site Name: New Site 1a — Discounted Total Expenditure: 940.62 US$ million

| Physical Parameters | | | Capital Costs: *description of key areas* | | |
|---|---|---|---|---|---|
| LNG Facility Size | 170,000 $m^3$ stored with | 500 mmscfd vaporiser | Existing FSRU | 0.00 | US$ million |
| LNG Facility Type | Existing FSRU | | Jetty | 134.03 | US$ million |
| Location | near shore on Jetty | | Dredging | 0.00 | US$ million |
| Ownership | leased | | Gas Transport Cost | 728.61 | US$ million (onshore + offshore) |
| Geology | acceleration <0.4 g | | Local Infrastucture | 0.00 | US$ million |
| Jetty Length | 200 m | | **Total** | **862.64** | **US$ million** |
| Breakwater | no breakwater required m | | | | |
| Dredging | 2000000 $m^3$ | | | | |
| Gas Pipeline (Marine) | None km | | | | |
| Gas Pipeline (Onshore) | 557 km | | | | |
| Gas Pipeline (Subsea) | 5 km | | | | |

| Financial and Economic Parameters | | | Operating Costs: *description of key areas* | | |
|---|---|---|---|---|---|
| Project Start Year | 2017 | | **FSRU Lease** | 51 | US$ million p/a |
| First LNG Date: | 2020 | | **Fixed Costs** Labour | 3 | US$ million p/a |
| LNG Import Term: | 10 years | | Insurance | 2 | US$ million p/a |
| End of LNG Contract: | 2030 | | Inspection & Maintenance | 2 | US$ million p/a |
| Discount Rate: | 10% | | Supporting Infrastructure | 0 | US$ million p/a |
| Lease Rate: | 140,000.00 US$ per day | | **Variable Costs** Fuel Oil | 0.00 | US$ million p/a |
| Fuel Oil Cost: | 470 US$ per ton 380cs Singapore | | Electricity | 0.00 | US$ million p/a |
| Electricity Cost: | 0.05 US$/kWh (70 kyats/kWh | | Towage | 0 | US$ million p/a |
| Tug Cost: | 15,000.00 US$ per day each plus | 1 days mobilisation | | | |
| | | | | 58.10 | US$ million p/a |




## Section 4 - Siting analysis




Section 4 of this report, together with the reports for the additional two locations provides an extensive analysis of the five potential locations that MOGE asked the Project Team to examine. These locations consist of five large geographical areas from which 37 different combinations of site and technology were initially examined. These options were then progressively reduced as sites were challenged with different commercial, operational, environmental and timing criteria. For example, onshore Sites 1A1, 3A1 and 3A4, could not be developed in time to meet Myanmar's expectations. Sites 3A3 and 3A6 were rejected on the limited amount of space available on Kalegauk Island. Sites 2A, B and C were simply too exposed in terms of metocean conditions to be of any real use. As a result of this analysis it became clear whilst no one location or site was perfect a number of the sites examined did have some merit which is summarised as follows:

Location 1 is well protected geographically and could accommodate either an FSRU or two FSUs. The Project Team opted for Site 1A1 with a single berth FSRU at Kyauk Phyu as security of supply did not appear to be an issue for MOGE.

Location 2 is exposed and limited by the metocean conditions, ruling out Sites 2A, B and C. However, Site 2D with a nearshore FSRU and therefore afforded some protection has potential.

Location 3 presented several different options between deep water projects and sheltered shallow water projects with either onshore or offshore connecting pipelines. In particular, Site 3A2 (Jetty mounted FSRU at Kalegauk Island with onshore gas pipeline) and Site 3B2 (Tower yoke mounted FSRU at Kalegauk Island with offshore gas pipeline), appeared to have some potential.

Location 4 combined an FSRU, a finger jetty and a direct offshore pipeline with an offshore connection to Yangon. A breakwater was required to mitigate the exposed nature of the site increasing the cost. In addition, whilst the remote location of the jetty offshore does pose some logistical challenges the close vicinity of Yangon as a commercial and technical centre is a clear positive.

Location 5 examined two main options both based on sharing the project costs and capacity with PTT of Thailand. Site 5A consisted of the purchase and conversion of a 10-year old LNGC moored in 26 m of water on a tower yoke mooring, combined with a new 15 km, shared 30" subsea pipeline (MOEE 56.25%, PTT et al 43.75%) which makes landfall adjacent to the existing pipelines from the offshore fields. The RLNG would then be transported to Yangon via a 540 km 30" onshore pipeline wholly owned by MOEE. Site 5B is similar to Site 5A with the RLNG from the FSRU being injected into two new subsea pipelines. One connecting into the existing Myanmar-Thailand lines at Kanbauk (wholly funded by PTT) and the second, a 265 km, 30" subsea pipeline making landfall to the south east of Yangon wholly funded by MOEE or private investors. [3]

After reviewing all the options the following sites were deemed suitable for further examination.

- Site 1A2 – Jetty mounted FSRU at Kyauk Phyu.
- Site 2D – Nearshore FSRU
- Site 3A2 – Jetty mounted FSRU at Kalegauk Island with onshore gas pipeline.
- Site 3B2 – Tower yoke mounted FSRU at Kalegauk Island with offshore gas pipeline.
- Site 4 – An FSRU, with a finger jetty and a direct offshore pipeline connection to Yangon.
- Site 5A and 5B – Where Site 5A consisted of a shared project with PPT (Thailand) using a refurbished LNGC, tower yoke and a land-based pipeline to Yangon and Site 5B was a similar project with an offshore pipeline to Yangon.

Therefore, having identified the above seven sites the Project Team then undertook a more detailed analysis drawing on combination of international experience and the use of SPT-Stage 3 (Discounted Expenditure Model), the conclusions of which are summarised in the following table.

*[3] A third option was considered for Location 5 which considered locating a power station near landfall and moving the energy as electricity. This was excluded on the basis that the proposed power station project would only provide limited power and no gas for Yangon.*

**Table 1 - Summary of the results of discounted expenditure selection**

<table>
<tr><th>Site</th><th>Schedule (Months)</th><th>Capital Investment (US$ million)</th><th>Operating Expense (US$ million per annum)</th><th>Discounted Expenditure (DEX) (US$ million)</th></tr>
<tr><td>Site 1A2</td><td>48</td><td>826</td><td>68</td><td>1,062</td></tr>
<tr><td colspan="5">The above calculation is based on a 557km connecting pipeline to Yangon. FSRU lease payment included in Operating Expense. If Site 1A2 was to opt for the shorter 290km onshore connection to either Pyay or Magway the CAPEX costs would be reduced by $320.4 million, with an equivalent reduction in the DEX figure.</td></tr>
<tr><td>Site 2D</td><td>48</td><td>350</td><td>81</td><td>682</td></tr>
<tr><td colspan="5">The above calculation is based on a 230km connecting pipeline to Yangon. FSRU lease payment included in Operating Expense. If Site 2D was to opt for the shorter 50km onshore connection to Pathein the CAPEX costs would be reduced by $204 million, with an equivalent reduction in the DEX figure.</td></tr>
<tr><td>Site 3A2</td><td>48</td><td>668</td><td>81</td><td>949</td></tr>
<tr><td colspan="5">The above calculation is based on a gas pipeline to Yangon. FSRU lease payment included in Operating Expense. If an intermediate solution was developed with the onshore pipeline stopping at Mawlamyine only 125km from where RLNG is landed from the FSRU a saving of around $330million would be possible.</td></tr>
<tr><td>Site 3B2</td><td>48</td><td>447</td><td>81</td><td>802</td></tr>
<tr><td colspan="5">FSRU lease payment included in Operating Expense.</td></tr>
<tr><td>Site 4</td><td>48</td><td>312.8</td><td>81</td><td>649</td></tr>
<tr><td colspan="5">The above calculation is based on an FSRU, a finger jetty and a direct offshore pipeline connection to Yangon. FSRU lease payment included in Operating Expense. However, due to the exposed nature of the site it would be necessary to include a breakwater to mitigate the exposed nature of the site, the cost of which could be quite variable.</td></tr>
<tr><td>Site 5A</td><td>45</td><td>855</td><td>15</td><td>808</td></tr>
<tr><td colspan="5">The above calculation is based on a joint project with PTT (Thailand) consisting of the purchase and conversion of a 10-year old LNGC (included in Capital Investment) , a tower yoke mooring, a new 15 km, shared 30” subsea pipeline (MOEE 56.25%, PTT et al 43.75%) which makes landfall adjacent to the existing pipelines and a 540 km 30” onshore pipeline to Yangon wholly owned by MOEE.</td></tr>
<tr><td>Site 5B</td><td>45</td><td>640</td><td>15</td><td>621</td></tr>
<tr><td colspan="5">Site 5B, is similar to the option for Site 5A, with the RLNG from the FSRU being injected into two new subsea pipelines. One connecting into the existing Myanmar-Thailand lines at Kanbauk (wholly funded by PTT) and the second, a 265 km, 30” subsea pipeline making landfall to the south east of Yangon wholly funded by MOEE or private investors.</td></tr>
</table>

One might assume that with such large differences in the discounted expenditure figures that choosing the best site would be simple. However, reasons for the large difference are more complex. For example, whilst Site 1A1 is the best marine site, lowest discounted cost with the fastest schedule, success of the project would be contingent on successfully laying a new pipeline in the existing ROW of the Shwe pipeline with any additional local reinforcement costs being socialised by the gas network. In fact, this project could be even cheaper if third party access to the Shwe pipeline could be negotiated.

Site 3B2 using a tower yoke mooring to the west of Kalegauk Island has a similar level of discounted cost, with the connecting pipeline consisting of subsea pipeline direct to Yangon. However, using a subsea pipeline marginally increases implementation schedule and raises concerns over estimated offshore pipeline costs.

Whereas the other project from Kalegauk Island, Site 3A2, requires a long connecting pipeline to deliver its gas into the heart of Yangon, which is the dominating factor in terms of the capital cost. This cost could potentially reduce if either the existing 20-inch pipeline was reinforced to accept the RLNG or the cost of the new 30-inch pipeline to Yangon was socialised by the gas network.

In many ways Site 4 appears to be the cheapest with its direct subsea connection to Yangon. However, the location of the FRSU and the need for a breakwater creates a high level of uncertainty in terms of cost.

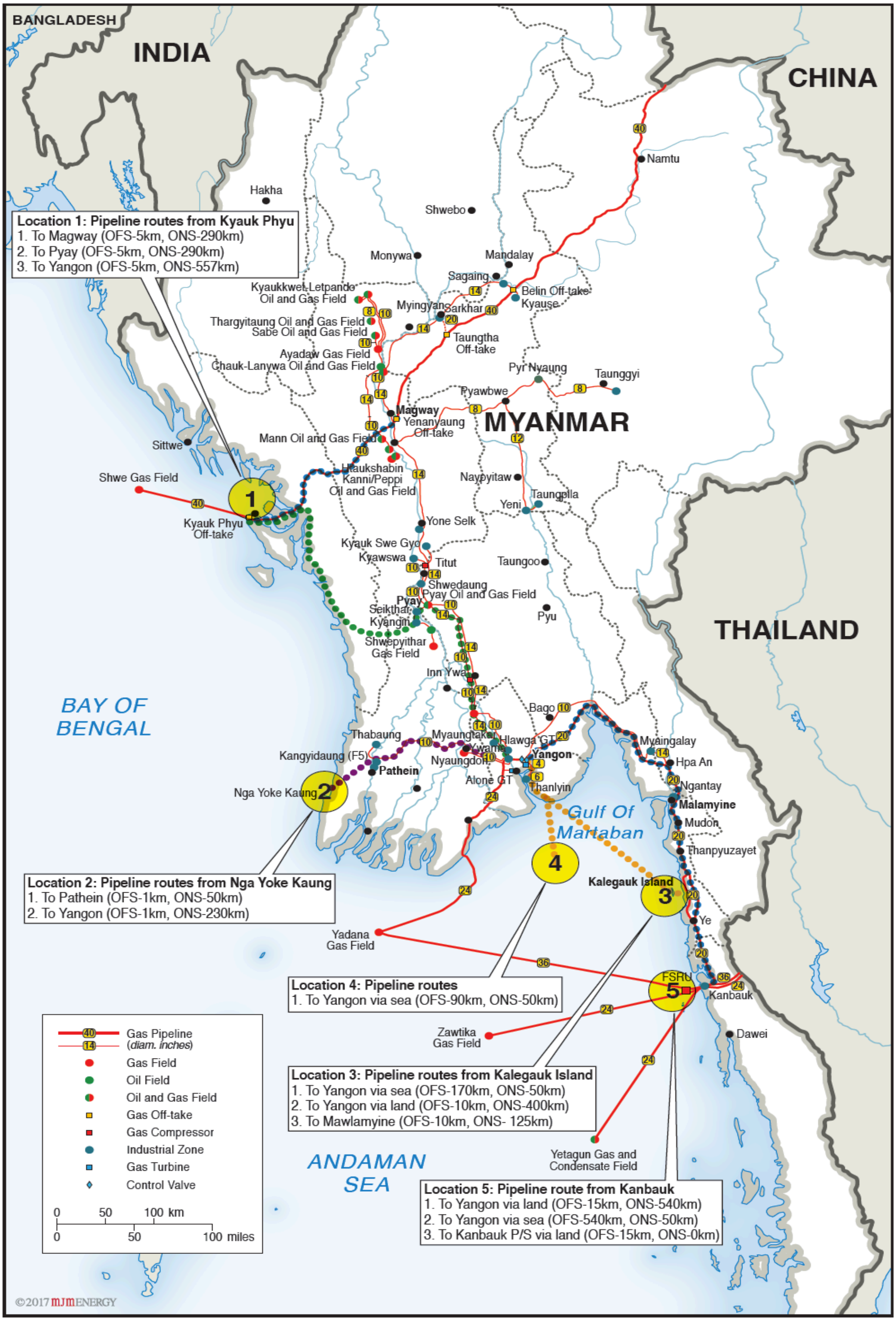
Sites 5A and 5B only really make sense if the project can be developed as a shared terminal with Thailand because, as earlier studies have shown, other sites are just as viable but closer to Yangon (i.e. as a Myanmar only terminal). For example, Site 3 is as good as Site 4 but 100 km closer to Yangon.

## Section 5 – Conclusions and recommendations

### Conclusions

***Task 1(a) Siting analysis*** – The siting analysis has narrowed down the potential options from five broad geographical locations, to fifteen possible options, to seven potentially credible sites. This was achieved through a combination of identifying suitable technologies, understanding the impact of local site metocean conditions, reviewing local conditions in relation to infrastructure (pipeline and marine) and costing the various options. The result of this analysis is summarised in table 1 above.

**Figure 1- Overview of the five main locations examined for MOGE**



***Task 1(b) Site Prioritisation Tool (SPT) –*** The SPT has been developed and consists of three stages: (1) Concept selection; (2) Qualitative selection and (3) Discounted expenditure selection. The spreadsheet model has been developed with simplicity of use in mind. Therefore, many of the default settings and cost settings could be recalibrated with costs local to Myanmar where appropriate.

**Recommendations**
In terms of recommendations each of the seven sites highlighted warrant additional work as follows:

***(1) Site 1A2 (Jetty mounted FSRU at Kyauk Phyu) –*** Whilst this site scores well in all categories, the pipeline connection cost is high, although the overall cost and associated construction risks could be reduced if access could be obtained to the Chinese pipeline. Therefore, we recommend firstly that MOGE consider discussions with the Chinese on TPA and secondly, in order to fully understand the implications of laying a new pipeline in the Shwe pipeline ROW, that MOGE undertake a feasibility study of laying a new 30-inch pipeline.

***(2) Site 2D (Jetty mounted FSRU at Nga Yoke Kaung) –*** Whilst the option is one of the closer options to Yangon it is also sensitive in terms of environment and social issues. Further work would need to be undertaken on both the environmental issues and pipeline costs to Yangon.

***(3) Site 3B2 (Tower yoke mounted FSRU at Kalegauk Island with offshore gas pipeline) –*** This option will be sensitive to subsea pipeline construction costs. Therefore, given the disparity between MOGE's initial offshore pipeline costs and international benchmarks we recommend that MOGE undertake a feasibility study of the long offshore subsea pipeline costs from Kalegauk Island to Yangon.

***(4) Site 3A2 (Jetty mounted FSRU at Kalegauk Island with onshore gas pipeline) –*** With costs in order of $948million this project is one of the more expensive options, although the actual pipeline costs may be less depending upon how the new connecting pipeline and the local gas network interconnect. Therefore, we recommend that MOGE undertake a commercial and operational study of the proposed connecting pipeline to establish a more accurate estimate of its cost.

***(5) Site 4 (FSRU, with a finger jetty and a direct offshore pipeline connection to Yangon) –*** Whilst Site 4 has the lowest discounted cost, these estimates come with high levels of uncertainty in relation to the cost of the offshore pipeline and the breakwater. Therefore, we recommend that MOGE undertake a technical costing study of both the offshore pipeline and the breakwater.

***(6) Site 5A (A shared project with PPT (Thailand) using a refurbished LNGC, tower yoke and a land-based pipeline to Yangon) –*** This project only really becomes viable if cost sharing with PTT becomes a reality, which seems unlikely. If the project were to go ahead, we recommend that MOGE undertake a feasibility study of laying a new 30-inch pipeline to Yangon, since a large proportion of the cost is captured by this pipeline.

***(7) Site 5B (A shared project with PPT (Thailand) using a refurbished LNGC, tower yoke and an offshore pipeline to Yangon) –*** The issues are similar to Site 5A. If the project were to go ahead, we recommend that MOGE undertake a feasibility study for laying a new 30-inch subsea pipeline to Yangon, since a large proportion of the cost is captured by this pipeline.

***(8) General recommendation on managing system reinforcement*** – in addition to the above we also recommend that MOGE considers its policy in relation to system reinforcement and where the costs of infrastructure development are allocated. For example, if some of the onshore connecting gas pipeline costs are absorbed by the local gas network because of the obvious system benefits then Site 3A2 may look more favourable.

# 1 Introduction

## 1.1 General

The high-level objectives of this project are to support the Government of Myanmar (GoM) in developing a gas sector development plan by focusing on the near-to-medium term options to meet the gas demand in Myanmar. Specifically, the project focuses on import options of LNG, initially as a bridging fuel while new gas exploration gets underway in Myanmar, including assessment of potential technologies and locations for LNG receiving facilities in Myanmar. Given the aspirations of the GoM for deliveries of LNG in 2018 or 2019, this suggests prospects for development of floating regasification LNG terminals.

Therefore, in keeping with these high-level objectives, this Report is submitted to the World Bank as a response to the delivery requirements of the project entitled 'Technical Assistance on Liquefied Natural Gas Import Options for Myanmar Phase 1 (Ref:1216215). In particular, this Report encapsulates the following two deliverables:

- Task 1(a) – Report on the siting analysis to assess potential locations of LNG import facilities in Myanmar.
- Task 1(b) – Report on the preparation of prioritisation framework and accompanying analytical tool for LNG import options and locations. The Site Prioritisation Tool (SPT) consists of the following two parts.
    - PT – Part 1 which is a decision making tool located on an Excel platform, using a deceptively simple 'Traffic Light' methodology.
    - PT – Part 2 the 'Discounted Expenditure Model' will also be delivered using a spreadsheet. This model allows an examination of capital costs and operating costs to be compared simultaneously.

### 1.1.1 Objectives of this report

Therefore, in the light of the above, this Report has the following objectives:

- To provide a robust analysis of the three possible LNG import sites proposed by MOGE, highlighting shortcomings in current data and areas for future work where necessary.
- To describe, the approach taken by the Project Team to developing the Prioritisation Tool (PT – Part 1 and PT – Part 2).

### 1.1.2 Structure of this report

As highlighted above this document provides reports for two of the three tasks 1(a) and 1(b), with 1(c) in a separate document. The structure of this report is as follows:

- Section 1 – Introduction.
- Section 2 – Technical introduction, covering LNG technology, metocean analysis, environmental, community and social issues, local infrastructure including tugs, roads, ports, people and pipelines.
- Section 3 – Description of the prioritisation tool (High-level traffic light model and Discounted expenditure model).
- Section 4 – Site analysis.
- Section 5 – Conclusions and Recommendations.

- Appendices – These will include full copies of the marine and metocean reports, plus guidance notes for the site prioritisation tool.

In addition to the above, copies of the site prioritisation tool for use on a 2010 Excel platform (or newer) will be provided.

## 1.2 Why is LNG needed for Myanmar?

Like many other countries in the region, Myanmar has an abundance of natural resources, in particular offshore natural gas. To an extent some of this gas has been exploited and has been exported to countries such as Thailand and China. Gas export is currently the largest sector for Foreign Direct Investment (FDI) in Myanmar and gas production is the largest income export earner with US $3.3billion in 2013-2014.

However, over the next few years Myanmar finds itself in the challenging position of having increased pipeline gas commitments to Thailand and China at a time when domestic demand, particularly in the gas-fired power sector is also growing, leading to a shortfall between gas production and demand. In order to meet this shortfall in gas supplies Myanmar is considering a number of possible options for sites to facilitate LNG imports.

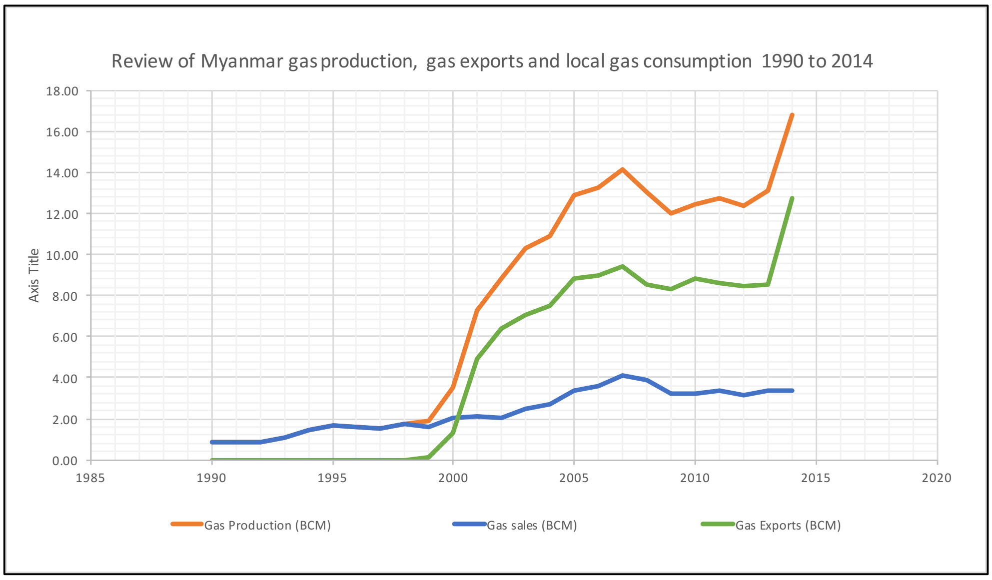
Therefore, in order to understand the importance of Myanmar's need to simultaneously export gas to Thailand and China, whilst also seeking to import LNG and the interaction between these two gas flows, it is useful to briefly examine the following:

- Myanmar's growing gas exports to Thailand and China
- Recent growth in local gas demand in Myanmar
- Current and future exploration and production activity

### 1.2.1 Myanmar's growing gas exports to Thailand and China

It can be seen from the following chart, that over the last decade gas production has increased substantially in Myanmar, largely mirroring the growth in pipeline gas exports to Thailand, and more recently China.

**Figure 2 Review of Myanmar's gas production, gas exports and gas consumption**




Natural gas exports to Thailand, which accounted for an average of 70% of Myanmar's natural gas output over the past decade reached 9.7 BCM in 2014, were joined by pipeline exports to China which commenced in 2014. This resulted in gas exports from Myanmar reaching 12.7 BCM in 2014.

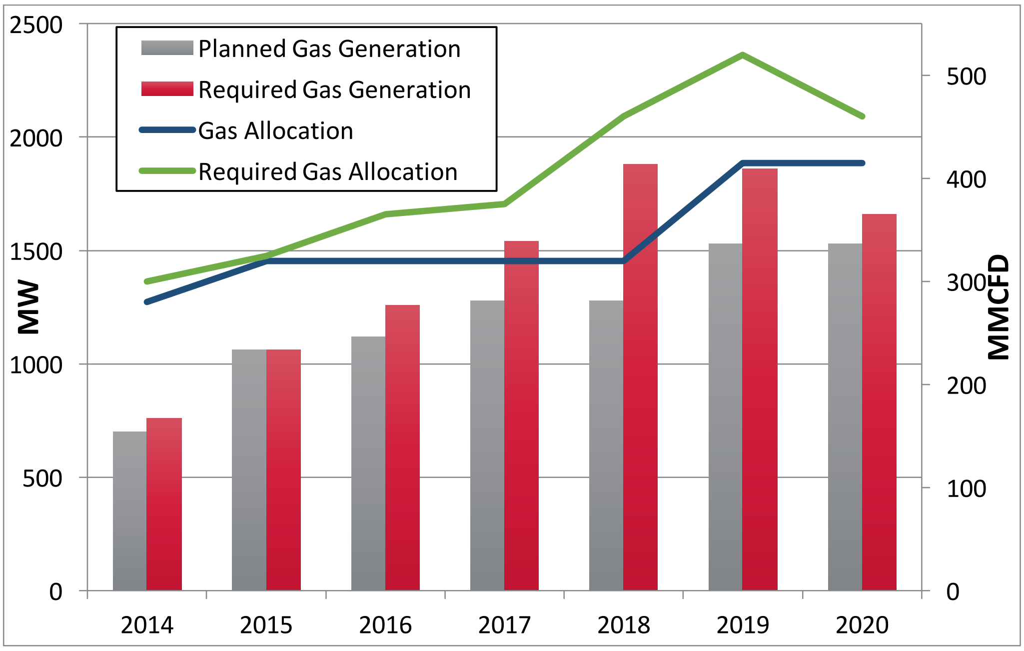
### 1.2.2 Growth in local gas demand in Myanmar

Myanmar is undoubtedly a country going through rapid development. However, much of its population is still cut off from modern grid-based electricity and modern fuels.[4] During the 2013-2014 financial year the domestic utilisation of natural gas in Myanmar accounted for 16% of the total amount produced. The majority of this 16% was used for gas-fired power plants. Domestic demand for gas has continued to rise as more power plants are built and as energy production capacities are improved. While Myanmar's gas discoveries in the past have been significant, in recent years the ability of Myanmar to exploit these reserves, find new reserves and increase gas production in order to meet its growing demand has been limited. Indeed, there is an expectation, at least in the short-term, that domestic gas production growth will be slow, leading to a shortfall in gas required to maintain sector growth.

This need is particularly acute in the gas-fired generation sector as evinced in the TOR and summarised below.

[4] *84% of households in rural areas are cut off from an electrical connection (http://www.worldbank.org/en/news/feature/2015/09/16/electricity-to-transform-rural-myanmar)*

**Figure 3 Supply and Demand of Natural Gas in the Power Sector**




As shown by the above graph, gas-fired power generation is likely to face gas shortages of an estimated 55 mmcfd in 2017 rising to 150 mmcfd in 2018. Therefore, as the demand for domestic gas continues to increase it has become clear that continued large-scale natural gas exportation is a chronic bottleneck to development of the domestic gas utilisation sector. Furthermore, while exports bring in a considerable income[5], gas sold to Myanmar consumers continues to be priced at below-competitive rates. If this were to carry on, then Myanmar's government may find itself running into financial trouble.

### 1.2.3 Current and future exploration and production activity

Myanmar has estimated proven gas reserves of 10 tcf, therefore the issue is not one of not having sufficient gas reserves, the issue is how long will it take to exploit those reserves. Despite its long history in oil and gas production, Myanmar has been slow to exploit its natural resources. For example, prior to 2011, there was no Oil & Gas bidding process in Myanmar with the GoM allocating blocks through direct negotiations. However, since 2010, a number of PSCs have been awarded through licensing rounds, which should eventually lead to additional gas production coming onstream. This future activity is important, since one of the possible solutions to Myanmar's current shortfall in gas supplies is to initiate some form of time swap, which entails future gas production in Myanmar being traded for LNG deliveries in the near future. However, whilst with financial instruments most future gas producers could facilitate a swap, it would be easier with a gas producer that also has LNG available. For example, in the January 2013 licencing round among the thirteen successful bidders were ENI, Brunei National Petroleum and Petronas, all of whom have links with the LNG market. Similarly, in the April 2013 bidding round other successful bidders with an LNG interest included Shell, Chevron, Statoil and Woodside.

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[5] *It was reported in 2015 that the government was earning approximately US$170million per month from gas exports. (http://www.mmtimes.com/index.php/business/15034-govt-earns-us-170-million-monthly-from-gas-exports.html)*

### 1.2.4 Temporary LNG imports for Myanmar

Therefore, if Myanmar is going to meet its rising demand for domestic gas, then the possibility of LNG importation needs to be considered. Also as highlighted above, it is possible that LNG could be used to supplement existing natural gas production for export contracts, until new domestic supplies of gas come on stream. Therefore the purpose of this study is to focus on import options of LNG initially as a bridging fuel while new gas exploration gets underway in Myanmar, either directly as LNG imports or indirectly as LNG swaps.

## 1.3 The MJMEnergy Project Team

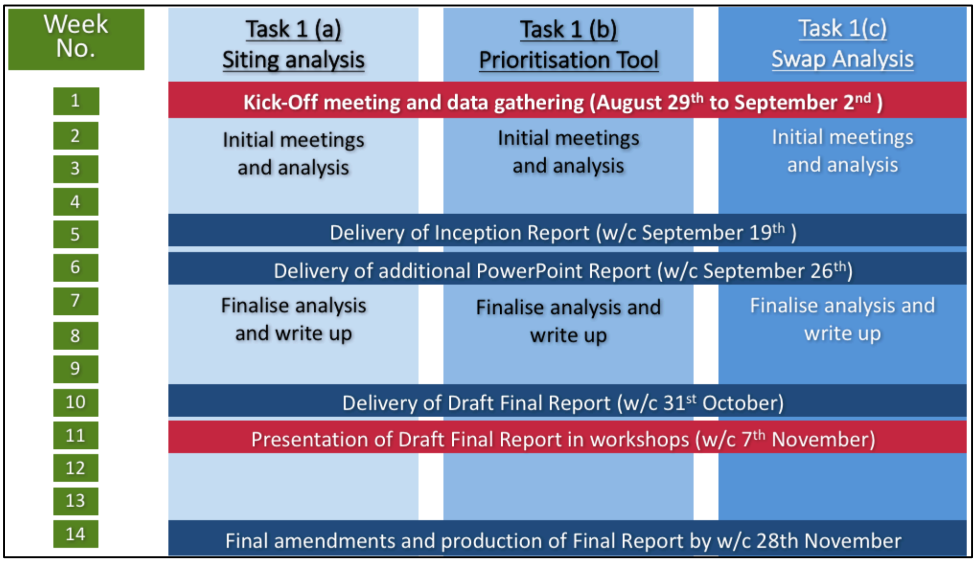
This report has been produced by ***MJMEnergy (UK)*** is associating with ***Penguin Energy Consultants (PEC) (UK)***, ***Economic Consulting Associates (ECA) (UK)***, and ***Drennan Marine Consultancy (UK)***. Together the Project Team brings extensive regional and international experience in all aspects of LNG imports and siting, the development of decision-making frameworks, and LNG markets. In particular, MJMEnergy's technical and commercial experience is complemented by PEC's in depth knowledge of LNG site location strategies, ECA's LNG market and modelling expertise, and Drennan Marine LNG's marine expertise. See Appendix I for more details on each company.

## 1.4 Overview of the process

### 1.4.1 Overall approach to this project

In order to meet the demanding timetable the workload has been divided into three key tasks in a similar fashion to the original TOR with the project overseen by the Project Director, Mike Madden.

**Figure 4 Overview of the process for delivering Tasks 1(a), (b) and (c)**



The work has been broken down into tasks with task leaders as follows:

- **Project Director** – Mike Madden – In order to meet the very demanding timetable the workload has been divided into three key tasks in a similar fashion to the original TOR, with the overall project management provided by Mike Madden.
- **Task 1 (a) – Siting analysis –** David Haynes has led the work on this task assisted by Tom Drennan of Drennan Marine and the CA-Metocean team of analysts.
- **Task 1 (b) – Development of prioritisation tool –** Mike Madden and David Haynes have jointly led this task with the Excel coding being undertaken by the team in the UK.
- **Task 1 (c) – Swaps Analysis –** William Derbyshire has led this area of the work and the report is included in a separate document.[6]

[6] *Task 1(c) – Swaps Analysis has been delivered in a separate report.*

# 2 Technical introduction

## 2.1 Introduction

Choosing a suitable location for an LNG terminal is a complex matter, and is often a compromise between four key physical factors. An ideal site should not be significantly affected by wind and waves, whilst having access to deep water, gas transmission pipeline (or alternatively end-users onsite), and to local infrastructure. These four physical factors are considered below.

Metocean conditions (wind and wave) are the main external factors in determining the availability and operability of an LNG terminal. Successful commercial operation requires the facility to operate for a very high percentage of the year (typically >97%). This requires the LNG facility to remain connected to the gas export pipework and be able to offload LNG from LNG carriers on schedule. A metocean report has been commissioned to determine, at a high level, the wind and wave climates at each site.

Marine terminals are a combination of physical 'hard' characteristics (deep water; shelter; infrastructure) and operational 'soft' characteristics (operational practices; competent services). Physical characteristics can be 'natural' such as natural deep water or "man-made" such as dredged channels for example. These physical characteristics, and the geography and geology that impacts on them, are crucial for enabling LNG vessels to access the facility.

The LNG terminal must be connected to the end user(s), in this case power generating stations. These could be located at the LNG site and then connected to the electricity grid by new cables or at some distant point requiring gas to be delivered by transmission pipeline. In Myanmar the power use requirements are centred on the major cities, particularly Yangon, so the emphasis is on providing additional pipelines or enhancing existing pipeline capacity. The size and cost of these gas transmission lines varies by their distance to market, the terrain which they pass through and the amount of gas supplied, providing another key factor in the relative merits of potential sites.

LNG terminals also have a number of local infrastructure needs:

- Tugs able to move and position the LNG carrier at the LNG facility.
- Roads or marine transport able to deliver construction equipment and material, operating consumables and provide access for staff and vendor representatives.
- Availability of ports able to provide services such as pilotage, importation of equipment, etc. and have appropriate rules and experience of hydrocarbon operations.
- Access to skilled people to operate or support the LNG facility or the ability for expatriates to access the facility.

In addition to the four physical factors provided above, international financiers will require assurances that people and the environment are not unduly damaged by the construction and operation of the LNG facility. Mynamar implemented an Environmental Impact Assessment procedure in December 2015 via the Ministry of Environmental Conservation and Forestry (Notification 616/2015). In addition, international financiers will look to the IFC Performance Standards and Equator Principles as minimum standards for environmental compliance. The recent adoption of the EIA guidance means that there has been limited survey work conducted in Myanmar on which to base assessments. Typical sensitive environments, at least in public perception terms, are:

- Impact on sensitive environmental areas such as national parks, marine reserves, coral and mangrove forests, etc.

- Impact on community issues such as fishing grounds and tourist areas (revenue generation).
- Impact on culturally sensitive sites such as temple complexes, sports stadia, etc.

These physical and environmental factors will also influence, and be influenced by, the choice of LNG technology deployed, whether a land-based terminal, an FSRU, or other approaches to LNG regasification.

This section of the report address each of these factors in greater detail as follows:

- LNG technology
- Metocean analysis
- Environmental issues
- Geography and geology
- Local infrastructure
- Pipelines

## 2.2 LNG technology

The purpose of this section is to provide an overview of LNG importation, storage and regasification technologies and highlight the advantages and disadvantages of each. LNG facilities are available in a variety of forms, located both onshore and offshore. Traditionally onshore terminals have been employed consisting of a marine jetty to berth LNG carriers, storage tanks, pumps and vaporisers. These terminals are then connected to pipelines and/or major gas users such as combined cycle gas turbine power plants.

More recently a range of offshore technologies have been developed for the importation of LNG. These essentially involve the modification of LNG Carriers (LNGCs) either through conversion or by including new elements in shipbuilding programmes. These are called Floating Storage and Regasification Units (FSRUs), Floating Storage Units (FSUs), GasPorts, gravity base structures (GBS) or LNG Regasification Vessels (LNGRVs).

Hybrid technologies are also employed. For example, an FSU needs a regasification unit which can be located onshore or on some other floating structure.

Each technology has several facets associated with it and those of prime importance that need to be examined for suitability for sites in Myanmar are:

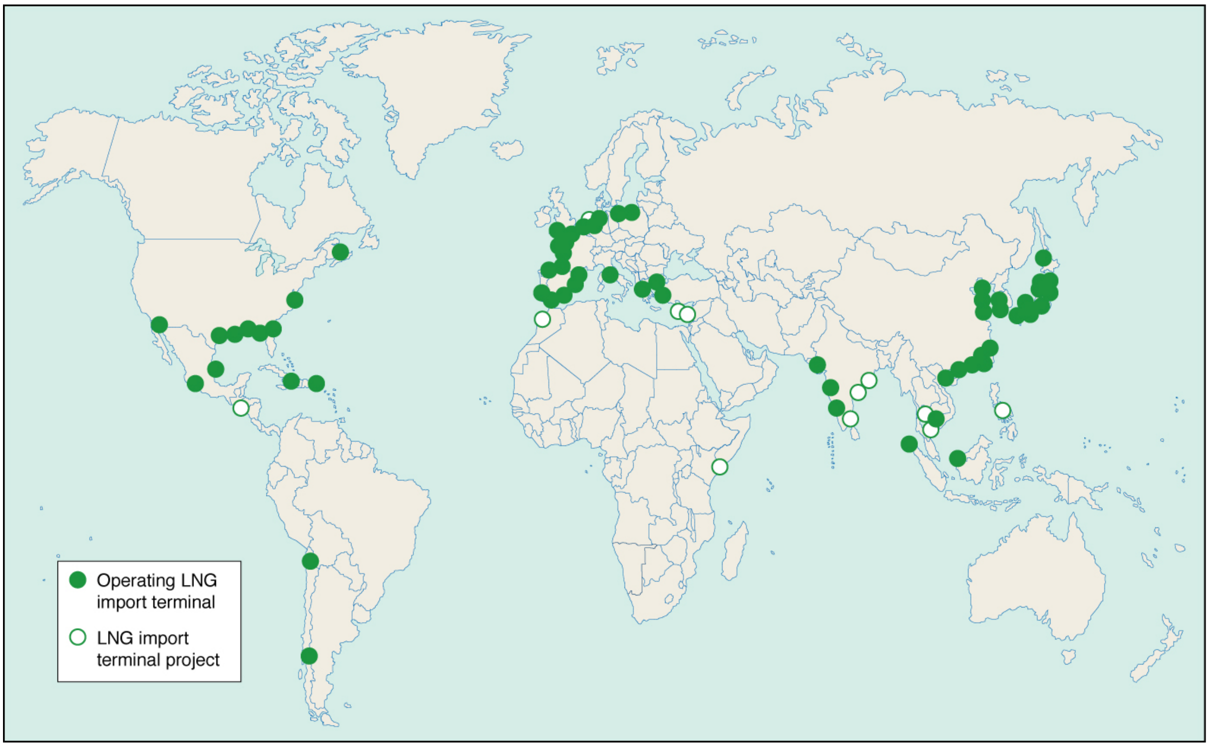
- *Cost* – This includes the capital costs of construction and the ongoing operating costs of the facility.
- *Schedule* – The time taken to design and build the facility.
- *Space* – This relates to how much area is required for the technology.
- *Metocean performance* – The ability to survive and operate in the local wind and wave environment

As described in Section 3 following, the LNG concept selection tool is designed to ask questions that address some of these more generic issues, before the use of the traffic light site selection tool that looks at more site specific issues such as space/local impact and metocean performance.

### 2.2.1 Onshore LNG Terminal

The first LNG terminal opened in 1964 at Canvey Island in the UK. Since then a further 94 LNG terminals have opened in 23 countries. All remain in operation apart from Canvey Island (which has been converted to import liquefied petroleum gases (LPG) rather than LNG) and Le Havre (the second terminal) in France. Both these terminals ceased LNG operations because they became too small for the increasing size of LNG carriers.

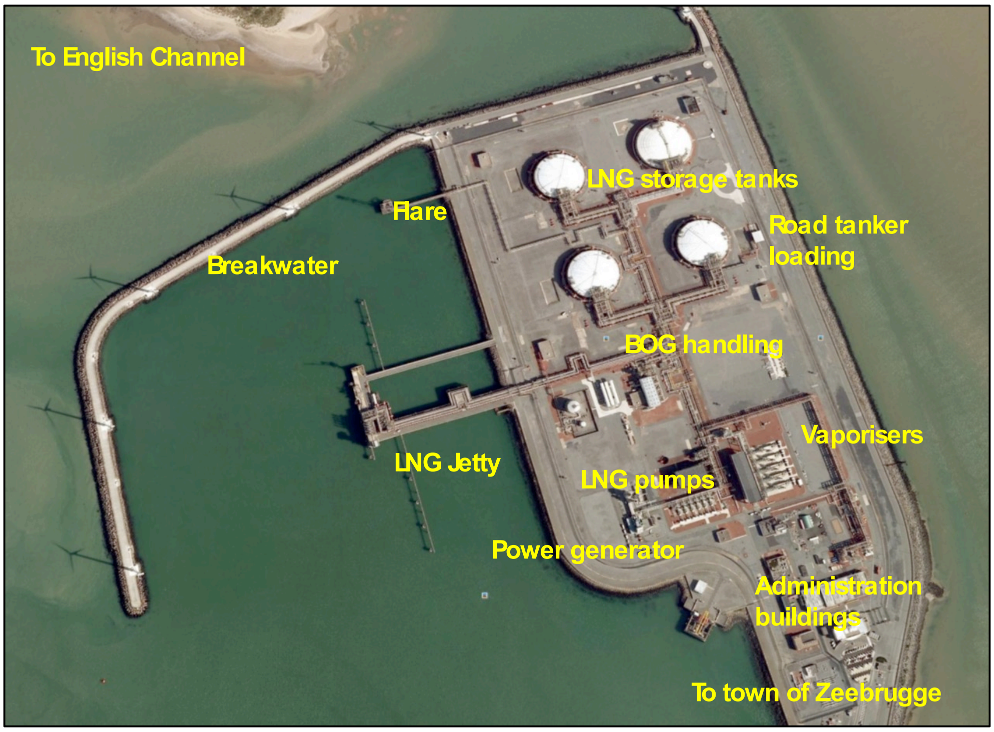
**Figure 5 – World map of LNG import terminals**




Onshore terminals continue to be built with two in Europe (Dunkerque LNG in France and Polski LNG in Poland) receiving their first cargos in 2016. Others are planned or under constructions in El Salvador, the Philippines and India. LNG import terminals cover a wide range of storage capacity and vaporisation capability. Small terminals, for example, Nagasaki in Japan provide the needs of small cities, Andres in the Dominican Republic supplies a single 350 MW power station while Japan and South Korea also have mega terminals that provide national supplies.

Import terminals consist of a marine jetty to moor the LNG carrier to facilitate unloading. The marine berth can be protected by a breakwater to ensure a large operating window for the unloading process. LNG storage tanks take a variety of forms but are essentially large conventional metal storage tanks. Several storage tanks can be used to create a large inventory of LNG storage which can meet national/political security of supply requirements, support seasonal operations and unload the largest LNGCs. Vaporisation technology can take many forms depending on the availability of local resources, but for an onshore terminal can include the use of seawater, air and natural gas.

**Figure 6 – Overview of a LNG import terminal (Zeebrugge, Belgium)**




The great advantage of an onshore import terminal is this variation in size and capability. Anything that can be envisaged can be built if the selected terminal site is sufficiently large. Subject to the design, LNG is available onshore, which means that it can also be transported by road and rail to isolated end users who do not have access to a gas pipeline, or alternatively to other fuel supply infrastructure for use as a transport fuel by vehicles, railways and shipping.

Other advantages include the creation and maintenance of local jobs, initially for construction and then at higher skill levels for operation and maintenance. The potential for security of supply is ensured as the terminal is located within the country. LNG terminals have shown appreciable longevity with many examples from the late 1960s and early 1970s still in operation, and only the first two built have been decommissioned due to increasing LNG ship sizes. Operating costs can be very low as "free" ambient energy (seawater, air) can be used for vaporisation. Finally, if sufficient land is available for redundant equipment, the terminal can ensure very high levels of availability (reliability) ensuring a continuous gas supply. Typical availability guarantees for import terminals are in the range 95 – 99.5% with some achieving 99.9% of their time online.

However, onshore LNG terminals do have some disadvantages, in particular relating to cost, schedule and environmental impact. Capital costs for import terminals can be high. This depends very much on the site selected. Geology and topography, both onshore and particularly offshore (bathymetry) play significant roles. Typically the two largest costs are the marine jetty, which needs to reach deep water, and the LNG storage tanks, which may need substantial foundations. In addition dredging and breakwater costs are often major factors in import terminal economics.

LNG terminals are typically owned by a local entity. This will require a creditworthy local company and/or a sovereign guarantee to secure funding. There is a limited possibility of established terminal operators building and operating the terminal for a fee (only Spain and Mexico provide examples).

The construction schedule is normally determined by the storage tanks which can take 30 to 55 months to build depending on the size and technology selected, with most facilities taking three to four years to complete. Methods to accelerate construction by using LNGCs as temporary storage tanks have been used in two projects in Chile. However, the cost of stranding an LNGC is significant and, like Chile, would require high prices due to exceptional fuel supply limitations to be economic.

The environmental impact of an onshore LNG terminal can be significant. Firstly the land required may be taking important resources away from local communities. If these resources are historically or culturally important the level of damage will be magnified. Visually the storage tanks are large and can often be seen from a considerable distance. If dredging or a breakwater is required, local hydrology can be affected resulting in potential impacts on local fisheries, coastal erosion and vegetation/habitats. Some vaporisation technologies produce significant amounts of cold water, including biocides, which can damage local fisheries and spawning grounds. Noise may also be a concern.

The advantages and disadvantages of onshore, conventional, LNG terminals are summarised in the following table.

**Table 2 – Advantages and disadvantages of onshore LNG terminals**

| Advantages | Disadvantages |
| --- | --- |
| Many operating examples | High capital costs |
| Wide range of storage and vaporisation rates used | Long construction schedule |
| Security of supply/availability is very high | Sovereign guarantee and debt most likely financing/construction model |
| Substantial local labour contribution | Environmental impacts |
| Longevity of implementation | |
| LNG available for other uses (transport, stranded users) | |
| Low operating costs | |
| Variety of vapouriser technologies to suit local environmental conditions. | |

## 2.2.2 Gravity Base Structures (GBS)

Gravity Base Structures (GBSs) are effectively manmade islands with an LNG import terminal built in. Their design retains most of the advantages of the onshore import terminal and is able to mitigate most of the environmental disadvantages.

Adriatic LNG in Italy is the sole example of this type of LNG facility. It was constructed between 2005 and 2008 in Spain and then towed to its site, 15 km offshore of Venice, Italy in the Adriatic Sea. The terminal is owned by a joint venture of Qatar Petroleum and ExxonMobil and has operated successfully for seven years.

A GBS consists of a concrete box inside of which are the storage tanks and above which is the vaporisation plant. The outside of the box acts as a mooring structure for LNGCs. The vaporisation technology is entirely conventional while the storage tanks are modifications of those used in LNGCs although cylindrical onshore type tanks have been envisaged by others. In theory the GBS can be relocated to another site. However, the design will be performed for the initial seabed geology and the options for re-siting may therefore be limited.

**Figure 7 – Overview of Adriatic LNG GBS import terminal[7]**

The main advantage of this design is that conventional technology can be used for the storage and vaporisation of the LNG. Any size of GBS could be built so storage capacity and vaporisation capability remains considerable. A GBS can, at least theoretically, be located anywhere, so can be positioned out of sight of local people and away from sensitive environmental, social and cultural locations, particularly fisheries and rare coastal habitats.

The remote siting of a GBS, however, can attract significant cost disadvantages. Capital costs are essentially based on the amount of concrete used and therefore water depth. The deeper the water the higher the cost and the lower the economic attractiveness. Adriatic LNG for permitting reasons needed to not be visible from the Italian coast, which resulted in it being sited in deep (29m) water and becoming a high cost solution. Other proposed GBSs in the US Gulf of Mexico (Compass Port, Pearl Crossing, Gulf Landing and Port Pelican), Taiwan and offshore Mexico were abandoned because of high costs. Various attempts have been made to reduce capital costs but as yet no new attempt to construct a GBS for LNG has been attempted.

In theory, GBS operating costs will remain low, but will be higher than for an onshore terminal as it is harder to get to work or deliver supplies to an offshore facility. The GBS can be constructed anywhere and locations with low construction labour costs are preferred. However, this substantially reduces the impact of the terminal on the local economy as construction jobs (and the resultant taxes) are outsourced. The construction schedule for a GBS remains relatively long and is generally comparable with an onshore import terminal. While most of the environmental impacts of an onshore terminal are mitigated, cold water containing biocides from vaporiser discharges may remain an issue.

[7] *http://www.lngworldnews.com/wp-content/uploads/2015/01/Adriatic-LNG-issues-single-cargo-tender.jpg*

There are other specific technical challenges for a GBS. The seabed geology is very important as the GBS must directly sit on the seabed. If the seabed is too soft the GBS may settle, while if the seabed is not homogenous then items such as rocks will need to be removed prior to installation. In addition cost issues mean that the length of the GBS needs to be minimised. This limits the ability of the GBS to protect a berthed LNG carrier. In open water, wind and wave strengths are often worse than near shore so greater ship protection is required. As a result of this the availability of a GBS LNG terminal will be less for an onshore terminal.

The advantages and disadvantages of a GBS LNG terminals are summarised in the following table.

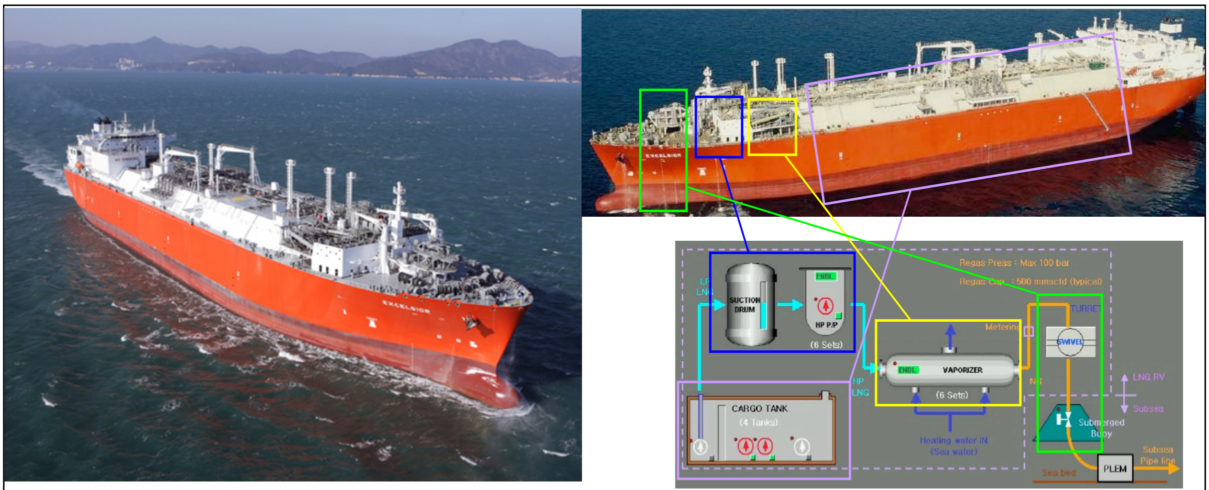
**Table 3 – Advantages and disadvantages of GBS LNG terminals**

| Advantages | Disadvantages |
|---|---|
| Wide range of storage and vaporisation rates possible | Only one operating example |
| Security of supply is good but limited | High to very high capital costs |
| Low to medium operating costs | Long construction schedule |
| Relocation possibilities (but likely to be limited) | Construction likely to be outsourced reducing labour and tax benefits |
| | Low environmental impacts |
| | Seabed geology plays a considerable role making site selection more challenging |

## 2.2.3 LNG Regasification Vessels (LNGRVs)

Whilst traditionally LNG terminals have been built onshore, over the last decade there has been rapid growth in the deployment of various forms of offshore LNG regasification technologies. The first offshore LNG terminals were LNG Regasification Vessels (LNGRVs), also referred to as the "energy bridge". Gulf Gateway, the first offshore regasification project, was commissioned in 2005.

**Figure 8 – Overview of an LNGRV**



The main concern at the time was the transfer of LNG from one vessel to another in open seas. LNGRVs avoided this by collecting LNG at a conventional berth at a liquefaction terminal and then exporting gas via a buoy and riser system common in the offshore oil and gas industry.

The LNGRV consists of a modified LNGC which has high pressure pumps, seawater vaporisation system and the buoy mooring system included in the bow of the LNGC. All the LNGRVs are able to operate as LNGCs if LNGRV service is not required. LNGRVs are very robust in terms of delivery capability as they can operate in turbulent sea and weather conditions. One vessel operated within 200 miles of Hurricane Katrina hitting the US Gulf coast in 2005. Considerable development and testing was performed prior to service which has assisted all the subsequent floating LNG terminals.

There are currently only two companies, Excelerate Energy and Hoegh, that own and operate LNGRVs. Most of these vessels are operating as GasPorts (FSRUs). The lack of competition and limited availability of the vessels may mean that charter (lease) prices will be high. Similarly there will be no opportunities for local workforce or taxes as the ships exist and are owned by others and worked by international crews. Using a lease route means that the host country will not need to take on any debt and that deployment times can be negotiated to fit with the gas market requirements, however short they may be.

LNGRVs have not been that commercially successful. The Gulf Gateway terminal was removed in 2012 after it had not been used for several years. The Northeast Gateway and Port Neptune which are both located offshore of Boston in the USA have not been used for some time and have been significantly affected by the shale gas revolution and low prices taking place in the US. The Gulf Gateway buoy was installed offshore of Hadera in Israel to enable fast schedule imports until the development of indigenous reserves. However, relocation of this technology is straight forward.

LNGRVs can be built on a similar schedule to LNGCs. This is faster than onshore LNG terminals at 24 – 30 months. At the current time (mid 2016) the large LNGC shipbuilding yards have construction slots available. Construction of the buoy and subsea pipeline can be faster than the LNGRV but is highly dependent on local and particularly permitting requirements.

Operating costs for LNGRVs are higher than import terminals. The LNGRV operates as a LNGC for most of its life collecting the LNG and transporting it to the buoy site. Fuel usage is therefore significant. While on the buoy, fuel will need to continue to be burnt if steam is required to vaporise the LNG. This is called closed loop vaporisation and does not have any environmental impact on the sea as no cold water is discharged. Gaseous emissions ($CO_2$, $NO_x$, particulate matter) are produced instead. If "open loop" vaporisation is allowed, local seawater will be used which returns cold water containing biocides. In addition the capital costs of the vaporisers, buoys and pumps are high considering the technology is only used infrequently.

LNGRV capital costs appear modest compared to LNG import terminals. However, each LNGRV has a penalty of about US$ 100 million over an LNGC of the same size for the additional equipment. At least one LNGRV will need to be static on the buoy during normal operations. Whether the capital costs are competitive with other forms of regasification depends on how many vessels are required to collect the LNG (acting as LNGCs). It only requires 2 or 3 of these LNGRVs to add sufficient extra capital to make the LNGRV a similar cost to a conventional onshore LNG terminal. The buoy and onshore pipeline capital costs also need to be considered and can add considerable expense in some scenarios. LNGRV owners have historically been reluctant to provide this infrastructure which then requires a separate contracting element. However this position is changing.

Security of supply is a major issue for LNGRVs. If continuous gas use is required then two buoy systems need to be installed so that when one LNGRV is almost empty another full vessel arrives and connects to allow a seamless switch over. Storage capacity on each LNGRV is limited.

The advantages and disadvantages of a LNGRVS are summarised below.

**Table 4 – Advantages and disadvantages of LNGRVs**

| Advantages | Disadvantages |
|---|---|
| Short schedule | Capital costs high and often similar to onshore terminals |
| Low or no environmental impacts | No local content (labour or taxes) |
| Can be easily relocated | Limited security of supply |
| Lease/charter structure means no local debt | High operating costs |
| Deployment may be short term | Limited vendors |
| Robust in more extreme wind and wave scenarios | Few operating examples and only one supplying baseload |

### 2.2.4 FSRUs and GasPorts

Floating Storage and Regasification Units (FSRUs) and GasPorts are essentially the same technology branded in different ways by competing companies. An FSRU is a LNGC with additional equipment to allow vaporisation and export of gas. Most FSRUs are able to trade as an LNGC if no regasification work is available. This remains essential to their financing, but the increased prevalence of FSRUs is diluting this requirement.

All current FSRUs except one operate in very sheltered port environments. Only the OLT Toscana FSRU in Italy operates in deep, unprotected waters. Early FSRUs were conversions of old LNGCs or used as LNGRVs in a port environment. This model remains an option, although subsequently new build FSRUs have been constructed for projects and on a speculative basis.

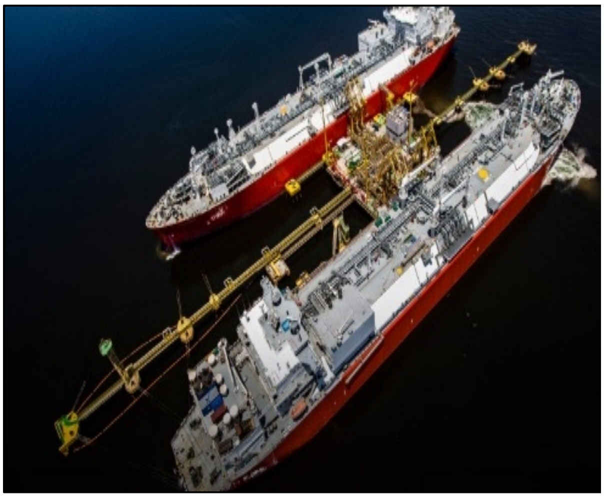
FSRUs appear the terminal of choice at the present time (mid 2016) but are not suitable to all locations or operating profiles. However, there are many examples of operating FSRUs and this is growing all the time.

**Figure 9 – Worldwide FSRUs**


FSRUs use a variety of mooring systems with some sort of jetty being the most popular. However turrets (OLT Toscana, Italy) and tower yoke (FSRU Lampung, Indonesia) systems have been employed as moorings at locations where the FSRU is exposed to variable wind/wave climates. The key difference between FSRUs and LNGRVs is that LNG is transferred from a normal LNGC to the FSRU. The FSRU does not need to collect the LNG. This means that all the additional and expensive equipment on board is used regularly and therefore more cost effectively. LNG transfer can be effected by many means, using either conventional Chiksan LNG offloading arms or flexible hoses. Hoses predominate as the loading arms prevent the FSRU trading as a LNGC. Flexible hoses have been available to the LNG industry as emergency offloading technology for a long time but have only been commercialised for regular LNG transfer in the last ten years. LNG transfer remains the main limiting factor for FSRUs as it can only take place in "benign" wind/wave conditions. This means that port environments remain preferred.

**Figure 10 – Mooring Configurations for FSRUs[8]**

Finger Jetty (FSRU Independence, Lithuania)

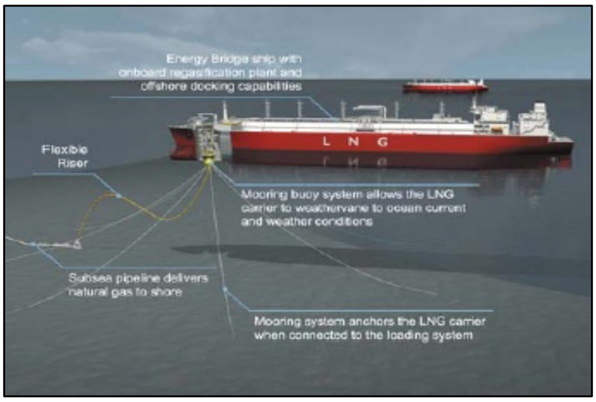


Island Jetty (Guanarbara Bay, Brazil)

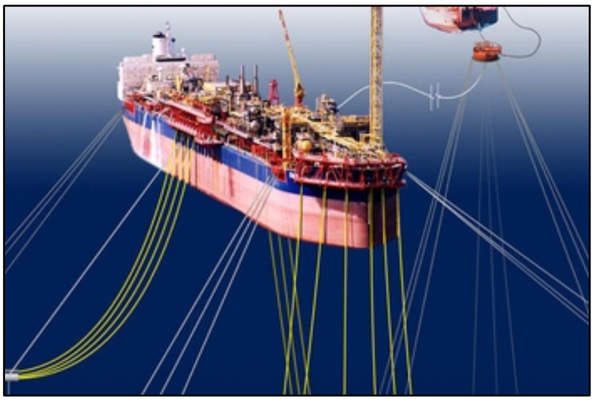
Tower Yoke Mooring (*FSRU Lampung, Indonesia)*

External Turret Mooring (OLT Italy)

[8] *Finger Jetty (FSRU Independence, Lithuania) http://www.lngworldnews.com/wp-content/uploads/2015/04/FSRU-Independence-received-one-LNG-cargo-in-March.jpg, Island Jetty (Guanabara Bay, Brazil) http://excelerateenergy.com/wp-content/uploads/2015/01/Excelerate_FSRU_Brazil_41-1024x457.jpg Tower Yoke Mooring (FSRU Lampung, Indonesia) http://www.rambuenergy.com/file/2014/10/FSRU-Lampung-Hoegh-LNG-photo-660x330.jpg External Turret Mooring (OLT, Italy) http://www.oltoffshore.it/en/fsru-image-gallery/ Spread Mooring http://fukymarintech.weebly.com/uploads/2/8/8/9/28896207/___8957783.jpg*




Internal Turret Mooring (*FLNGRV Gulf Gateway, USA)*



Spread mooring schematic (None Known)

There are a range of different mooring systems in use (as shown), as their effectiveness is dependent on weather conditions and water depth. The key features are shown in the following table.

**Table 5 – Mooring system features**

| **Mooring** | **Variant** | **Wind/wave protection** | **Water depth** | **Comments** |
|---|---|---|---|---|
| Jetty | Finger jetty | Breakwater | <20 m | Several examples |
| | Island jetty | Breakwater | <20 m | Several examples |
| Tower Yoke | | Weathervaning | 20 – 50 m | 1 in Indonesia |
| Turret | External | Weathervaning | >50 m | 1 in Italy |
| | Internal | Weathervaning | >50 m | Original GasPorts |
| Spread mooring | | Not possible | Deep water | Anchor/mooring lines can interfere with LNGC approach |

Sloshing is an issue for all floating LNG facilities. Sloshing is the formation of waves inside the LNG tank caused by waves outside of the FSRU. When sloshing waves hit the tank wall they transfer some of their kinetic energy into the structure of the tank. Membrane type tanks, in particular, can be damaged by this phenomenon and need to be specially reinforced to operate at all tank filling levels. LNGCs only operate empty or full. This makes conversion of LNGCs more difficult. FSRUs can use open and closed loop vaporiser systems dependent on location and its environmental sensitivity.

**Figure 11 – Overview of an FSRU (Dubai)**


There are currently only four companies, BW, Excelerate Energy, Golar and Hoegh, who own and operate FSRUs, although several LNGC owners are now looking to enter this market with MOL, Marangas and Dynagas currently building their first units and GasLog and Teekay reviewing options. Historically there has been limited competition and poor availability of the vessels, which led to high charter (lease) prices. This trend has started to reverse in recent years with FSRU charters expiring and being replaced with vessels from alternative suppliers (Kuwait replaced Excelerate with Golar, Dubai replaced Golar with Excelerate). However the availability of FSRUs remains limited and high charter rates remain (eg press reports on Bangladesh).

Capital costs for FSRUs are largely on the basis of LNGC plus the additional equipment. At the current time (mid 2016) this is approximately an extra US$ 70 million. Any jetty/mooring system, pipeline connections (onshore and offshore) and site preparation such as dredging needs to be added to these costs, and if these add on costs are extensive, FSRUs lose their competitiveness against onshore import terminals.

FSRUs remain classed as ships and therefore need to follow maritime regulations for maintenance and crewing. As a result operating costs are significantly higher than for onshore import terminals. As FSRUs are mostly on a lease basis there will be no opportunities for local workforce or taxes as the ships exist or are built and owned by others and worked by international crews. Using a lease route means that the host country will not need to take on any debt and that deployment times can be negotiated to fit with the gas market requirements, however short they may be.

FSRUs can be built on a similar schedule to LNGCs. This is faster than an onshore LNG terminals at 24 – 30 months. At the current time the large LNGC shipbuilding yards have construction slots available. Construction of the supporting infrastructure mooring/jetty and subsea/onshore pipeline is highly dependent on local and particularly permitting requirements and may negate the construction advantage. However, FSRUs have achieved remarkable Financial Investment Decision (FID) to in service times – for example, 12 months for the Teesside GasPort (UK) – when an existing unchartered FSRU is available.

FSRUs have limited storage capacities which can only be as large as the ship's hull. Typically this is 170,000 $m^3$ for modern new builds but could be as large 260,000 $m^3$ (GNL del Plata in Uruguay is building this size of FSRU). The FSRU storage capacity needs to reflect the size of the LNGCs supplying the project. LNGCs have been increasing significantly in size over the last 10 years with current LNGCs under construction now in the range 160,000 – 175,000 $m^3$. This has significantly reduced the attractiveness of converting old tonnage (typically 125,000 – 138,000 $m^3$) as the percentage of the LNGC fleet able to serve these vessels is fast reducing.

A lack of available FSRUs has once again highlighted the potential of LNG carrier conversions, this time however using larger and less old vessels, say in the range 145,000 – 155,000 $m^3$. These vessels are only 10 – 15 years old and therefore will require a larger capital investment to purchase. Excluding the identification and purchase of the hull, capital investment in the regasification systems is of the order of US$ 70-90 million and takes 20-22 months. These schedules are longer than many quoted in the media but the previous conversions mostly took longer than the project developer's hoped.

Conversion of LNGCs under construction in shipyards is also possible. The two limiting factors are the storage tank technology and purchase of the additional equipment. If a membrane type LNG tanker is to be converted the storage tank needs to be of the reinforced type. Tank construction starts 9-12 months after keel laying, if this time is exceeded the tanks would need to be removed and rebuilt extending the schedule and increasing costs. Similarly the high pressure pumps, vaporisers and any additional BOG equipment need to be ordered. These are relatively long lead time items (currently about 12 months) so again there is a schedule cut off point where the conversion increases delivery times.

Similar to LNGRVs, environmental impact largely depends on the vaporisation technology used (open or closed loop), however, the physical size of a LNGC/FSRU is significant and has a visual impact which is why OLT Toscana was moved 22 km offshore. Relocation and reuse is anticipated for many FSRUs being operated or constructed at the current time, although local environmental regulations will determine how much modification is required and therefore how effective this assumption is. Replacement on the expiry of existing charters has occurred.

Barges have been proposed as alternatives to ship-based FSRUs. Barges can often be built locally and more cost effectively. However, they lack mobility and to date have been less attractive from a financing perspective as they cannot trade if FSRU activity is absent. Belgian LNG ship owner, Exmar, is currently building a small regasification barge of 26,000 $m^3$ in China and a similar-sized FSRU is located off the Indonesian island of Bali.

**Table 6 – Advantages and disadvantages of FSRUs**

| Advantages | Disadvantages |
|---|---|
| Many example projects available | Capital costs moderate to high, non-FSRU elements such as dredging, pipelines or mooring can dominate |
| Short schedule often defined by permitting and not purchase/construction | No local content (labour or taxes) |
| Low or no environmental impacts | Limited security of supply as storage volume limited (particularly conversions) |
| Can be easily relocated | High operating costs |
| Lease/charter structure means no local debt | Limited vendors but steadily improving |
| Deployment may be short term | |

## 2.2.5 Floating Storage Units (FSUs)

Floating Storage Units are FSRUs without any vaporisers. Vaporisation is carried out onshore or on another floating structure. The premise for this technology option is that an old LNGC can be purchased inexpensively and quickly converted to serve as a floating storage tank resulting in a step change in costs. Vaporisation can be separately contracted, often ashore to reduce costs and schedule. Only one FSU import terminal is in operation (Malacca LNG, Malaysia) with a second about to start commissioning (Malta). Other LNGC owners have used LNGCs for storage on a temporary basis. Many project developers are examining this option because of the current oversupply of LNGCs and therefore low prices for resale of old tonnage which are close to scrap values. The LNGC market tends to operate in boom and bust cycles, so it would be expected that these very low second hand prices will be of limited duration.

**Figure 12 – Operating FSUs[9]**

*Malacca Strait, Malaysia*


*Maltese FSRU preparing to leave Singapore*

FSUs to date have all been moored against jetty type structures. Any form of weathervaning mooring would be difficult as the FSU has to transfer LNG, first from a LNGC and then to the vaporisation unit. The former option is possible (see FSRUs), but the transfer to a fixed vaporisation unit is problematic and would require some form of subsea LNG piping system. These have been much discussed by the industry for about 15 years; designs are available but the technology is yet to be commercialised. FSUs are therefore currently limited to ports or locations with unidirectional waves or protected structures where a jetty structure can be used and LNG transfer from the LNGC to FSU will be by hoses or hard arms.

Similar to FSRUs, sloshing is potentially an issue. When converting an LNGC to FSU, use of Moss type LNG carriers would be preferable as reinforcement of membrane would be a major piece of reconstruction.

[9] *Malacca Strait, Malaysia http://www.thestar.com.my/~/media/online/2016/02/11/18/45/bizd_5a_sabry_17.ashx/?w=620&h=413&crop=1&hash=B3C2FB8763B5F40C67CA4EDCF6608DB52E4B3F80, Maltese FSRU preparing to leave Singapore http://worldmaritimenews.com/wp-content/uploads/2016/08/Maltas-LNG-Floating-Storage-Unit-Ready-for-Work-622x468.jpg*

Capital costs for FSUs will depend strongly on the LNG charter market and scrap prices. Current prices suggest older, smaller vessels are available for US$ 20-30 million, although at points in recent years prices as high as US$ 100 million have been suggested. Conversion costs may not be inconsiderable but are highly dependent on the state of the existing vessel and the capabilities required. Again infrastructure costs such as jetty/mooring system, pipeline connections (onshore and offshore) and site preparation such as dredging needs to be added.

It is debateable whether an FSU would remain classed as a ship and therefore need to follow maritime regulations for maintenance and crewing. If the FSU needs to move as part of cyclone/hurricane/bad weather avoidance it may need to retain is ship status and a marine crew. Inspection in-situ should be possible. If the FSU will always be stationary or even grounded then another form of classification may be possible with significantly reduced operating costs. Agreement with the local Port and Flag State organisations will be required. If the FSU retains a ship classification operating costs will be moderate to high, if it becomes a fixed structure operating costs would be probably low to medium. As with FSRUs, barges have been proposed as alternatives to ship-based FSUs, however, none have been built to date.

The FSUs currently in operation are provided on different bases – the two LNGCs used by Malacca LNG are wholly owned while the Maltese FSU is leased (from Bumi Armada). Ownership is more widely discussed as the capital costs are low and therefore the attractiveness to charterers is limited. If an FSU is owned by the project, operating staff could be local but debt, albeit at relatively low levels, will be required. For a lease option local content may be non-existent. The capital values of these older ships is limited to short term operation until retirement (or redeployment) which should not incur significant penalties.

The conversion schedule for an FSU should be in the range 12 to 18 months depending on how extensive the conversion needs to be and shipyard availability. For example Bumi Armada's recent conversion for Malta took 17 months. So far Singapore yards have provided all the conversion work but construction of the supporting infrastructure, mooring/jetty and subsea/onshore pipeline, is highly dependent on local and particularly permitting requirements, which may negate the construction advantage.

The older tonnage currently being considered for FSUs is relatively small (typically 125,000 – 138,000 $m^3$). Similarly to the converted FSRUs, the FSU would be significantly smaller than most of the LNGCs under construction (160,000 – 175,000 $m^3$). This may affect commercial flexibility in terms of the shipping and traders willing to sell LNG to the FSU, Two FSUs may be needed to give shipping flexibility; this obviously doubles the capital cost but also the amount of space required for a project.

Environmental impact of FSUs largely depends on the vaporisation technology used and whether this is offshore (see LNGRV/FSRU) or onshore (see import terminal). The physical size of one or more FSUs will be significant and has visual impact implications. Relocation and reuse is not anticipated for most FSUs which are converted from older tonnage already nearing the end of its working life, although it could be considered if required.

**Table 7 – Advantages and disadvantages of FSUs**

| Advantages | Disadvantages |
|---|---|
| Capital costs low to moderate, non FSU elements such as dredging, pipelines or mooring can dominate. | Only 2 example projects available |
| Short schedule often defined by permitting and not purchase/construction | Limited security of supply as storage volume limited - multiple FSUs may be required |
| Deployment may be short term | no defined commercial structure |

## 2.3 Metocean analysis

Wind and wave conditions are of vital importance for the safe, secure and continuous operation of LNG facilities, therefore metocean analysis is an important part of assessing the suitability of LNG facility sites (and indeed technologies). Much of Myanmar lies between the Tropic of Cancer and the Equator. It is impacted by a southwesterly monsoon, with coastal regions receiving over 5,000 mm (196.9 in) of rain annually, while annual rainfall in the delta region is approximately 2,500 mm (98.4 in). Temperatures in the coastal and delta regions are above 18°C all year and peak at an average maximum of 32°C.

For each potential site, coastal waves have been simulated by means of numerical modelling (one model domain per interest location) from offshore waves based on satellite and ship observations over 20 years. These time series of wave height, wave direction, wave period, wind speed and wind direction have been used as input to the model along the open boundaries. The simulations have also been used to assess the level of exposure to metocean conditions for each location. Additionally historic cyclone tracks are analysed and level of exposure to cyclones at each location assessed.

As Myanmar's coast is entirely exposed to the SW Monsoons, locations with natural shelter are preferable to building breakwaters. Suggestions for berth protection are made on a qualitative basis under each site.

## 2.4 Environmental issues

Myanmar has a requirement for environment impact assessment for major projects, although it is currently uncertain whether this applies to LNG projects. Whatever the case, for financing the project, developers will need to perform an environmental assessment to meet, at least, the IFC Performance Standards and Equator Principles. These are used as the basis of the assessment in this section.

In the environmental assessment the level of harm depends on the degree of damage as well as the value of the site. For example, internationally recognised sites such as UN Ramsar sites or UNESCO World Heritage sites are more difficult to encroach than larger areas of national or local importance. The general public also make value judgements which means that species such as elephants, turtles or coral are percceived to be much more important than insects or woodland, whatever their actual ecological value might be.

### 2.4.1 Environmental Impacts

Myanmar has designated or is processing applications for about 56 national parks/nature reserves to protect plants and animals of national importance. To date only one internationally important (UN Ramsar) site has been identified and is distant to all the proposed pipeline routes and LNG facilities.

The activities related to LNG facilities that can impact local environments are shown in the table below.

**Table 8 – Environmental impacts**

| Activity | Impact |
|---|---|
| Dredging | Dredging involves removing the top of the seabed to create deeper water at a location. Dredging may need to be performed initially (capital dredging) and periodically to maintain the appropriate depth (maintenance dredging). The removal of the top seabed levels reduces visibility and can disturb decaying organic material or contaminated sediments. All of these effects impact local fisheries. Fish will move out of the area and feeding grounds can be degraded or permanently destroyed.<br>Dredged material must also be disposed of at another location. The same detrimental effects will apply here. |
| Breakwaters | Breakwaters whether made of rock mounds or precast concrete structures reduce or prevent waves impacting on the moored FSRU and/or LNG carrier and potentially causing it to break its moorings. Breakwaters will destroy the seabed immediately beneath and will temporarily create disturbance of the neighbouring seabed causing affects similar to dredging. In the longer term, breakwaters can act as reef structures and attract fish and plant species.<br>Breakwaters block waves by changing the flow patterns of waves. This can have unwanted effects on local hydrology. Currents can change speed and direction leading to high levels of erosion in some areas and/or deposition in others. This can, over time, have a major effect on local and even not so local fisheries. |
| Subsea pieplines | Laying pipelines in underwater trenches and burying them has long term benefits in that fisherman can fish directly over the pipeline. However, initially the trenching process acts like localised dredging. However, spoil from the trenching is largely reused to cover the trench after the pipeline has been laid. |
| Pipeline landfalls | Where a subsea pipeline meets the land a landfall needs to be created. This involves removing part of the beach or coastline to accommodate the pipeline within a concrete or sheet piled structure. Local disturbance will be caused with similar, if less extensive, effects as dredging. Removed material will generally be placed back onto the landfall as part of the reinstatement process. |
| Noise & Vibration | LNG facilities create noise, which can travel significant distances especially at night. A range of frequencies can be produced from pipework and machinery. Siting LNG facilities next to populated areas is therefore not recommended. Construction noise, albeit short lived, can be much louder and more disturbing. Pile driving for LNG storage tanks or jetties is particularly bad and may have to be restricted to daylight hours. Noise can disturb animals and birds and piling during bird breeding seasons is often prohibited. Animals and birds adapt quite quickly to operating noise levels of the finished facility. However, humans do not. |

| Activity | Impact |
|---|---|
| | The propellers used by LNG carriers produce low level sound frequencies which can be attractive to aquatic mammals. Coelacanths are particularly affected but whales can also be affected. Determining whether any of the sites are on migration routes or near calving areas needs to be examined. |
| Visual impact | LNG facilities, both onshore storage and flares and FSRUs, are large and therefore can be seen from significant distances. LNG tanks can reach 50 to 70 m in height while the upper parts of FSRUs and LNG Carriers can be 30 to 40 m high.<br>All LNG facilities are lit during the hours of darkness which emphasises their size. Lighting can also affect animal and bird behaviour changing distribution of home ranges and affecting migration patterns. Turtles are one species that are affected by light levels and may be reluctant to enter beach areas with high lighting levels to lay their eggs. |
| Air emissions | LNG facilities may have combustion plant primarily to generate electricity but also to run emergency power and firefighting systems. These plant items will create greenhouse gases (primarily $CO_2$ but possibly also $N_2O$ and methane). They will also create more dangerous compounds such as $NO_2$, CO, $SO_2$ and particulate matter.<br>FSRUs have the same equipment, but it is generally larger and used continuously to generate power and heat for the regasification process. Prescribing clean liquid fuels may be required to reduce emissions.<br>LNG plant will leak minutely from flanges, valve stems, etc. These are known as fugitive emissions. These emissions are primarily methane which is a greenhouse gas about 25 times more potent than $CO_2$. The leak rates generally increase with time until remedial action is required. Monitoring systems may be required to monitor emissions. |
| Water emissions | If seawater-based vaporisers are used the seawater will be cooled to warm and vaporise the LNG. This cold seawater will be disposed of back into the surrounding water body. Cold water reduces the growth of plant life and therefore the availability of basic feedstocks for fish such as krill. The area around the FSRU or terminal will therefore be less biologically productive. Fish will move away, but plankton and fish larvae will not be able to do this. Cold water must not be allowed recirculate to the intake of the vaporisers as additional cooling will occur further increasing local ecosystem damage. International standards on seawater return temperature limits and dispersion distances need to be used and the impact on local marine life evaluated.<br>In all waters, but particularly in warm waters such as around Myanmar, marine growth is continuous and aggressive. This growth needs to be prevented from growing within the FSRU or terminal equipment. This is achieved by periodically dosing the seawater with chlorine. This stops marine growth, but not all the chlorine is destroyed so exits with seawater increasing the ecological damage to the area around the FSRU/terminal. |

### 2.4.2 Social & Cultural Heritage

Myanmar has one UNESCO World Heritage site – the Pyu Ancient Cities which covers the remains of three brick, walled and moated cities of Halin, Beikthano and Sri Kestra. This is not impacted by the

LNG or pipelines. Myanmar has 14 further sites under consideration, none of these are likely to impact the LNG/pipeline project.

The IFC Equator principles state that impact on the local population must be considered and where possible minimised.[10] The activities relating to LNG facilities that can impact local social and cultural heritage are shown in the table below.

**Table 9 – Impacts on social and cultural heritage**

| Activity | Impact |
|---|---|
| Displacement of people | It is preferable that no settlements or even individual farms are relocated. If they need to be moved the process should be voluntary and the residents must be receive land and housing of equal value to those that they are vacating. If portions of a farm need to be purchased for the easement of a pipeline or for part of a terminal site then the owners must be recompensed at the market rate. As the potential to impact settlements varies between sites this needs to be considered. For any pipeline disruption impacts are considered to be the same wherever the location but the length of the pipeline is used to determine the detrimental impact of the project. |
| Degradation of human life experience | This category covers loss of, or loss of access to, sites of social and cultural significance such temples, cemeteries, play areas and traditional fishing or hunting locations. At this level of evaluation, this is hard to consider as sufficient data is not available. All sites will be considered to be the same, unless specific and significant information and impact are discovered during the siting analysis. If this occurs a negative factor will be added to the previous category. |
| Loss of reputation and/or income | Myanmar has sacred landscapes of considerable size, which are important to locals and tourists alike. The terminal and pipeline should not damage or negatively impact the experience of attending these sites. Similar arguments can be made for other culturally important sites such as historic buildings, nature reserves and eco-tourism locations. |

### 2.4.3 Hazard & Risk Considerations

There are various concerns regarding hazards and risks associated with LNG facilities. Leaks of natural gas are flammable and in enclosed or congested areas can burn so rapidly that an overpressure can be created (explosion). LNG is not flammable but quickly vaporises to become natural gas. LNG is very cold and can cause damage to humans and failure of some metals. LNG hitting water can vaporise extremely quickly generating an overpressure (rapid phase transition).

The degree of hazard depends on the size, duration and pressure behind the leak and the local weather conditions. Significant safety separation distances are required to prevent flammable gas clouds or explosion overpressures reaching and injuring or killing members of the public. Worst case scenarios can reach distances as large as 500 to 1000 m. The LNG facility therefore needs to be constructed and operated at some distance from human populations. The larger the population the greater the potential harm, and therefore the more important or larger the distance. Areas containing

*[10] The Revised IFC Performance Standards - Guidance on Implementation By EP Association Members came into effect from 1 January 2012. Therefore, IFC updated its Sustainability Framework, which includes the newly revised Performance Standards, and applied them from 1st January 2012. These are consistent with the current Equator Principles (EP) framework. The EP Association Steering Committee agreed that the newly revised IFC Performance Standards will also take effect for EP Association Members on 1 January 2012.*

large populations such as temples, sports stadia, etc. are particularly important, as are buildings where residents are unable to leave quickly such as hospitals and prisons.

Several layers of safety systems are included in LNG plants to minimise an occurrence, and in the unlikely event that one occurs to minimise the consequences. The primary causes of safety incidents are shown in the table below.

**Table 10 – Hazard Scenarios to be considered**

| Scenario | Impact |
|---|---|
| Failure of equipment | Equipment within a facility can fail if not properly constructed, operated or maintained. This is unlikely and also equally likely across all sites so is not a factor to be considered for site selection. |
| Human error | Human operators are fallible. Training improves competence and operating performance. Training and safety culture is a national level issue and is therefore not considered for site selection. |
| Navigational error or collision | The most hazardous operation for a ship is entering and leaving ports as sea room is limited by the land and infrastructure and other ship movements are more frequent and closer to the LNG carrier. There is an increased risk of collision between ships and the LNG carrier, between the LNG carrier and the land or the seabed (grounding). Limited visibility from fog or heavy rain can exaggerate the hazard.<br>Approaches to the FSRU will vary between sites as will the level of other marine movements. The provision and quality of safety mitigations such as tugs, pilots and port rules can also vary between locations. Similarly the incidence of visibility reducing weather events can vary between locations. |
| Geological Events | Earthquakes and tsunamis are the highest risk issues but subsidence and damage can also be caused by other ground movements such as active faults or collapse of karst structures (for example caves in limestone areas). Most eventualities can be designed for, for example, Japanese LNG terminals survived the Fukushima earthquake and tsunami relatively intact despite the Sendai terminal being within 30 km of the epicentre. However, additional design has a financial impact. |
| Strong Winds and Large Waves (typhoons) | Significant waves and/or strong winds hitting the LNG carrier and/or the FSRU have the potential to break mooring lines. This could set the LNG carrier and/or FSRU adrift causing it to damage or be damaged by collisions or grounding. Wind and wave environments differ between the various potential sites.<br>Typhoons (elsewhere hurricanes and cyclones) are the most intense combinations of high winds, large waves and heavy rainfall which need to be considered. |
| Air crash | An aircraft or helicopter could crash land onto the LNG facility which could cause significant damage and LNG or gas leaks. Most aircraft failures are during take-off and landing and therefore the close proximity of airport runways to a potential site is important and will be considered in the siting analysis. |
| Malicious Act | Deliberate actions taken by disgruntled staff, population discontent (protest through to full riot) and terrorists can lead to damage to the LNG facility. The |

| Scenario | Impact |
| --- | --- |
| | potential for civil unrest and terrorism is assumed to be uniform across all the sites in Myanmar and therefore not considered in the site selection. |

## 2.5 Geography and Geology

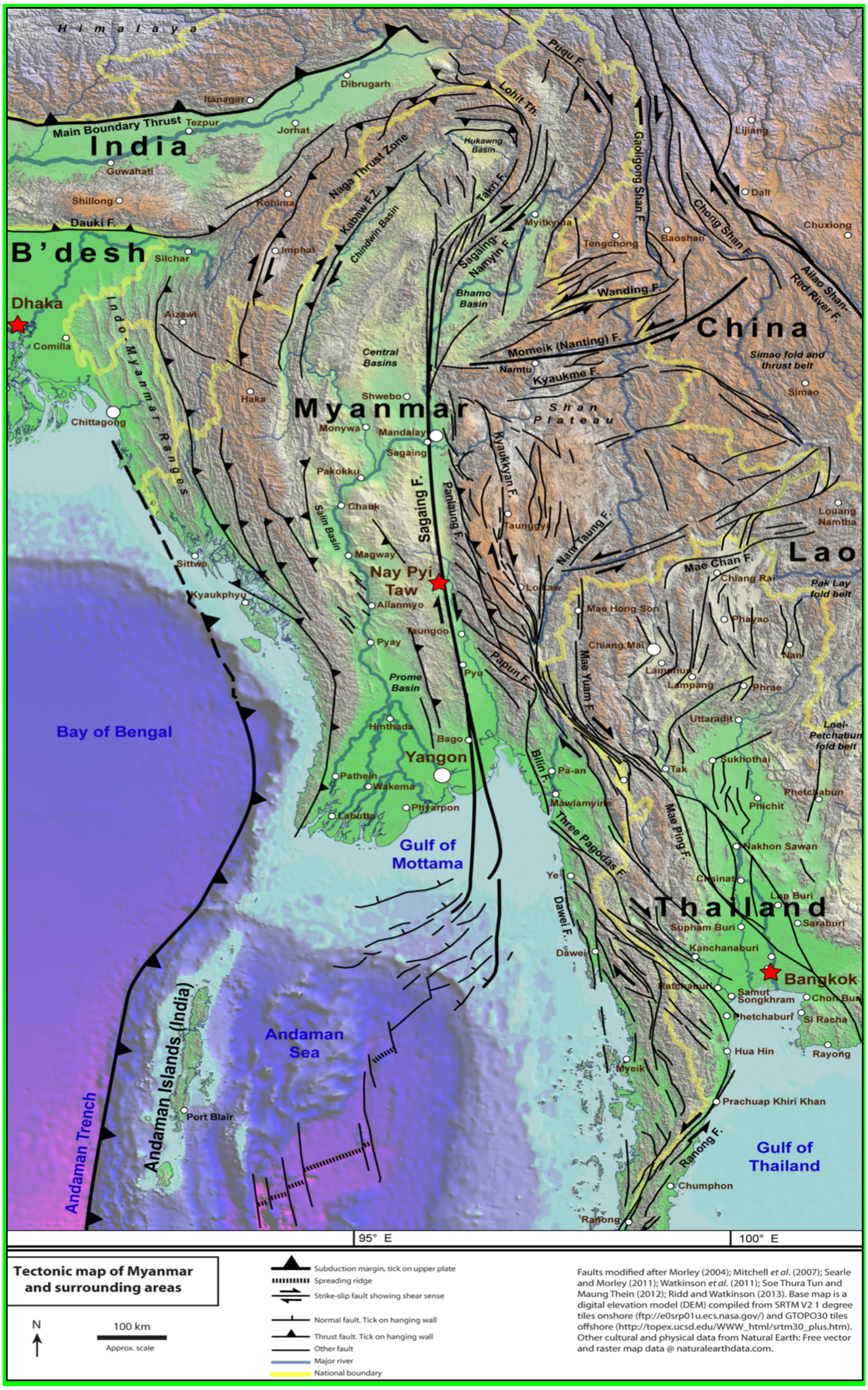
The geography and geology of each site is important in considering its suitability for an LNG facility. On a geological basis, the key concern relates to seismicity and the risk of damage by earthquake, tsunami, volcanic eruption or other geological events. The geography of Myanmar, in particular its mountain ranges and rivers systems will have an impact on the cost and feasibility of building connecting pipelines to each site, while climatic conditions, including the impact of monsoons, have the potential to adversely affect LNG operations. Offshore, sea depth (as measured by bathymetry) and other marine factors, are important for determining suitability for LNG vessels, requirements for dredging and implications for terminal design (breakwaters, jetties etc).

### 2.5.1 Geology

The geology of Myanmar is complex involving three major tectonic plates (Sunda, Indian and Eurasian) and the Burma microplate which is usually considered to be part of the Eurasian plate. The Indian plate continues to move north at about 35mm per year putting a sideways pressure onto the Eurasian plate. The Sunda plate is moving southwards from the Burma plate through seafloor growth. This pressure built up between the Eurasian plate and the Burma plate is primarily relieved by movements in the Sagaing Fault, a major strike-slip structure that cuts through the centre of Myanmar (including Nay Pyi Taw) broadly dividing the country into a western half including Sites 1 and 2 moving north and an eastern half including Site 3.

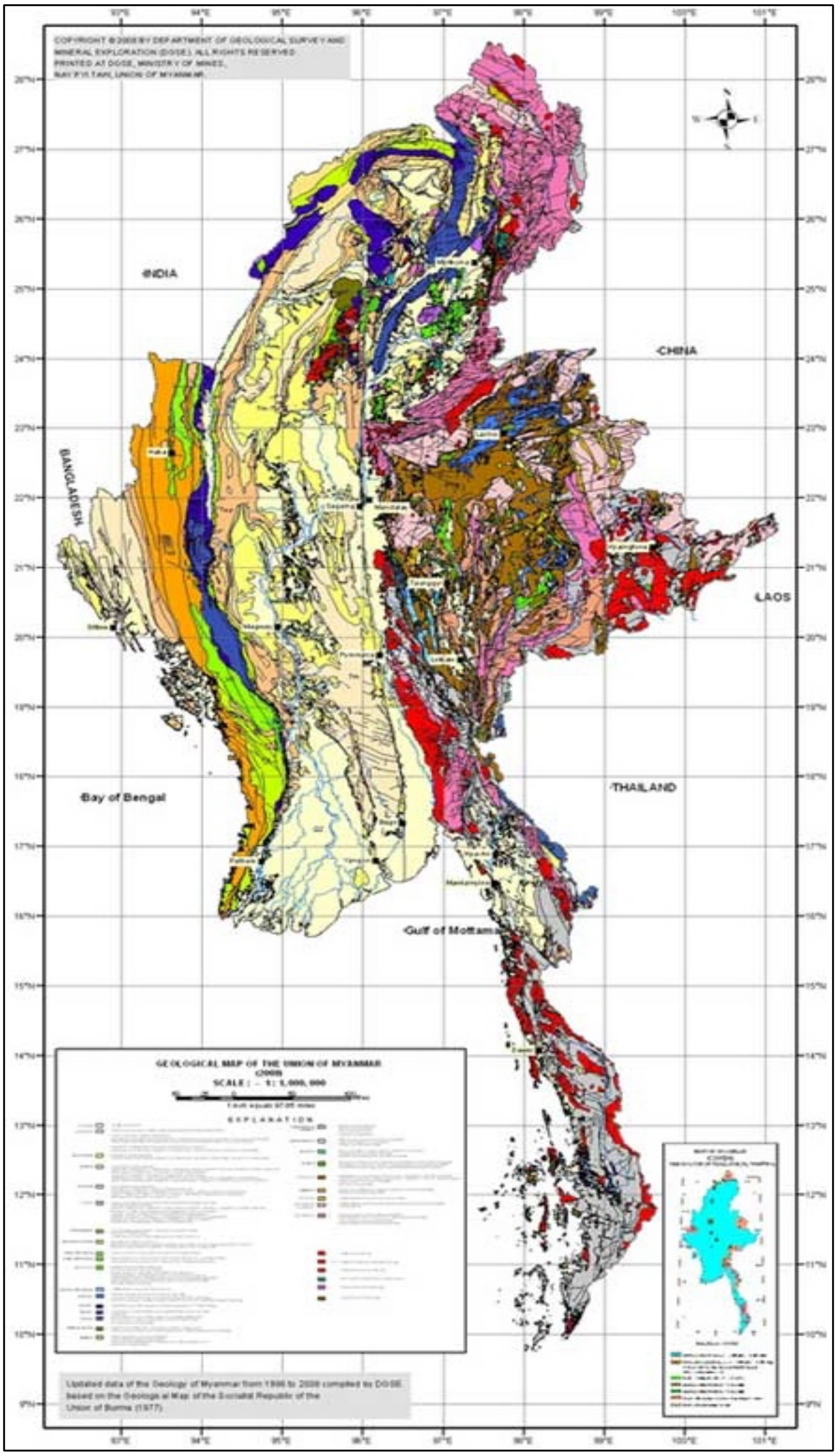
The plate boundary between the Burma and Indian plate lies offshore of north western Myanmar and then runs down the Andaman Islands. The larger Indian plate is subducting (moving beneath) under the Burma plate and has formed the Sunda Trench. These plate tectonics mean that earthquakes in Myanmar are common.

## Figure 13 – Tectonic plates & faults[11]




[11] *http://www.sagaingfault.info/index.html*

**Figure 14 – Geology of Myanmar[12]**




[12] *http://www.mining.gov.mm/DGSE/1.DGSE/1.DGSE_Menu_112/dgse6.jpg*

### 2.5.2 Geography

Myanmar is separated into separate geographical areas by north-south running mountain chains. These mountains divide Myanmar into three river systems, the Irrawaddy, Salween (Thanlwin), and the Sittaung Rivers. Fertile plains exist in the valleys between the mountain chains. Myanmar has 1,930 km (1,200 miles) of coastline along the west of the country, bordering the Bay of Bengal in the North and the Andaman Sea/Gulf of Martaban in the South.

The Rakhine coastline hosts two of MOGE’s preferred sites (Kyauk Phyu and Nga Yoke Kaung). The climate around Kyauk Phyu is a tropical monsoon climate and consists of relatively constant warm temperatures and wet and dry seasons. Nga Yoke Kaung has a more tropical savanna type climate which differs from further north in that rainfall is less pronounced. Coastal vegetation is likely to include Mangrove forests, seagrass and coral. Pipelines from these sites will need to cross the Arakan (also known as the Rakhine Yoma) mountain range.

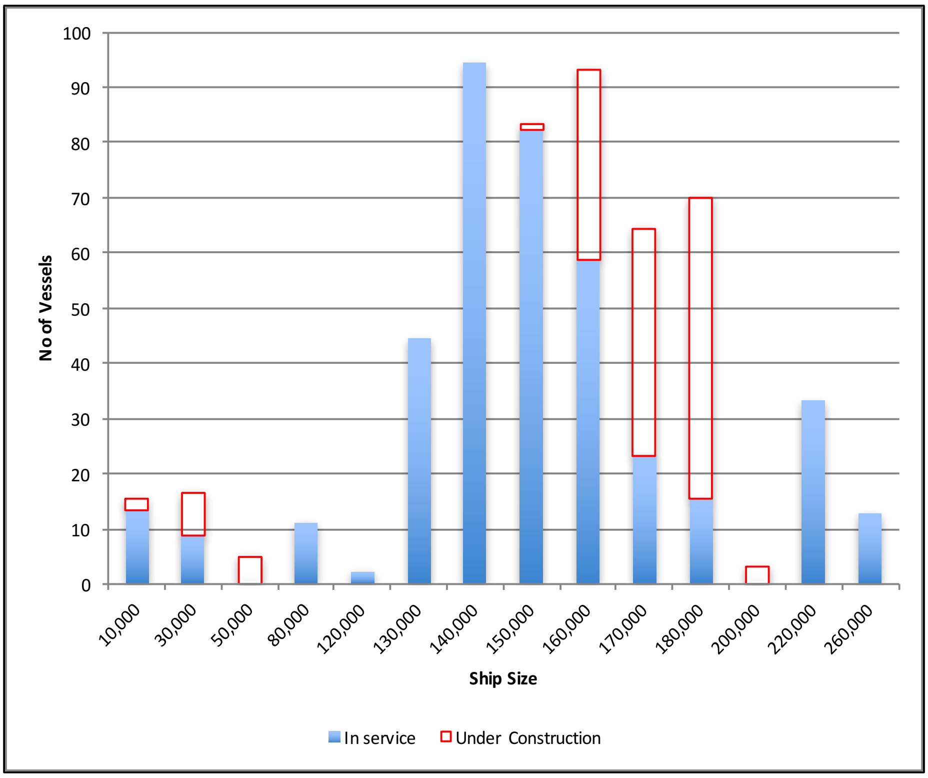
The southern site at Kalegauk Island lies within the delta region of the main rivers, particularly the Irrawaddy. It has a tropical savanna type climate. The large amounts of mud/silt washed down from the river systems means that coral and seagrass will not be present. Pipeline connections must run along the shore line or offshore because inland lies the environmentally sensitive Tanintharyi national park, a conserved tropical evergreen forest.

### 2.5.3 Bathymetry

The deltaic areas of Myanmar are characterised by shallow water depths over mud and soft mud sea floors. The bathymetry (water depth) at each site has been assessed using marine charts. These charts have not been updated with new survey information for some years and can only be taken as indicative of the current depths and sea floor characteristics. Suggestions for dredging and jetty length are therefore made on a qualitative basis under each site based on standard industry expectations (eg SIGTTO). The numerical modelling exercise, described in the metocean report has been based on the GEBCO bathymetry database.

Wherever an LNG marine terminal is located, the berth must have safe navigational access for LNG carriers under a range of environmental conditions. Navigational analysis needs to have a “design ship” as its basis. The current and under construction world fleet of LNG carriers is shown below.

**Figure 15 – World LNG Fleet**




An LNG terminal must have a storage volume equal to and preferably larger than the LNG carrier undertaking delivery. Selection of the design ship would be based on the expected range of LNG carriers to be used based on the LNG supply. In this instance the LNG supply has not been negotiated and therefore a design ship which represents current best practice and is able to unload the majority of the fleet has been selected. The design ship selected is a 163,000 $m^3$ membrane type LNG carrier, which is the preferred size for many owners at the current time. The "Maersk Methane" is a vessel of these parameters and is described in Figure 16 and Table 12.

**Figure 16 – Design Ship "Maersk Methane"[13]**

**Table 11 – Design ship main parameters**

| Characteristic | Value |
|---|---|
| Length Over All (LOA) | 285.0m |
| Beam Width | 43.4m |
| Maximum Draft | 12.1m |
| Displacement | 113,609 tonnes |
| Deadweight | 82,115 dwt |
| Capacity | 163,195 $m^3$ |

Industry best practice on navigation[14] is defined by industry organisation the Society of Gas Tanker & Terminal Operators (SIGTTO) as:

**Table 12 – Industry best practice on navigation**

| Characteristic | Value |
|---|---|
| Minimum water depth required | LNGC draft x 1.1 |
| Channel width required | LNGC width x 4 or 5 |
| Turning circle required | LNGC length x 1.5 to 2.0 |

[13] *http://www.shipspotting.com/photos/middle/5/2/7/1165725.jpg*
[14] *SIGTTO Working Paper 14*

**Figure 17 – Typical minimum water depth requirement for LNGC**

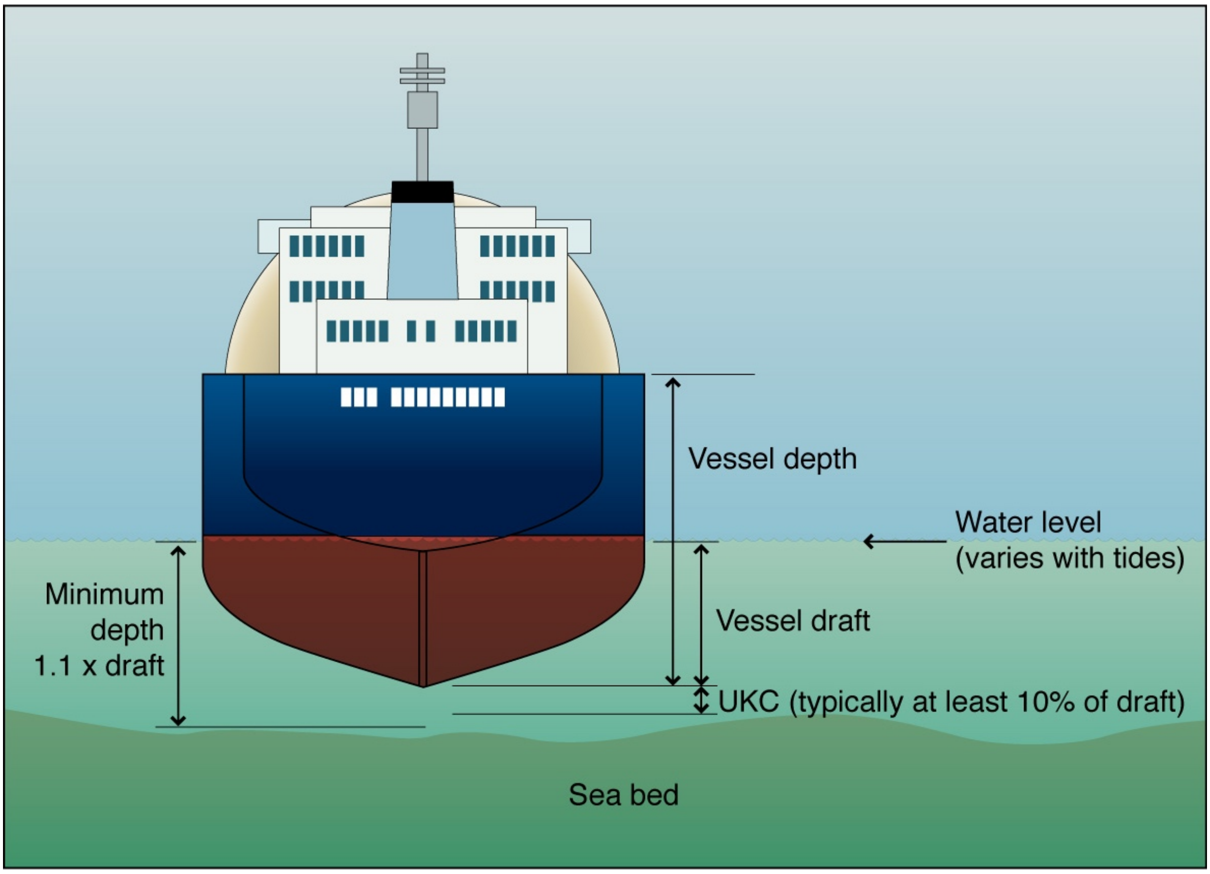



**Figure 18 – Typical channel width requirements for LNGC**

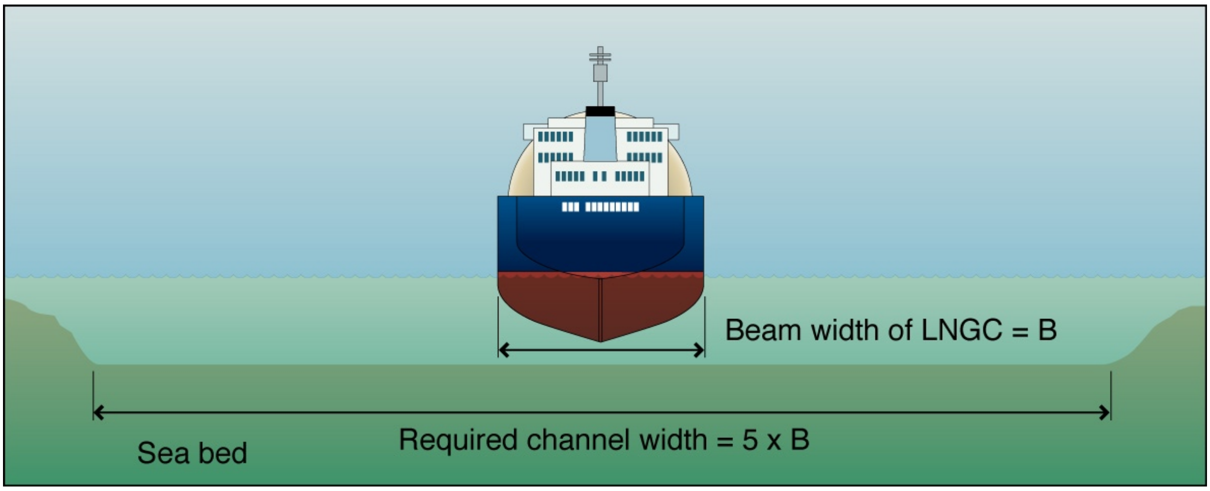
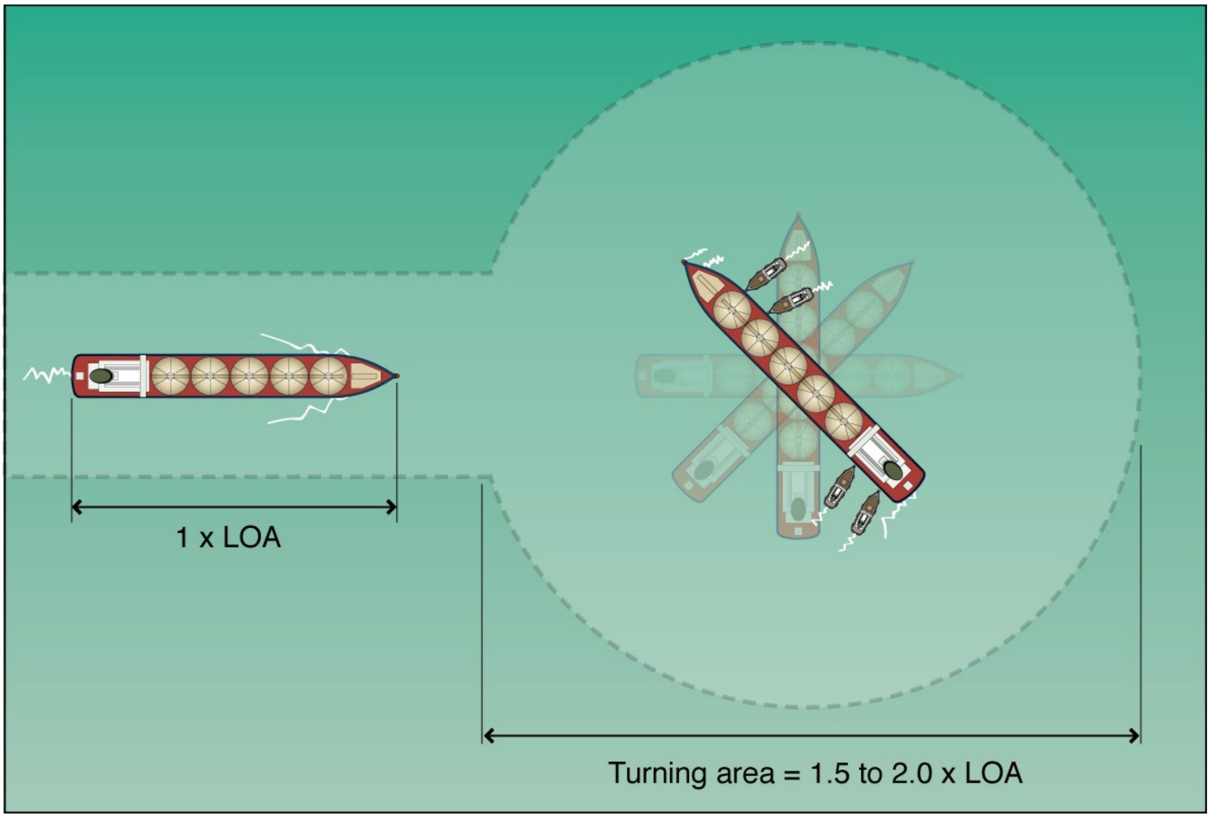


**Figure 19 – Typical turning circle requirements for LNGC**




Therefore, the "Design Ship", for any of the study port sites to be viable must have:

**Table 13 – Navigational Requirements of Design Ship**

| Characteristic | Value |
|---|---|
| Minimum water depth required (LNGC draft x 1.1) | 13.3m (say 14.0m) |
| Channel width required (LNGC width x 4 or 5) | 174m to 217m |
| Turning circle required (LNGC LOA x 1.5 to 2.0) | 428m to 570m |

The above are indicative values based on SIGTTO guidance and best practice. The actual water space requirements may vary depending on local factors and more detailed analysis beyond the scope of this report. No tidal analysis has been performed for this report.

## 2.6 Local infrastructure

Constructing and operating an LNG regasification facility is a major industrial operation, and requires significant local infrastructure in order to manage the safe and orderly docking and unloading of LNGCs (by tugs), the delivery (and removal) of construction and operational materials (by road, rail, port and air links), and operation of the facility by a skilled workforce. The availability of local infrastructure (or the ability to construct/source such infrastructure) is an important consideration in assessing potential LNG facility sites.

### 2.6.1 Tugs

Tugs are required to berth LNG carriers onto a berth or alongside a moored FSRU/LNGRV. LNG carriers have large windage areas. LNG is a relatively light cargo so the ships sit high in the water. This exposes more of their flat side to wind effects. Traditionally LNG carriers have used steam turbine propulsion, which can make manoeuvring sluggish, and therefore the vessels are more difficult to control than many ship types.

Tugs allow the LNG carrier to be manoeuvred without error. Normally three or four tugs are used to manoeuvre, turn and berth an LNG carrier. The key parameter is the strength, defined as bollard pull, that the combined tugs have available. In harbour conditions about 150 tons of bollard pull is required. In less protected water, around an offshore mooring, waves are generally larger and tug power needs to increase. Generally only two or three tugs would be required for the berthing manoeuvre.

SIGTTO suggests that a standby tug is available at all times that an LNG carrier is alongside and that this tug is capable of firefighting. On an offshore buoy/mooring typical offshore practices for platforms or FPSOs are adopted and a standby vessel may be required depending on local Myanmar practice.

### 2.6.2 Roads, Rail, Ports and Air links

Access to the LNG facility is required both during construction and operation. During construction heavy machinery and materials will be required at the facility site. These can be provided by boat if a construction dock (not the LNG jetty) is built, or by road/rail from a nearby port. Some of this material is large and heavy and roads may need to be modified, for example bridges strengthened or corners modified to allow access to the facility. Construction labour also needs to access the site. Labour levels could be as high as a few thousand people. They may live in a construction camp if road access is poor. International vendor service personnel will need to attend to commission their package equipment.

During the operational phase staff will need to get to and from work and be supported by international vendors, particularly during maintenance and breakdowns. Access may be by road, boat for moderate distances or helicopter. Maintenance spares and consumables will also be required.

### 2.6.3 People

Skilled staff will be required to construct and operate the LNG facility. Some will be expatriates, particularly if a lease type arrangement is preferred. Myanmar needs to consider what degree of local content it requires and how high skill levels can be achieved. Elsewhere in Myanmar skilled operators are present in the oil, gas and chemicals industries so similar training arrangements should be possible.

## 2.7 Pipelines

While importing LNG to Myanmar may be important in overcoming the forecast supply shortfall, in order to be utilised the regasified LNG (RLNG) must be transported to end-users. The distance of the LNG import facility from a suitable entry point either on Myanmar's high-pressure gas pipeline system, or a large customer such as a power station is also an important factor that needs to be taken into account when reviewing possible locations for an LNG import facility. Although the location could be the actual point of consumption such as a power station, which receives gas directly from the FSRU via a connecting pipeline, in the context of Myanmar, and its focus of power generation near the major cities, it is more likely to be an entry point on the gas transmission system where the RLNG enters the local gas transmission network for onward transportation. In this context there may also be issues surrounding whether there is sufficient capacity in the existing network to receive additional RLNG supplies, or whether some form of network reinforcement is necessary.

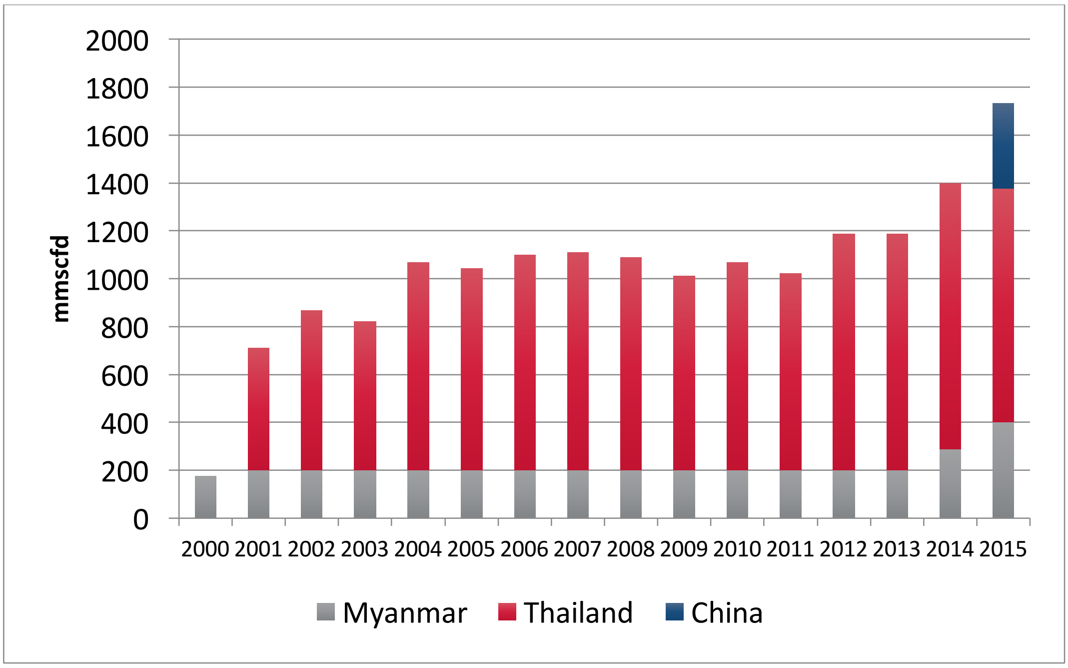
Therefore prior to examining the specific challenges associated with the three potential LNG import locations that are the focus of this study, this section provides a general overview of gas infrastructure issues, focussing in particular on the following:

- Myanmar's gas transportation network.
- Offshore connecting gas pipelines.
- Onshore connecting gas pipelines.
- Network reinforcement.
- Data collection from MOGE

### 2.7.1 Myanmar's gas transportation network

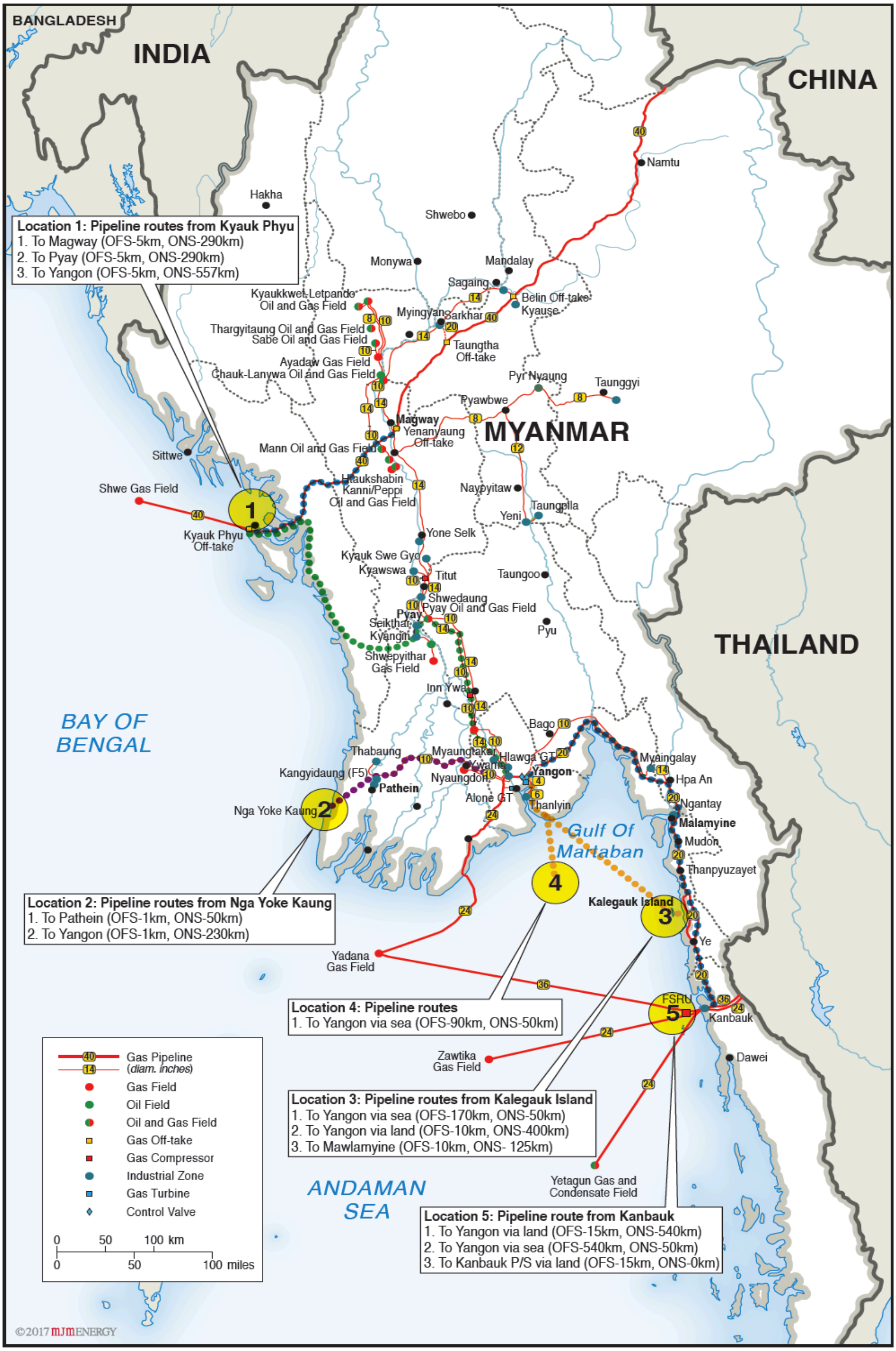
Myanmar became a major natural gas producer in 2000 with the start of the offshore production at Yadana field, which was followed by the development of the Shwe, Zawtika and Yetagun gas fields. However, as shown in the graph below the majority of Myanmar's gas production is exported to Thailand and China. This emphasis on pipeline gas exports from Myanmar to China and Thailand, whilst earning valuable foreign currency, has hindered the development of Myanmar's national gas transportation system with the focus being on international gas transportation.

**Figure 20 – Gas supply in mmscfd by destination 2000-2015**




For example, one can see in **Figure 21**, that despite being a relative newcomer to gas, Myanmar appears to have an impressive gas transmission network that should facilitate the onward transportation of RLNG relatively easily.

**Figure 21 – Myanmar's gas transportation network in relation to the five import locations**



However, during discussions with MOGE and other relevant stakeholders in Myanmar it became clear that the network is constrained for a number of reasons.

- ***No access to the 42" Myanmar to China export pipeline*** – The 42" pipeline that supplies gas from the Shwe field to China, which transverses northern Myanmar, could potentially provide a route for RLNG to large process users in central and northern Myanmar. Unfortunately, it would appear that is very difficult for Myanmar to access any spare capacity in this pipeline, which shall be discussed later in this report.
- ***Poorly maintained with insufficient capacity*** – In discussions with MOGE it also emerged that parts of the gas transmission network have been poorly constructed, maintained and under-invested in for a number of years. For example, the high-pressure gas transmission pipeline infrastructure between Yangon and Kanbauk is badly corroded and leaks, which is the result of poor construction and maintenance. This means that the pipeline has to be run at lower pressures, limiting its capacity to 100 mmcfd, and its capacity cannot be easily increased through upgrading the maximum operating pressure or the installation of compressors.
- ***Limited investment in gas transmission infrastructure*** – Whilst MOGE is undertaking replacement of leaking and corroded pipelines, its efforts are hindered by budgetary constraints. For example, upgrading work is taking place on the 300km Mawlamyine to Yangon pipeline at a rate of 20 to 30 km per year.

Therefore, whilst the ideal solution would optimise the location of the FSRU with offshore, onshore and general system reinforcement costs, for the reasons highlighted above, it seems likely that significant lengths of onshore pipeline will need to be constructed to transport gas from the FSRU to demand centres in the midst of Myanmar's gas network.

### 2.7.2 Offshore connecting gas pipelines

In some cases, it will be necessary to construct offshore high-pressure gas pipelines to connect the RLNG delivered from the FSRU to the mainland. For example, if the FSRU is located near a small island close to the mainland, only a short subsea pipeline may be needed. Whereas, if the FSRU is located in deeper water some way offshore, then much longer offshore subsea pipelines will be required. For example, one option that has previously been considered for Myanmar required an 80km subsea pipeline to be constructed from an FSRU in the Gulf of Martaban to the Yangon River.

Apart from the obvious difficulties of actually laying high-pressure subsea gas pipelines offshore, a number of other challenges can occur. These include uneven subsea terrain with deep trenches that can be difficult to transverse, inclement weather, saltwater corrosion, and pipeline infringements from anchors and fishing nets. Where possible subsea pipelines should be located in trenches to provide protection, with additional protection provided by placing concrete mattresses over the pipeline.

### 2.7.3 Onshore connecting pipelines and metering

Whilst the quantity of LNG delivered is measured on the LNG vessel, the RLNG is also metered. The actual location of the custody point metering can vary depending on operational and logistical constraints, but is typically at the point the RLNG leaves the connecting pipeline either for immediate consumption or onward transportation via the main gas network. This is typically achieved with a gas metering and pressure reduction station.

As highlighted above, once the RLNG has landed onshore the ideal solution would be to connect to the nearest high-pressure gas transmission pipeline. However, this is not always possible because the nearest high-pressure gas pipeline may not be able to accommodate the RLNG at the pressure and flows required. Under such circumstances the onshore connecting pipeline needs to connect at a point on the local gas transmission system that is able to accommodate the pressures and flows required.

### 2.7.4 General reinforcement of the existing system

Even when a suitable entry point can be identified for RLNG to be delivered into Myanmar's gas network, additional work may be required to strengthen the local gas network to accommodate the additional gas. This may be as simple as building a connection, upgrading the maximum operating pressure of the pipeline, or something more complex and expensive. For example, in some cases the existing pipeline network needs to be upgraded by looping some pipelines. Typically, this work is referred to as 'general reinforcement' since not only does the reinforcement work allow the additional RLNG to be accommodated by the local gas network it also strengthens the overall gas network with all consumers benefitting.[15]

### 2.7.5 Data collection questions for MOGE

During the course of this project the Project team asked MOGE a series of questions in relation to pipeline construction and system reinforcement costs in Myanmar. The questions asked together with the answers provided are summarised in the following sections.

#### *2.7.5.1 Onshore gas pipeline construction costs*

MOGE were asked to provide an estimate of the construction cost of onshore high-pressure gas pipelines. MOGE provided the following data for onshore gas pipeline construction costs.

- Costs for a 24" pipeline are made of the following:
  - Pipe + Material Cost = $548,200 per mile.
  - Pipe laying Cost = $1,043,658 per mile.
  - Crop Compensation = $7,917 per mile.
  - Total = $1,599,775 per mile.
- Costs for a 30" pipeline are made up of the following:
  - Pipe + Material Cost = $613,000 per mile
  - Pipe laying Cost = $1,304,573 per mile
  - Crop Compensation = $7,917 per mile
  - Total = $1,925,490 per mile,

Therefore, for the purpose of estimating onshore pipeline costs, the following estimated costs have been used. However, it should be noted that the methodology used by the Project Team can easily accommodate changes in these estimates where MOGE has more accurate cost data.

[15] *This raises an issue which is largely beyond the scope of this report but should nevertheless feature in the thinking of MOGE. If one of the site options requires a considerable amount of additional reinforcement to strengthen the local network, how will MOGE account for that cost, since whilst the additional reinforcement is a cost to the project, there is also a significant benefit to the overall system.*

**Table 14 – Estimated onshore pipeline costs**[16]

| Type of pipeline | Cost in USD per mile ($million) | Cost in USD per kilometre ($million) |
|---|---|---|
| Onshore 24" pipeline | 1.6 | 1.0 |
| Onshore 30" pipeline | 2.0 | 1.2 |
| Onshore 36" pipeline[17] | 2.5 | 1.6 |

#### *2.7.5.2 Offshore gas pipeline construction costs*

MOGE was also asked to provide estimates for the construction cost of offshore high-pressure gas pipelines. In response MOGE provided one figure of $800,000 per mile for the pipe laying cost. In order to create equivalent offshore cost to the onshore costs, the same material and labour costs were used as follows:

- Costs for a 24" pipeline are made of the following:
  - Pipe + Material Cost = $548,200 per mile; Pipe laying Cost = $800,000 per mile.
  - Total = $1,348,200 per mile.
- Costs for a 30" pipeline are made up of the following:
  - Pipe + Material Cost = $613,000 per mile; Pipe laying Cost = $800,000 per mile.
  - Total = $1,413,000 per mile.

However, as can be seen above, the resulting offshore pipeline costs were in fact less than the Project Team had expected, with the offshore pipeline construction costs less than the onshore pipeline construction costs. Typically, offshore pipeline construction costs are greater than their onshore equivalent in the range of $2.0-3.0 million per mile.[18] Nonetheless, the Project Team does recognise that different jurisdictions can have local geographical, demographic or commercial circumstances that cause them to deviate from the international norm.[19]

Therefore, for the purpose of this analysis and the operation of the Site Prioritisation Tool, the Project Team have taken a prudent and cautious approach elevating the offshore pipeline costs to a point mid-way between what the Myanmar data suggested and international norms. These cost estimates are still at the lower end of any potential range.

*[16] These are 'rule of thumb' budget estimates and will be subject to variations based on terrain, material and labour costs. In addition, the figures have been rounded to one decimal place.*
*[17] Estimate based on local and international data.*
*[18] A typical 'rule of thumb' cost for an offshore gas pipeline would be circa $2-3 million per km for a 30" pipeline. For example, in the 'Feasibility Study for Introduction of LNG Receiving Facilities in Myanmar' produced by the Japan Research Institute the 'rule of thumb' estimate for a 24" gas pipeline was $3 million per mile ($1.925 million per km).*
*[19] Whilst the Project Team did query these figures no answer had been received at the time of writing this report.*

**Table 15 – Estimated offshore pipeline costs[20]**

| Type of pipeline | Offshore pipeline costs based on data from MOGE | | Adjusted offshore pipeline costs | |
|---|---|---|---|---|
| | Cost in USD per mile | Cost in USD per kilometre | Cost in USD per mile | Cost in USD per kilometre |
| Offshore 24" pipeline | 1.35 | 0.8 | 2.4 | 1.5 |
| Offshore 30" pipeline | 1.41 | 0.9 | 3.0 | 1.8 |
| Offshore 36" pipeline[21] | 1.60 | 1.0 | 3.8 | 2.4 |

#### *2.7.5.3 Gas network reinforcement costs*

The Project Team also requested MOGE to provide specific information in relation to the three sites under consideration in relation to pipeline access and reinforcement costs. Whilst MOGE was unable to provide specific answers to these questions, it did explain the condition and related capacity in the areas of the system under consideration. Details of the specific questions asked and the answers provided by MOGE are provided in the discussion on pipeline access in relation to each site.
Site selection for an LNG facility involves assembling large amounts of data, site visits and consultation with local stakeholders. It is a time consuming and complex process, and the criteria and underlying assumptions used can have a major impact on the conclusions reached. Task 2(b) in the TOR requires the consultants *'Prepare prioritisation framework and accompanying analytical tool for LNG import options and locations'*. To achieve this end the consultants have developed a Site Prioritisation Tool (SPT), based on an Excel platform. The purpose of this exercise is to rank and short list the three proposed sites and create a tool that can be used on additional sites by MOGE staff. This chapter of the report provides an explanation of how the SPT works, including the criteria and underlying assumptions. The following chapter provides an analysis of the three proposed sites, using the SPT, however, based on this work the SPT can be applied to other potential sites as required.

It should be noted, however, that this study is necessarily limited within the TOR, and cannot provide a full assessment of the feasibility of LNG importation at the potential sites. This study is therefore a screening activity to the full site selection process and is only aimed at highlighting major issues that might prevent a later, more detailed approach being successful. As study work and data are not available in detail at this stage, a qualitative ranking system is acceptable. The primary ranking system used in the main Stage 2 of the SPT is based on the familiar worldwide concept of traffic lights, which provide a visually clear means of recording the site selection process. Green is go or in this case good, red is stop or bad. To improve granularity both yellow and orange are used as intermediary points, with yellow being closer to green and orange being closer to red. Qualitative by definition means comparison in a loose way between sites and international norms, and not specific scores against attributes to form a numerical conclusion.

Other approaches assign numbers to answers to give a score. In the consultant's experience this is not particularly helpful as those involved may concentrate on massaging the numbers for some particular end and can lose site of the major issues involved. Additionally a quantitative approach would appear to offer more certainty than the underlying data warrants. The qualitative approach chosen here is quite deliberate to try to avoid these problems. Nonetheless, Stage 3 of the SPT does provide an indicative quantitative analysis of the economics of the potential sites, whilst being subject to strong provisos due to the limited data availability.

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[20] *These are 'rule of thumb' budget estimates and will be subject to variations based on terrain, material and labour costs. In addition, the figures have been rounded to one decimal place.*
[21] *Estimate based on local and international data.*

The SPT is designed in three discrete stages to address different elements of the process:

- ***SPT-Stage 1 (Concept selection***) – This first stage asks a series of generic questions in relation to gas demand, timing, security of supply and ownership that whilst not site specific the answers to these questions will influence site selection. SPT-Stage 1 then uses this data to identify a suggested LNG import technology option such as an FRSU or land-based LNG import terminal, although the user can override this suggestion with their own preferred choice. The output from SPT-Stage 1 is then summarised in a simple chart.
- ***SPT-Stage 2 (Qualitative site selection)*** – Having made a technology choice, the user is then asked a series of questions that fall under the following four categories: (1) Getting LNG to the LNG facility; (2) Storing the LNG shipments; (3) Getting LNG out; and (4) Area Local infrastructure. The user's responses are analysed and scored using the traffic light methodology.
- ***SPT-Stage 3 (Discounted expenditure selection)*** – Whilst SPT-Stage 2 is by definition qualitative and high level, SPT-Stage 3 has been devised by the Project Team to compare the financial, operational and commercial aspects of the different site selection options. Fundamentally, the approach taken is a Net Present Value (NPV) model. However, in the absence of income data, SPT-Stage 3 is based solely on a discounted expenditure approach.

Therefore the purpose of this section is to provide a high level review of the Site Prioritisation Tool, with a further description provided in Annex C.

## 2.8 SPT-Stage 1: Concept selection

This section looks at technology and project management parameters that influence the type of LNG facility utilised and therefore its impact on each site. Answers to these questions will help determine the most suitable technology for the project, whether land-based, FSRU or an alternative approach. In addition, they will aid in determining the scale and commercial arrangement of the facilities. The questions are generic, covering gas demand and timing issues that are not site specific, but will influence site selection. These questions are designed to understand what quantity and timing of Myanmar's LNG import needs.

The questions are:

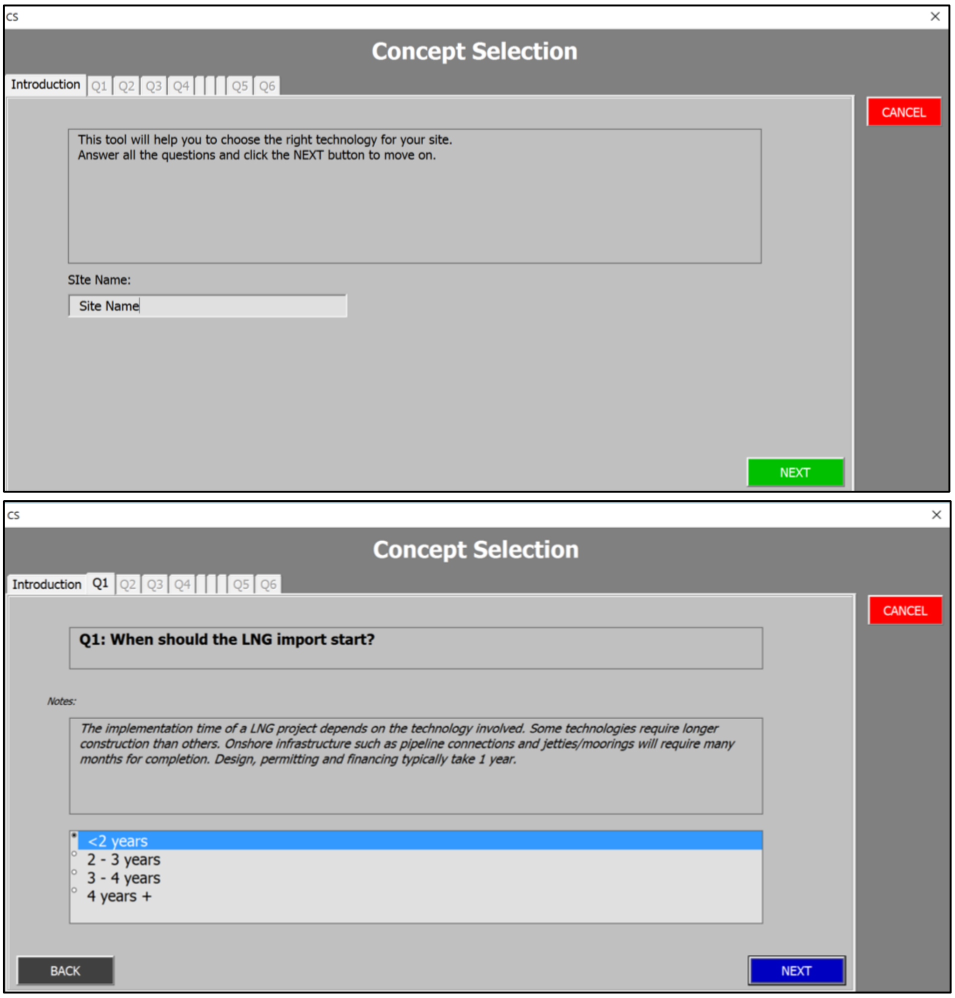
- Question 1: When should LNG import start?
- Question 2: What is the duration of LNG supply?
- Question 3: What gas vaporisation rate is required?
- Question 4: What degree of ownership and control is required?
- Question 5: How much security of gas supply is required?

### 2.8.1 Using the Concept Selection Model

The model starts with a data entry screen where the main parameters of the project may be entered. These are:

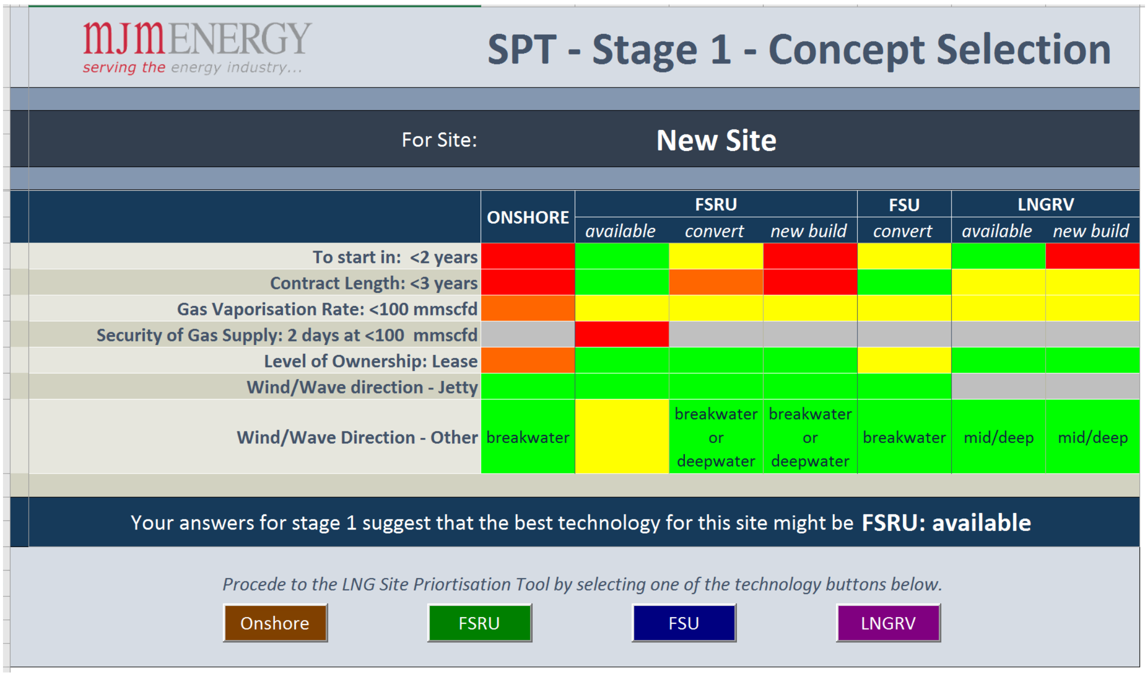
- Vaporisation rate (in mmscfd)
- Security of Supply (storage capacity contingency)
- Project assessment (FID) date and duration
- Ownership requirements

**Figure 22– Examples of project data entry screens from the Concept selection tool (SPT-Stage 1)**




Based on this data a table will be displayed where each technology is colour coded for its suitability. The data table is the result of the analysis and is then used by subsequent models. The results screen is shown below.

**Figure 23 – Examples of the results screen from the Concept selection tool (SPT-Stage 1)**



The traffic light approach is summarised below.

**Figure 24 – The traffic light approach**

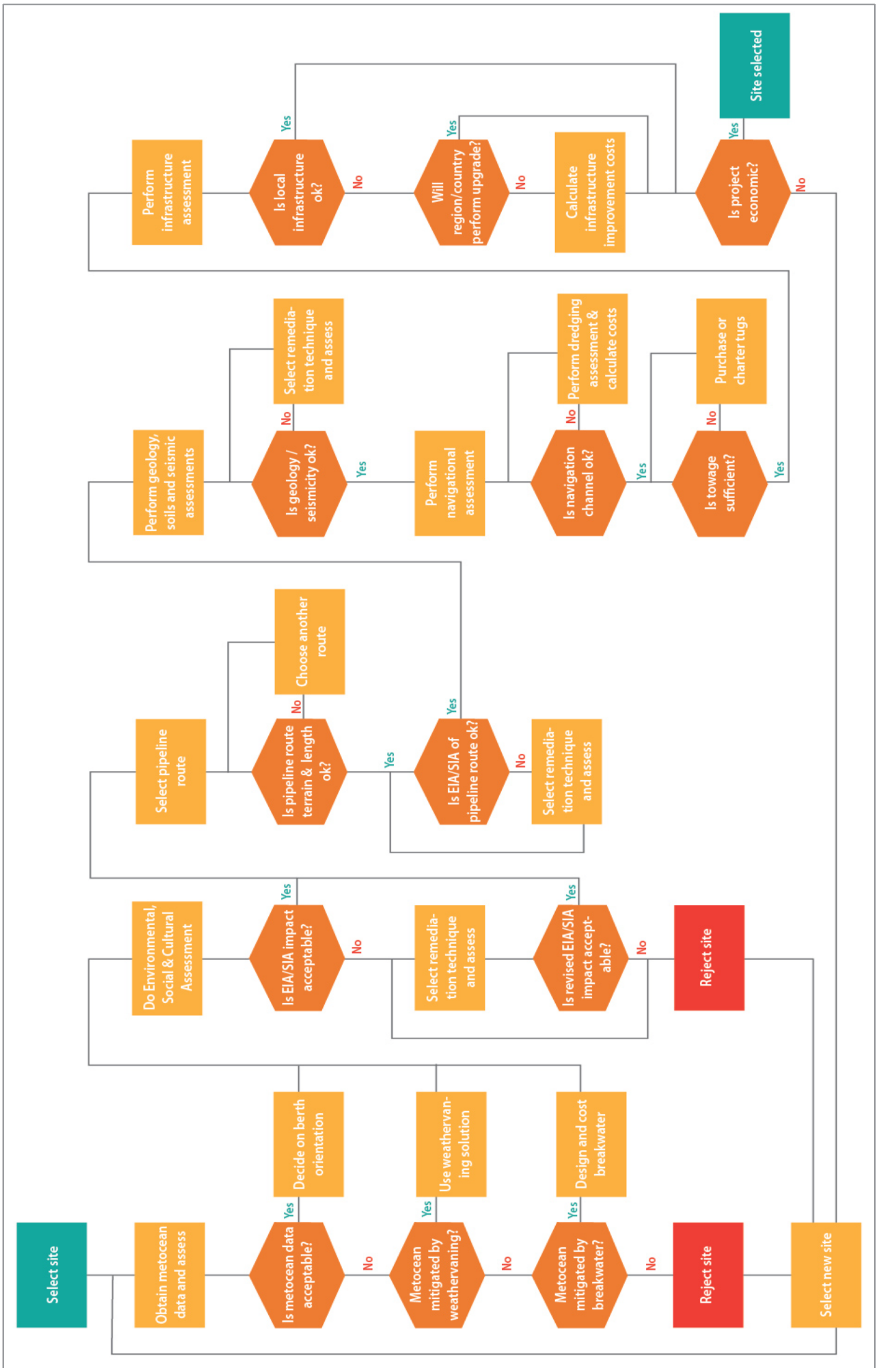
| Colour | Implication |
|---|---|
| Red | A red light indicates that the site has an issue which may prevent the site being cost effectively developed as a LNG facility. One red light may not be sufficient to stop the project, but will impact cost and/or schedule in a major way. Multiple red lights indicates the project is not viable |
| Orange | An orange light indicates that the site has significant issues that will impact either capital expenditure or schedule |
| Yellow | A yellow light indicates that the site has some issues but these are anticipated to be corrected with only minor capital expenditure or short schedule delays |
| Green | A green light indicates that the site has no significant issues and could reflect worldwide best practice in the LNG industry |

## 2.9 SPT-Stage 2: Qualitative Site Selection

The SPT is designed on a hierarchical basis with the most important topics considered first as illustrated in the selection flowchart in Figure 25. The first topic is weather (and metocean data), which cannot be completely mitigated by designing additional features such as breakwaters and higher wind loadings. Weather therefore can exclude a site, add significant costs to the site and/or have little effect. Similarly environmental, social and cultural issues may be so fundamental to the local or national conscience, that they are intractable and the project will be unable to proceed.

These two topics, with overarching financial considerations, largely select the technology required to import the LNG, as all other issues can be solved by capital investment. They are analysed on the magnitude of cost impact they are likely to have on the project. Protecting against geological events is considered first, followed by navigation/technology, gas pipeline connections and finally infrastructure concerns.

## Figure 25 – Selection flowchart



### 2.9.1 Key Site Selection Questions

The Stage 2 of the SPT and accompanying analysis will be informed by a multiple choice questionnaire consisting of up to five questions provided for each main topic. The following topic areas will be used:

- Getting LNG to the LNG facility (marine access requirements and metocean)
- Storing the LNG shipments (is there space for tank farms? etc.)
- Getting LNG out (via pipelines or with localised power plant and electrical cables)
- Required LNG infrastructure (e.g. housing for workers etc.)

The following sections detail the questions asked. Please note a further explanation of the questions and answers is provided in Annex C.

Where a question has been asked in Stage 1, the answer is automatically included but a button allows the user to modify their original position.

### 2.9.2 Getting LNG to the LNG facility

LNG carriers need to get to the LNG facility and unload on a consistent basis. The questions in this section cover what type of facility needs to be constructed and what other factors may interfere with the transit of the LNG carriers.

- Question 1: How much dredging is required to create a channel to the terminal?
- Question 2: What Subsea pipeline length OR what jetty length (depending on options selected) is required to connect the FSRU/LNG Carrier?
- Question 3: How much marine traffic is currently being experienced?
- Question 4: Are there local visibility limitations?
- Question 5: Are there any other factors that limit the site?

### 2.9.3 Storing the LNG shipments

This section looks at issues that decide the long term availability of LNG from the terminal and its impact on the environment. The wind and wave conditions at the berth are crucial if any form of floating LNG facility is to be used and remain important if a fixed onshore terminal is selected. Storage margins are the key mitigation for most negative events but are limited by technology. Finally, environmental, social and cultural impacts may decide whether a LNG facility at this location proceeds or not.

- Question 1: What is the wave environment like?
- Question 2: How variable is the wind/wave environment?
- Question 3: Might the LNG facility be impacted by extreme weather?
- Question 4: Will the site cause any destruction or exclusion to environmentally sensitive areas?
- Question 5: Will the site cause any destruction or exclusion to culturally and historically sensitive areas?
- Question 6: Will the site development and operation impact the local community in any detrimental way?
- Question 7: Will the site development and operation increase the risk of harm/fatality to the local community?
- Question 8: Are there risks to the LNG facility from geological events?

### 2.9.4 Getting LNG out

LNG is only useful to Myanmar if it can be exported on demand and reaches the power plants that will be using it. There may be times that vaporisation cannot happen for technical or operational reasons. The difficulty (capital and environmental/social impact costs and schedule) of getting gas from the LNG facility via a gas pipeline also needs to be considered. If the pipeline is full then little additional gas can be made available via LNG.

- Question 1: Can LNG be vaporised in sufficient volume and in an environmentally acceptable way?
- Question 2: What is the onshore pipeline length?
- Question 3: What is the difficulty in laying the onshore pipeline?
- Question 4: What is the offshore pipeline length?
- Question 5: What is the difficulty in laying the offshore pipeline?

### 2.9.5 Local Infrastructure

This section looks at local infrastructure to assess whether a suitable workforce and supporting services are available. It also looks at the ease of getting personnel and equipment to the site from international vendors both during construction and operation.

- Question 1: Is there sufficient towage available to berth the LNG carrier?
- Question 2: Is there currently any port rules and infrastructure appropriate to hydrocarbon importation at the proposed LNG site?
- Question 3: Is there sufficient infrastructure to accommodate workers and their families, expatriates and vendor personnel?
- Question 4: Is there emergency response and Health care capability?
- Question 5: Is the local skills and education infrastructure useful to the project?
- Question 6: Is there access to a major port with connecting roads?
- Question 7: Is there access to an international airport with road/rail links?
- Question 8: How adequate is the marine infrastructure?

### 2.9.6 Using the Qualitative Site Selection tool

See Annex C.

## 2.10SPT-Stage 3: Discounted Cashflow Selection

The traffic light methodology by its definition is qualitative and high level. This is suitable for screening but does not produce any preliminary costs and schedules and therefore leaves the viability of a site undetermined.

A second tool has been produced to overview these economic issues. The key issue for this assessment is that projects under consideration are different with technology and site factors producing different schedules to reach maturity, offering significantly different capital investments and attracting very different annual operating costs. The only way to analyse these different scenarios on a common basis is to use some form of "time value of money" process where future expenditure is discounted based on its date.

The approach taken is basically a Net present Value (NPV) model. However, to perform a classic NPV calculation both income and costs need to be assessed. The project is too immature to be able to estimate costs of LNG delivery and value of gas sales so income cannot be determined. The economic model will therefore be based solely on a discounted expenditure approach.

The next sections describe this model.

### 2.10.1Key Cost and Schedule Factors

#### *2.10.1.1 Schedule assessment*

In recent years the LNG market has been overheated with a lack of availability of engineering contractor capability, shipyard construction slots and long delivery times on cryogenic equipment. Even relatively small diameter cryogenic valves had delivery times of many months. The market has changed with the oversupply of LNG. Most design and construction resources are now back to normal availability, prices and schedules.

Historically FSRU projects have been very fast to market with claims made often for schedules of a year or even less. This was the result of ship owners ordering vessels speculatively and then not finding markets immediately for them and the re-use of existing infrastructure such as jetties. The current interest in FSRUs means that most speculative vessels are now employed. With the strength and time delay in the market many companies are looking at LNG carrier conversions to improve schedule. Because of this the full schedule advantage of existing FSRUs may not be realised before 2019/20.

The key schedule items are:

- Pre FID studies, permits & financing
    - Feasibility and FEED studies will be required to determine the suitability, costs and schedule of the project
    - Site measurements will be required, often over a period of months, to determine metocean suitability, environmental impact, soil conditions and bathymetry/topography
    - engineering is not the rate determining step, permitting and financing dominate and are of similar duration for all options
- Final Investment Decision (FID)
    - This is the "go/no go" decision point which is typically not a single event but a time period. During the kick off meeting MOGE suggested 3 – 6 months

- Engineering
    - Detailed engineering of the facility to allow the purchase of all equipment items
    - As FSRU/FSUs are essentially generic it may be performed for them at an earlier time period by the owner pre project FID
    - Marine facility and connecting gas pipeline engineering also needs to be performed regardless of the LNG technology used
- Procurement
    - Purchase of and delivery to the construction site of all equipment items
    - Some long lead items may be purchased early to expedite this process but this involves risk for the owner – however it can be contemplated for a "generic" FSRU
- Construction
    - Construction of the LNG facility
- Delivery & Commissioning
    - Delivery of the FSRU/FSU from a shipyard takes time and may only be available at certain times of the year to avoid poor metocean conditions, for example the SW monsoon
    - Connection of FSRU/FSU to mooring or jetty
    - Drying out, pressure testing and inerting of all LNG equipment, hydrotesting and inerting of gas pipelines
    - Cooling down of LNG systems and pipework
    - Performance tests

Typical schedules used in the model (each including 12 months feasibility/design, permitting and financing and 3 months FID) are shown in the following table.

**Table 16 – Typical development schedules**

| LNG import option | Time required for feasibility, design, permitting and finance (Months) | Time for engineering, procurement and construction (Months) | Total time required (Months) | Comments |
|---|---|---|---|---|
| Onshore terminal | 15 | 39 | 54 | |
| Existing FSRU | 15 | 3 | 18 | Limited availability (See box) |
| New build FSRU | 15 | 21 | 36 | |
| FSRU conversion | 15 | 15 | 30 | |
| FSU | 15 | 12 | 27 | |
| Existing LNGRV | 15 | 3 | 18 | None available |
| New build LNGRV | 15 | 21 | 36 | |
| GBS | 15 | 39 | 54 | |
| Onshore gas pipeline | 12 | 12 | 42 | Can be seasonal |
| Jetty | 15 | 21 | 36 | |
| Breakwater | 15 | 24 | 39 | |

These schedules include all activities from project inception through first LNG. The schedules shown differ from many proposed by industry sources who only consider the LNG component and exclude studies, jetty/mooring and connecting pipelines. The schedules of some fast to market technologies are diluted as the technology is not the rate determining step. Site based location factors, for example, no existing jetty facilities have been identified and need to be built from scratch and the pipeline network needs significant reinforcement, will determine overall schedule.

There are currently 24 FSRUs available for operation with a further 13 under construction. Of the 24 existing vessels five may become available but all have restrictions:

**Table 17 – FSRU availability**

| FSRU | Current employment | Comments |
|---|---|---|
| GDF Suez Cape Ann | CNOOC, Tianjin, China | Will leave in 2017 after onshore terminal completed (although a recent site visit suggests this may be later).<br>Chartered to GDF Suez for 30 years (to 2040) but a subcharter may be available. |
| Excellence | Trading | Currently relief ship for Excelerate's other FSRUs (to allow dry docking etc) probably long term committed to Point Aguirre, Puerto Rico. |
| Excelsior | Trading | Committed to Bangladesh from 2018. |
| Golar Spirit | Petrobras, Brazil | Charter expires in 2017. Petrobras appear to have lost the jetty site in Pecem so project may be terminated.<br>Old converted LNG carrier of small size. |
| Golar Freeze | DUSUP, Dubai | No longer used as replaced by Excelerate FSRU but charter is still effective until 2018<br>Old converted LNG carrier of small size. |

Of the 13 FSRUs under construction four are already committed (Chile, Uruguay, Pakistan and Brazil). Hoegh and Golar both appear to have one uncommitted vessel for 2017-2018 deployment. Two new builds should be available in 2019 and one more in 2020. With the strength and time delay in the market many companies are looking at LNG carrier conversions into FSRUs with Hoegh and Golar planning a vessel each for 2017-18. Excelerate are also looking at options but have not made their plans public.

More details of the schedule assumptions are provided in Appendix C.

#### *2.10.1.2 Capital Cost Assessment*

The accuracy of capital costs in this project are at a feasibility level, ie +/- 50% (known as a Class 5 estimate[22]). Capital costs have not been sourced for this project. Costs from other similar projects have been selected on size and technology type and factored to potential conditions in Myanmar. The LNG import project lacks sufficient definition to provide anything more detailed at this stage.

[22] *AACE International Recommended Practice No. 18R97 COST ESTIMATE CLASSIFICATION SYSTEM – AS APPLIED IN ENGINEERING, PROCUREMENT, AND CONSTRUCTION FOR THE PROCESS INDUSTRIES*

Capital costs were developed using proprietary cost models and have then been "paramatised" to allow general use in this site selection tool. MOGE should not rely on these costs for any activity more detailed than site screening.

The costs presented are based on equipment items purchased or subcontracts tendered adjusted to include bulk materials (electrics, controls, pipework, etc), labour (factored based on anticipated productivities in Myanmar) and contractor costs and contingencies.

The key capital costs are:

- Berth protection/breakwater (typically US$ 50 – 100s million)
  - If required, breakwaters can be extremely expensive as they consist of a pyramid of rock from the seabed (-15m) to the highest wave height (5-6m for Myanmar + margin) of considerable length – the volume of rock is considerable
  - Seabed may need to be modified to support this weight of rock
  - Rock needs to be sourced locally or regionally and transported to the site by truck or for Myanmar more probably by ship (after truck/rail transport to the port)
  - Specialist offshore construction vessels must be mobilised to position the rock
- Dredging (US$ 10 – 100s millions)
  - If required, a dredger must be mobilised to dredge the seabed.
  - Dredge spoil dumping can be difficult and may involve the employment of barges or other vessels to remove and dispose of the dredge potentially at some distance from the dredging location
- Jetty/Mooring & pipelines (US$ 20 – 200 million)
  - Distance from the jetty head (LNG unloading point) and shore determines the cost which may be considerable
  - Seabed conditions and water depth affect the base cost of a unit length of jetty
- LNG storage (US$ 150 – 400 million)
  - The amount of storage whether in onshore tanks or within the hull of the FSRU/FSU is a major investment
  - Costs vary depending on technology and ground/seismic conditions
  - Foundation costs of onshore tanks may be considerable
- LNG Vaporisation (US$ 10 – 50 million)
  - Not a key cost, relatively small compared to other components such as storage and jetty
- Gas Pipeline (US$ 2-3 million per km)
  - Gas pipeline costs are roughly split materials (20-30%), labour (20-30%) miscellaneous (20-30%)

More details of the capital cost assumptions made are provided in Appendix D.

#### *2.10.1.3 Operating Cost Assessment*

The accuracy of the operating costs in this project are at a feasibility level, ie +/- 50% (known as a Class 5 estimate). Operating costs have not been sourced for this project. Costs from other similar projects have been selected on size and technology type and factored to potential conditions in Myanmar. The LNG import project lacks sufficient definition to provide anything more detailed at this stage.

Operating costs were developed using proprietary cost models and have then been "paramatised" to allow general use in this site selection tool. MOGE should not rely on these costs for any activity more detailed than site screening.

The key operating costs are:

- Lease/tolling fees (typically US$ 120 – 160,000 per day)
  - Payment of fees to the FSRU (or other technology) owner to cover debt payments, fixed operating costs and other agreed owner's costs
- Debt repayment (highly variable)
  - Payment of interest and repayment of debt principal on owned facilities
- Labour costs (wages and overheads) (US$ 3 – 5 million/year)
  - Payment of staffing costs including pensions, health insurance, corporate overheads, etc
- Inspection/classification costs (US$ 0.5 million/year)
  - Providing in-situ inspection or dry docking to maintain FSRU/FSU within Classification Society rules
  - Remaining in Class is not essential but may be a condition of financing or insurances
- Insurance (US$ 1 – 3 million/year)
  - Payment of insurance premiums for FSRU/FSU P&I club membership
- Hull/fabric maintenance (US$ 1 – 6 million/year)
  - Maintenance of equipment, replacement of spare parts and fabric (concrete, buildings, etc) or hull
- Transport to/from offshore facilities and support base (US$ 0.75 - 2 million/year)
  - Provision of boats and/or helicopters to ferry staff to/from land to an offshore facility.
  - Warehousing and local office.
- Cost of fuel/power
  - Purchase of fuel for the generation of electricity and heating primarily on an FSRU or purchase of power from the local system for onshore use within the LNG facility or gas compressor stations.
- Tug costs
  - Chartering of four tugs with a total bollard pull of 160 ton to moor and unmoor the LNG carrier.
  - Tugs could be available at all times for a low charter rate but with low utilisation or be brought to site only when required at a higher charter rate plus relocation costs.

### 2.10.2 Economic Parameters

The two key economic parameters in the model are.

- Project duration
  - The length of time that the facility will be employed to deliver LNG into Myanmar
- Discount rate
  - The interest rate used to calculate the value of future cash flows based on the project risk (uncertainty of future cash flows)

   - Many companies use their weighted average cost of capital (WACC) if the project's risk profile is similar to that of the company. However, if the project’s risk profile is substantially different from that of the company, the Capital Asset Pricing Model (CAPM) is often used to calculate a project-specific discount rate that more accurately reflects its risk.

### 2.10.3 Description of the Discounted Expenditure Model (SPT-Stage 3)

A simple discounted cash model has been created in a spreadsheet using Microsoft Excel. The details of the methodology are provided below along with the assumptions made for costs and schedules of each option.

The discounted expenditure model totalises the costs incurred by a project in each year. These costs are:

- Capital investment
  - Purchase and construction of owned equipment and employment of construction services
  - Financing and owners’ costs are excluded
- Fixed operating costs
  - Leasing costs (FSRU)
  - labour costs, inspection/classification costs (FSRU/FSU), insurance, hull/fabric maintenance and transport to/from offshore infrastructure
- Variable operating costs
  - Fuel and/or power purchase

The model has three phases

- Construction prior to operation
  - Determined by the implementation schedule of the technology
  - Annual cost is capital investments spread over the implementation schedule using a phasing factor for the technology
- Operation
  - Determined by the LNG contract duration
  - Annual cost is the summation of both fixed and variable operating costs
  - For simplicity, no capital investment is assumed during the operating period
- Post operation
  - After expiry of the LNG contract
  - Annual cost is zero
  - Zero decommissioning costs are assumed

In each year the annual cost is discounted using:

$$\text{Cost now} = \text{cost at start} \times \frac{1}{(1 + \text{discount rate})^{(\text{year now} - \text{year start} - 1)}}$$

Discounted annual costs will be totalised and plotted against time to show their accumulation and eventual out turn at the end of the project.

### 2.10.4 Using the Discounted Expenditure Model

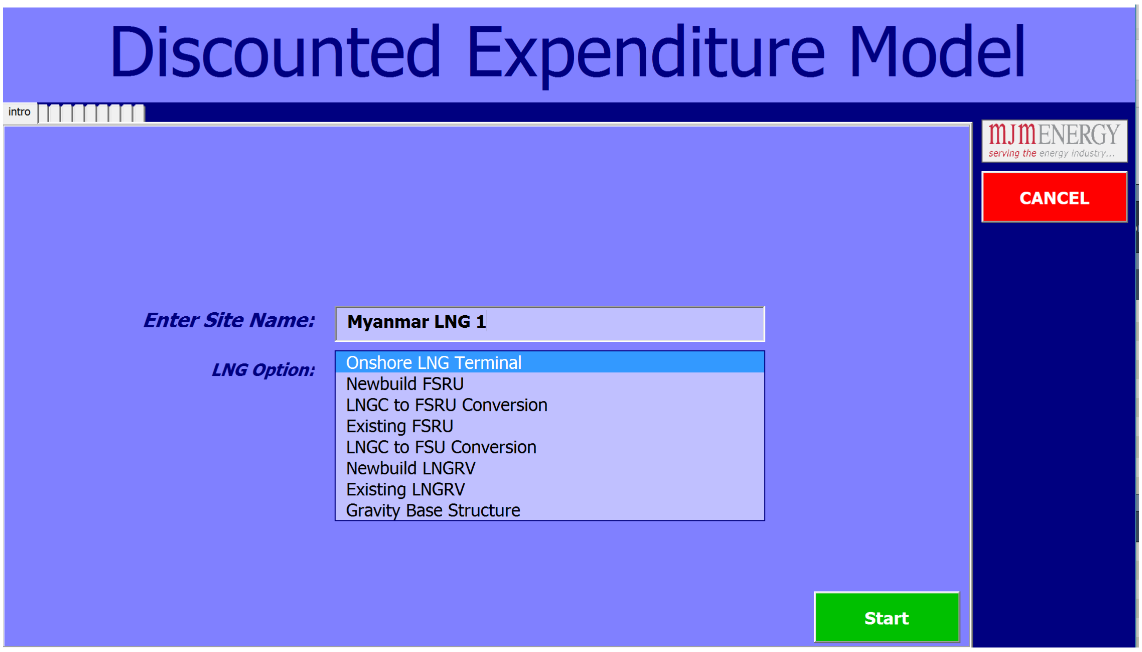
The model starts with a data entry screen where the main parameters of the project is entered. These are:

- Vaporisation rate (in mmscfd by year)
- Storage capacity (in $m^3$ LNG)
- Project type (FSRU, onshore terminal, etc)
- Project assessment (FID) date and duration
- Discount rate

Values selected in the previous stages of assessment will be automatically included where possible with an option to modify.

The entry screen is shown in Figure 26.

**Figure 26 – Project data entry screen**



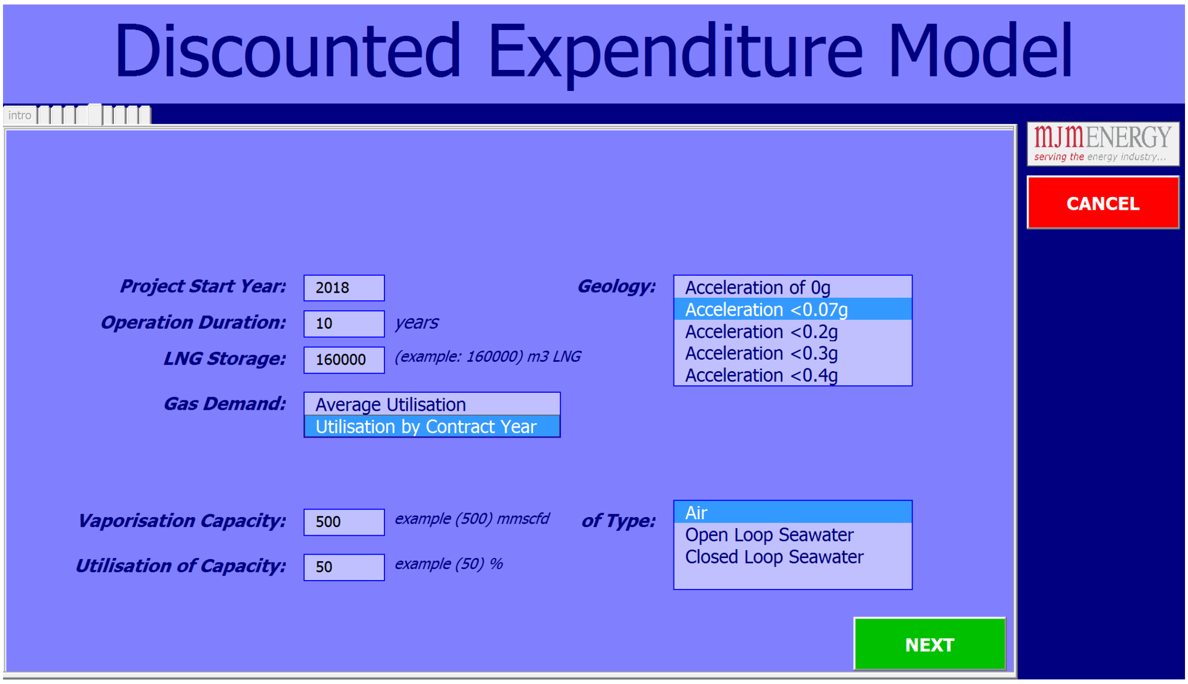

The capital costs of each part of the project is then input by the user. These can be sourced from two places; firstly using the estimates determined from the data in the traffic light analysis or second using more specific data entered at this stage, for example the exact jetty length. Different data are required based on the site and technology selected.

Information will be required on the following:

- Jetty/mooring type and length
- LNG terminal or FSRU cost if wholly owned
- dredging/breakwater costs
- Offshore and onshore pipeline connections
- Local infrastructure

Details of the capital cost estimates are detailed in a following subsection.

**Figure 27 – Capital cost data entry screen**



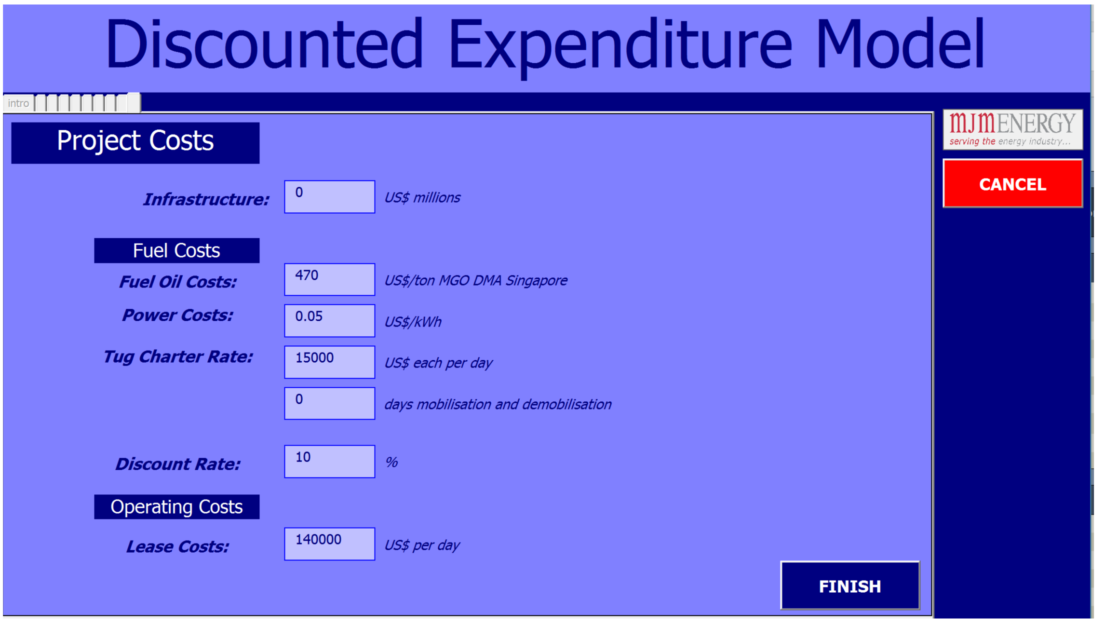

The operating and lease costs of each part of the project is then input by the user. These can be sourced from two places; firstly using the estimates determined from the data in the traffic light analysis or second using more specific data entered at this stage. Different data are required based on the site and technology selected.

Information will be required on the following:

- FSRU lease rate
- Fuel/power costs
- Vaporisation related costs

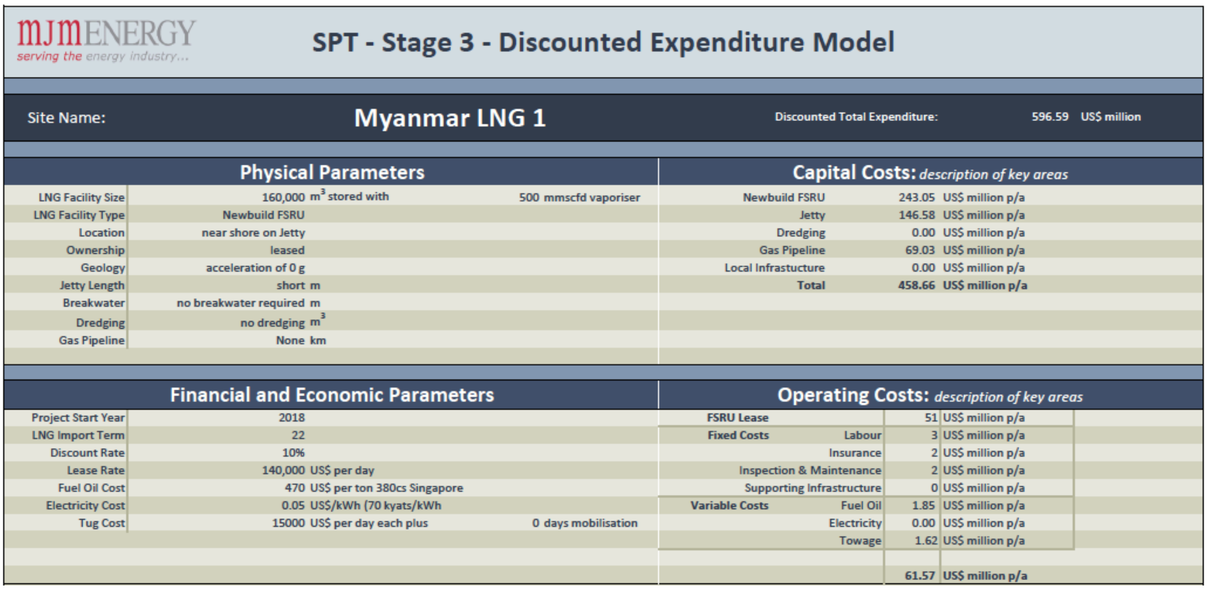
Details of the operating cost estimates are detailed in a following subsection.

**Figure 28 – Operating Cost Data Entry Screen**




The output is shown in Figure 28

**Figure 29 – Results Screen**



mjm ENERGY
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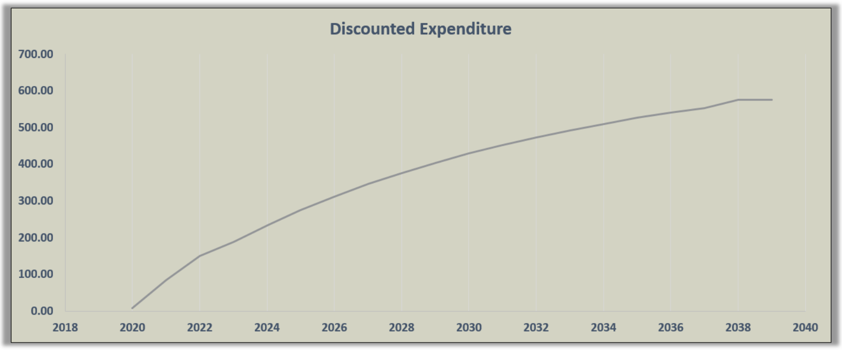
## SPT - Stage 3 - Discounted Expenditure Model graph 1




mjm ENERGY
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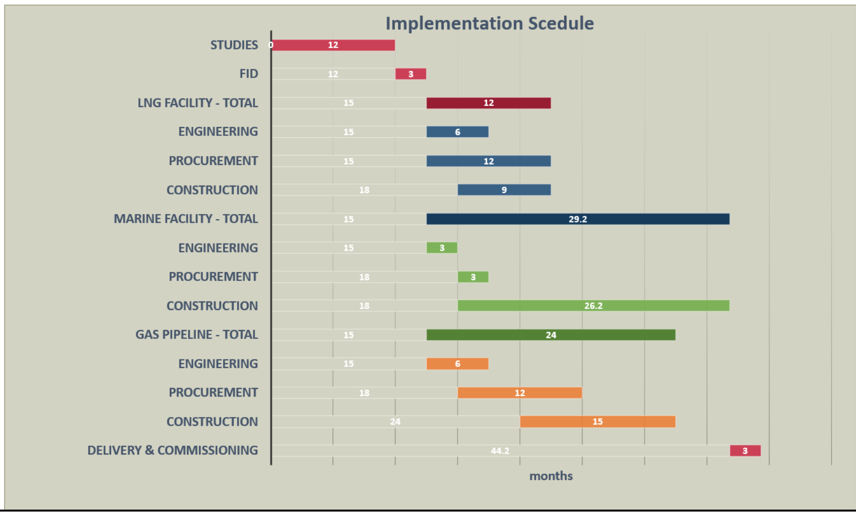
## SPT - Stage 3 - Discounted Expenditure Model graph 2




For a further explanation of using the SPT-Stage 3 discounted expenditure model see Annex C.

# 3 Analysis of the chosen locations

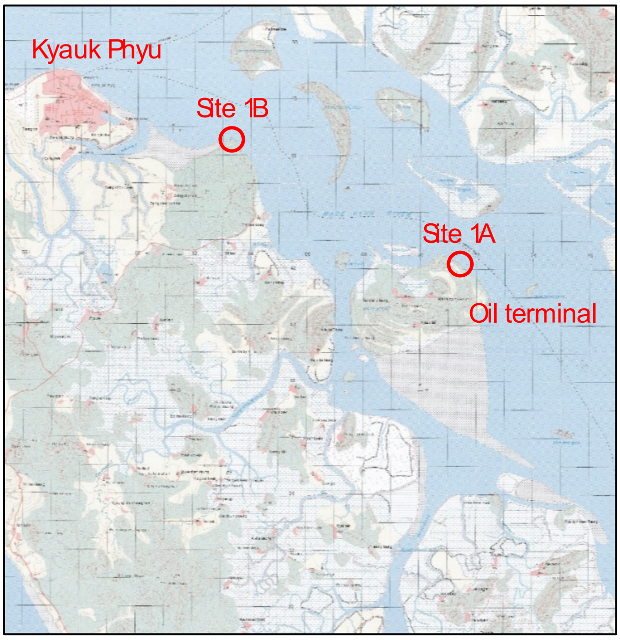
## 3.1 Location 1: Kyauk Phyu

The first location considered is the most northerly location situated close to the town of Kyauk Phyu in Rakhine state, as shown in the following diagram. The terminal is located in the general area of the city of Kyauk Phyu in Rakhine province. Two potential sites present themselves, firstly Site 1A on Maday Island (various spellings including Made and Madae) close to or adjacent to the existing Chinese oil import terminal and secondly Site 1B adjacent to the existing ports on the edge of Kyauk Phyu itself.

Kyauk Phyu Special Economic Zone (SEZ)[23] includes an on-going commitment to support the Sino-Myanmar Oil and Gas Pipeline (as evidenced by the Maday Island Oil Terminal), and a planned "Deep Water Port" in conjunction with the Chinese. However, progress has been slow and may have stopped entirely.

**Figure 30 – Location of Sites 1A and 1B[24]**


*Overview map for Location 1*




*Detailed map for Location 1*

The terminal is also where the pipelines from the offshore Shwe field are landed and then proceed through northern Myanmar to the Chinese border.

[23] http://www.idsa.in/backgrounder/myanmar-in-chinas-push-into-the-indian-ocean_jmpaul_120316
[24] Overview Location Map for Site 1 http://www.wineandvinesearch.com/myanmar/myanmar.png
Location Map for Site 1 Ministry of Agriculture and Irrigation, Survey Department, Government of Myanmar (Sheet No. 1993.11 Rakhine State: Kyaukpyu District)

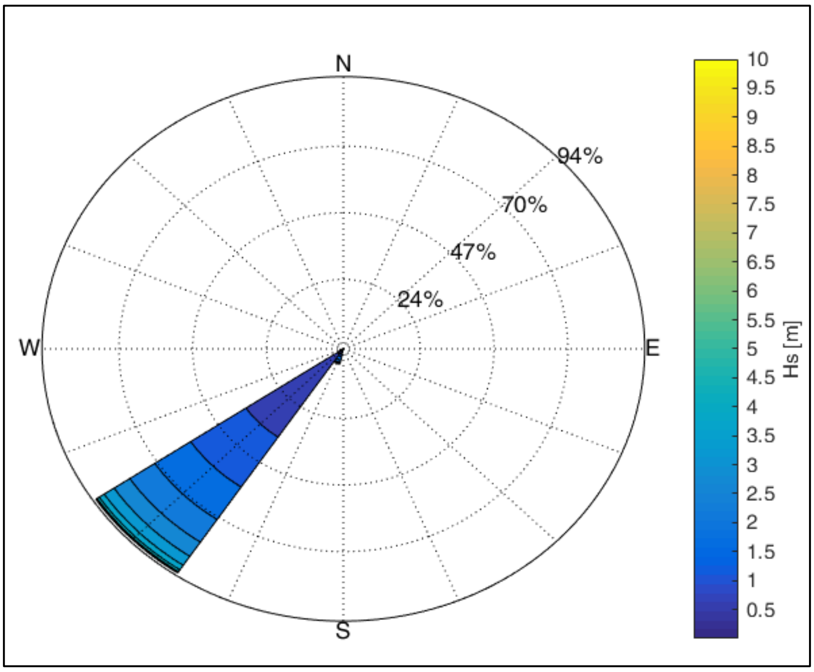
### 3.1.1 Weather

The metocean study has examined the inshore wave environment around the terminal site and a proposed pilot transfer station. The assessment is based on offshore waves over a 20 year period which have been propogated to the site by means of a numerical modelling exercise.

#### *3.1.1.1 Waves*

The offshore waves are almost wholly from the south western direction. At this site over a 20 year period the mean significant wave height (Hs) is 1.6m and a standard deviation of 0.9 as shown below.

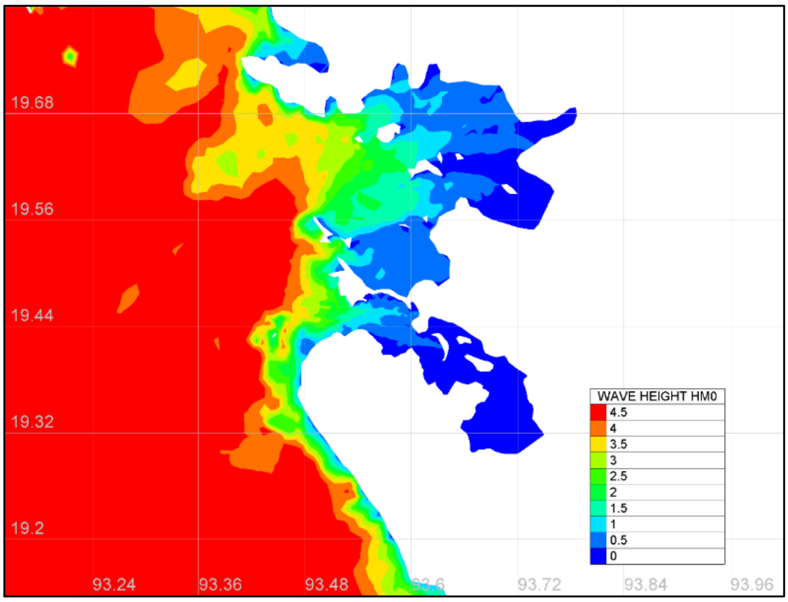
**Figure 31 – Wave environment**




As a result of its location the proposed berth can only be exposed to North Westerly winds (where it opens into the Bay of Bengal) and largest wave from this direction is predicted to have a height of < 0.5 m Hs.

The following figure shows that even in a non-cyclonic storm the wave heights at the berth are less than 0.5 m.

**Figure 32 – Inshore Waves for non Cyclonic Storm**




Wave protection of any LNG berth will not be required.

The wave exceedance curves for the pilot transfer station at 19.4998°N 093.3332°E are as follows:

**Figure 33 – Wave height exceedance curve at pilot station**

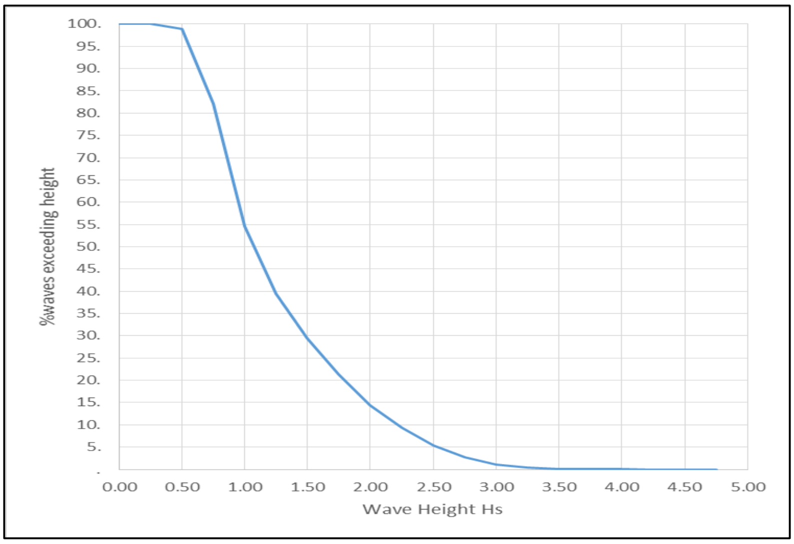
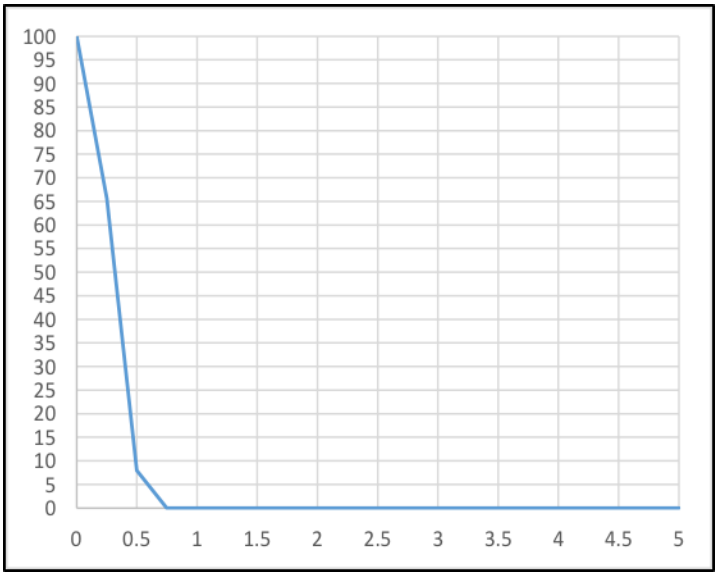


**Figure 34 – Wave height exceedance curve at berth**

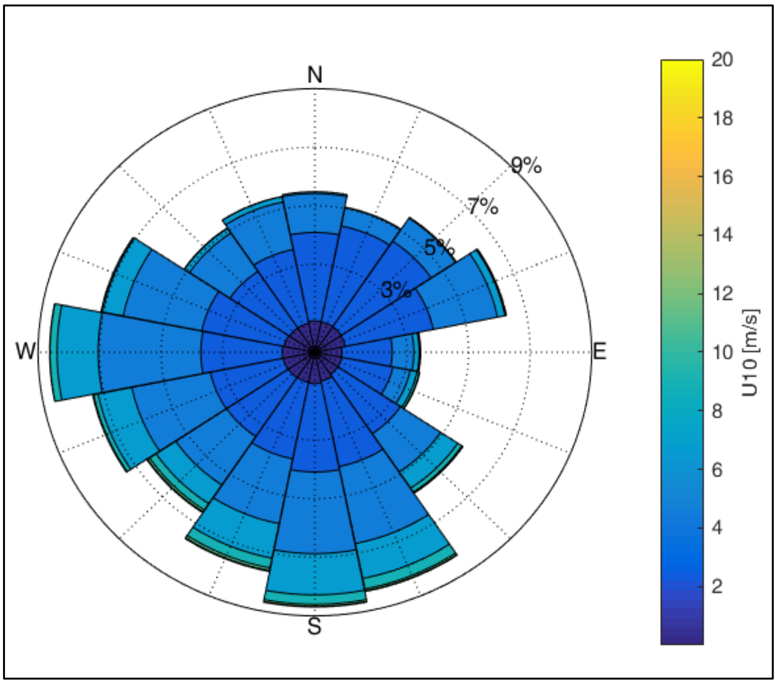



Pilots can consistently board LNG carriers in waves with heights of 1.75 m and less, 78.7% of the time at this location. This point is more exposed and represents the limiting wave condition for a terminal at Kyauk Phyu.

#### *3.1.1.2 Wind*

LNG carriers and FSRUs have high windage areas. The cargo is relatively light compared to water and therefore the flat side of the LNG carrier is higher out of the water and subject to wind loads. High winds can blow the vessel off the berth or onto the berth, preventing the LNG carrier escaping in an emergency. The metocean study examined offshore winds which can come from all sectors, with a mean hourly wind speed of 5 m/s over 30 years and standard deviation of 2.4, as shown below.

**Figure 35 – Wind rose**




The land masses of Ramree and Made islands and the Arakan mountains will provide some wind shadow reducing wind impacts but this cannot be quantified at the current time. Winds from the north west and south east will be unmitigated. However these will hit the bow and stern of the LNG vessel and have a limited impact.

LNG industry body SIGTTO provides wind roses for various operating criteria on LNG carriers. Based on a berth alignment where the LNG carrier/FSRU is positioned bow to the prevailing waves, in this case north westerly, wind limits are exceeded only from a south westerly direction and only stop unloading for 0.15% of the year. The modelled wind levels never exceed typical strengths in mooring loads.

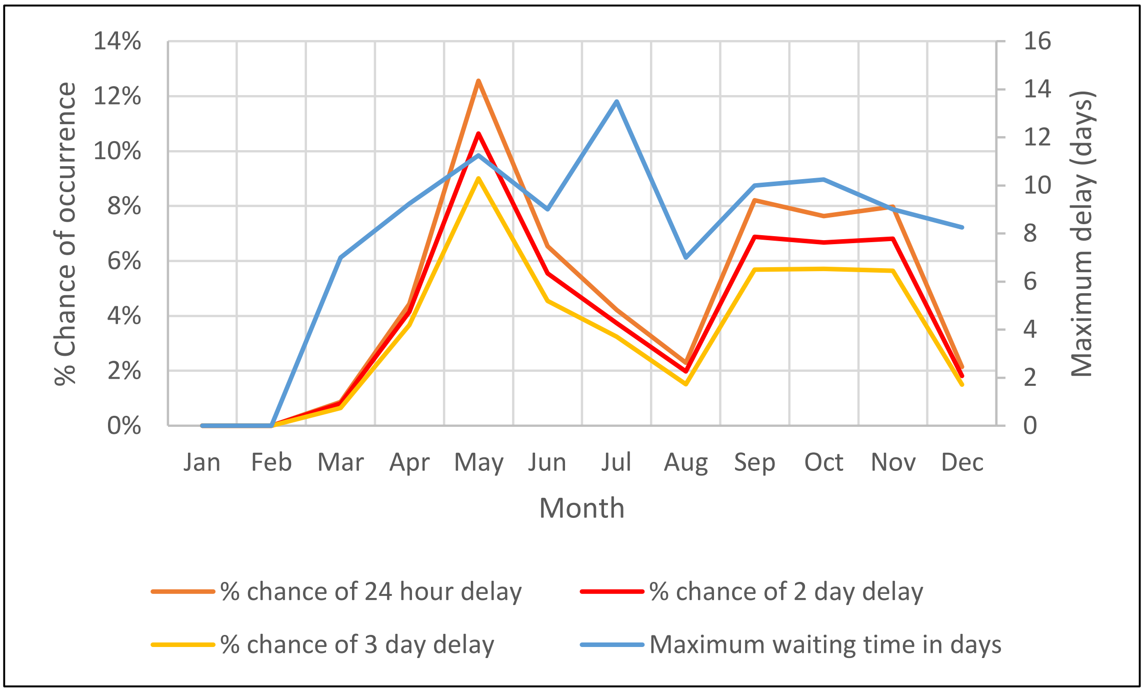
Weathervaning at this location is not required.

#### *3.1.1.3 Storm durations*

Storms that produce wind or waves that exceed operating limits of either the berthing/unloading process, vaporisation/send out or mooring need to be considered for prevalence and duration. The storm duration is important in defining LNG storage volumes.

The following graph shows the probability of different durations of weather that prevent a 24 hour window of waves less than 1.5 m Hs which are typically required to unload a LNG carrier.

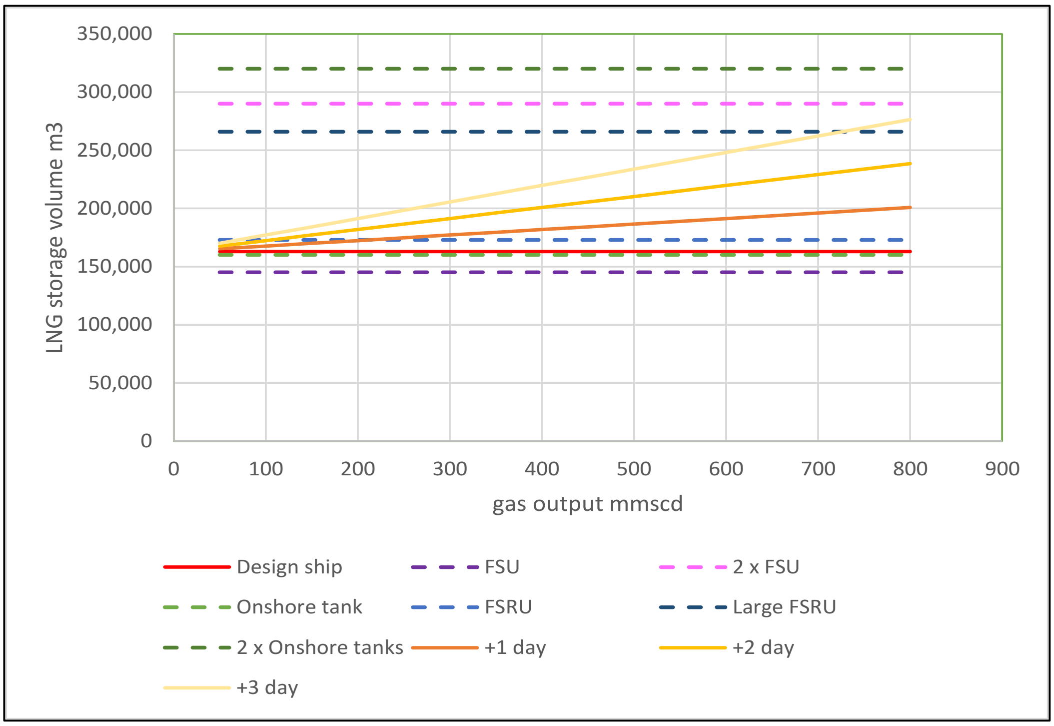
**Figure 36 – Weather window durations and probabilities**




The above graph shows in blue and on the right hand axis the maximum recorded duration when a 24 hour unloading window is not possible. This is about 10 days apart from in July when it increases to 14 days. Building in 14 days of excess storage capacity would cover all historical events of the last 30 years but could prove to be expensive. More typically lower levels of storage are used. The red-orange lines and the left hand axis look at the probability of a 24 hour window not being available in any month, for 1, 2 or 3 days duration. This is quite low (<3%) for all months except May and a secondary peak in the monsoon season of September to November. However during this latter period significant rainfall should have occurred allowing maximisation of hydroelectric generation and the reduction of any security of supply requirements from gas/LNG fired units. Security of supply is a political question for MOGE/Myanmar to decide. However, the graph shows a significant impact of moving from 1 to 3 days storage. Often 2 days is provided to provide some degree of weather window. Two or three days of storage would provide a useful mitigation as long as no technology step changes occur that would add substantial additional cost.

The following graph shows the how large the LNG storage capability needs to be for the design ship (163,000$m^3$) and a variety of gas send out/LNG vaporisation rates for 1, 2 and 3 days additional storage.

**Figure 37 – Vaporisation rate versus storage cover**



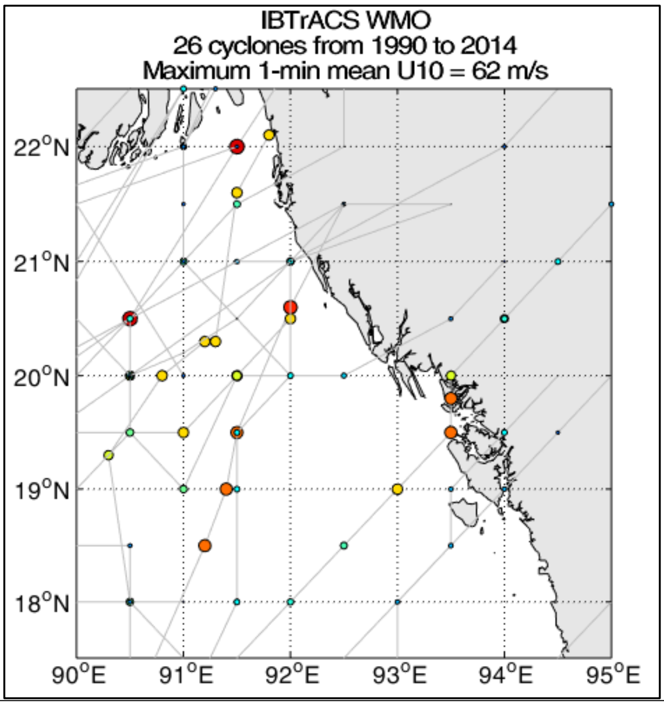

Up to 3 days of storage reserve volume is possible with an onshore terminal and FSU but would require two storage tanks/FSU. With the FSRU, storage volumes of the same scale are possible but are not currently being built by the market except for deployment in Uruguay. The FSRU would therefore need to be a new build.

Alternatively a smaller design ship could be selected based on the contract negotiations with individual LNG suppliers.

### 3.1.1.4 Extreme Weather

Cyclones are prevalent in northern Myanmar and will impact this location.

**Figure 38 – Cyclone map[25]**




| IBTrACS WMO data - Area 1 - Period: 1990-2014 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | All-year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of events [] | 0 | 0 | 0 | 3 | 9 | 1 | 0 | 1 | 2 | 5 | 4 | 1 | 26 |
| Maximum 1-min U10 [m/s] | 0 | 0 | 0 | 62 | 56 | 22 | 0 | 12 | 27 | 52 | 44 | 22 | 62 |
| Mean 1-min U10 [m/s] | 0 | 0 | 0 | 34 | 27 | 22 | 0 | 12 | 20 | 20 | 22 | 18 | 24 |

Historical cyclone activity analysis records 26 cyclones in 24 years in northern Myanmar and southern Bangladesh combined, almost 1 per year. May is the most likely month for a cyclone and along with April is when the highest wind speeds are recorded. Ramree Island will mitigate the winds slightly but is not sufficiently large to significantly impact the analysis.

Flooding from cyclones is also recorded with less than 2000 people affected during August 2015 and again during cyclone Giri in 2010.

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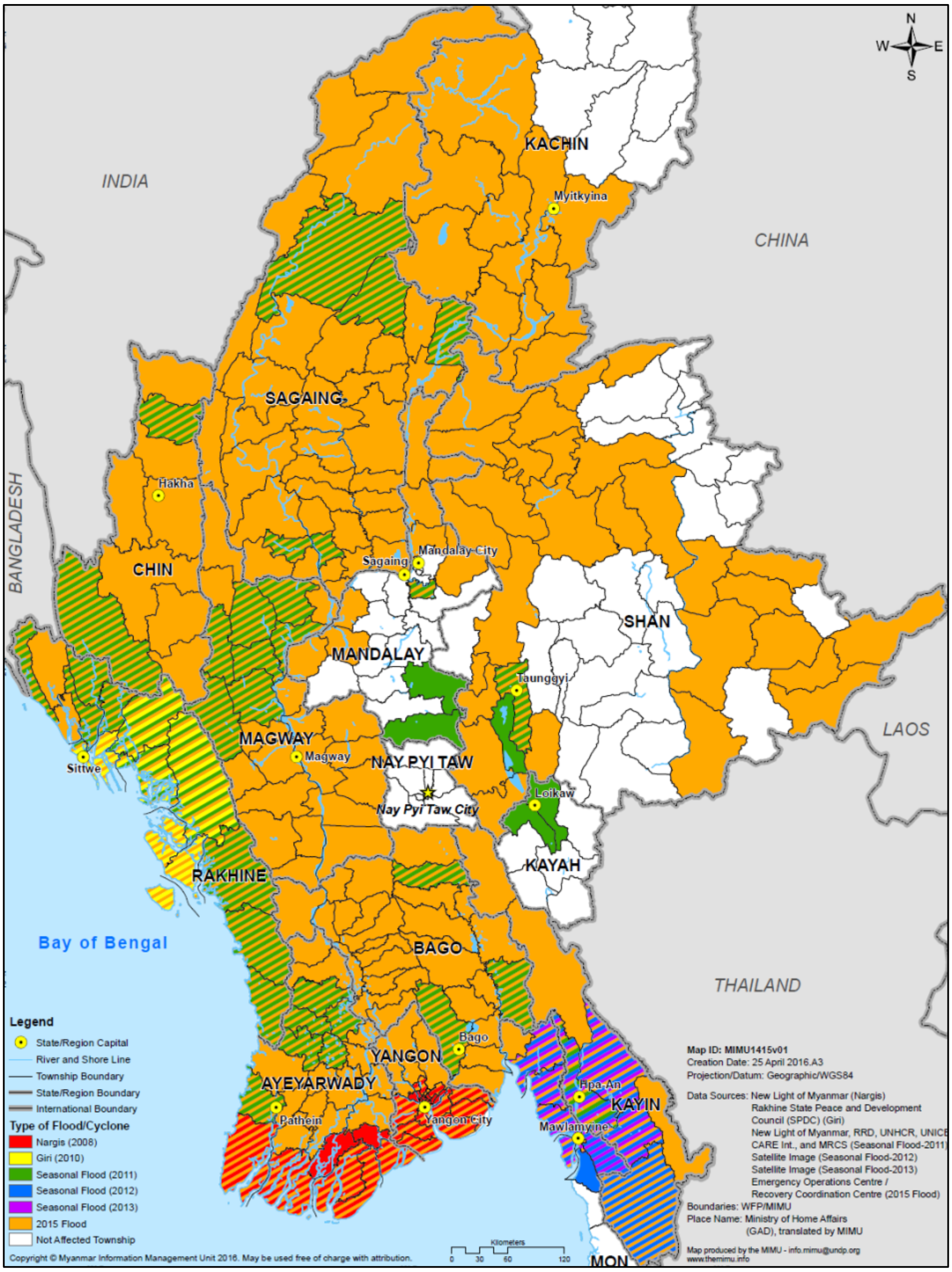
25 *http://reliefweb.int/sites/reliefweb.int/files/resources/Affected_Map_Areas_of_Potential_Vulnerability_based_on_FloodCyclone_Events_MIMU1415v01_25Apr2016_A3.pdf*

**Figure 39 – Flooding map[26]**




[26] *http://www.burmalibrary.org/docs21/Nanthaporn-&-Palioplee-2013-SEISMIC_HAZARD_ANALYSIS_FOR_MYANMAR-en.pdf*

## 3.1.2 Environmental, Social & Cultural Impact

### 3.1.2.1 LNG carrier transit

There is a single, small (3 $km^2$) marine nature reserve at Wunbiak in Combermere Bay which is primarily designated for its mangrove forest. This is sufficiently north of the marine manoeuvring area to not be an issue. However, mangrove forest, coral and seagrass appear to be present along most of the Rakhine coastline and therefore some environmental sensitivity might be anticipated along the navigation channel. There is very little survey information available to confirm or reject this general comment.

### 3.1.2.2 LNG facility

***Environmental***

There is little survey data available but mangrove forest, coral and seagrass appear to be present along most of the Rakhine coastline destruction or damage to one of these habitats is possible.

The siting and construction of the Shwe oil terminal has resulted in negative local feeling. This will heighten any environmental concerns (primarily mangrove forest) so a conservative approach has been taken in suggesting that a few small sensitive areas are within the local area. However, the Shwe oil terminal has probably already caused the most significant damage to the area. The Site 1A berth site may need to moved close to the Shwe terminal to limit new damage or further north along the navigation channel to avoid any remaining pockets of mangrove which anecdotal comments by environmental activists suggest are still present.

Site 1B should not suffer from the Shwe oil terminal issues but heightened local awareness, particularly among activists is likely. The area proposed is next to an existing naval base and port so is also not a pristine environment.

***Social & Cultural***

Kyauk Phyu includes *Gant-gaw-taw,* a pagoda which is one of the most sacred Buddhist shrines in Myanmar. This and a viewpoint known as the Point are within the township 20 km north of the site 1A and will therefore be unaffected by a LNG facility here. However, they are close to Site 1B so there may be a noise and visual impact.

The only historical event recorded was the battle of Ramree Island during the Second World War. This is significantly south of the site and appears to be a general area rather than a specific place. It will not therefore be significantly impacted.

There appear to be three settlements on Maday Island plus some additional farmsteads. None of the settlements are close to the proposed LNG site 1A so relocation would not be required. The terminal would preferentially be sited on the areas which appear to have been used as a construction camp for the oil terminal. All the floating options would require only a jetty and small onshore compound so could be laid out to avoid impact on farm land. An onshore terminal would require a much larger land take and is likely to impact on foreshore mangrove areas and might impact local farmland in a minor way.

There is no permanent road access to the island so most construction materials and equipment would be delivered by boat directly to the terminal site and not significantly increase traffic.

Site 1B is at Careening Point, closer to Kyauk Phyu but still over 3 km distant. There are buildings in the immediate area associated with the naval base and port facilities. There does not appear to be public dwellings in the immediate vicinity (1000 m). A road serves the port facilities.

***Hazard***

For site 1A limited information is available but the three settlements on Maday Island appear small, perhaps 50 – 100 people each and are all 1 km or more distant from the LNG site. One farm is about 500 m from the LNG facility.

For Site 1B there is no public population but the naval base would be expected to be manned 24 hours a day and the vessels present in the Google earth satellite images suggests a sizeable military presence.

#### *3.1.2.3 Pipeline*

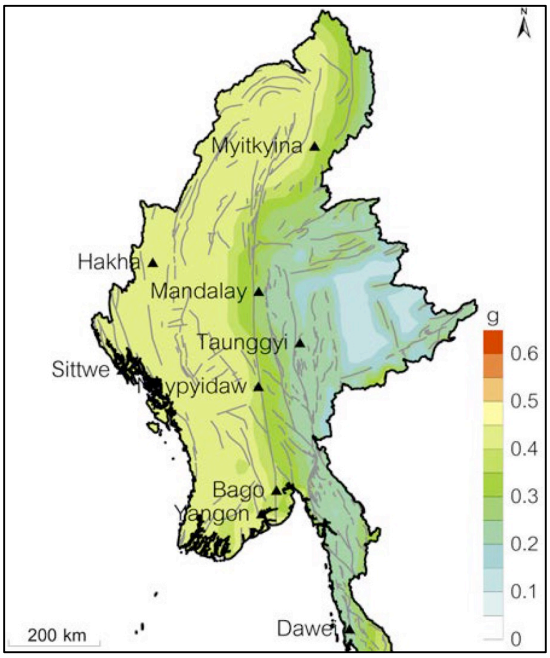
The right of way for the existing Shwe pipeline could be re-used for a second pipeline. Anecdotal comments are that this pipeline route has caused landfalls and is not popular with the local community.

Yoma Elephant range to the south of the pipeline could have been extended to the Thandwe-chaung and Tanlwe-ma-e-chaung areas. If so, any new direct pipeline will cross these areas. Site is key for wild Asian elephant and endangered and indigenous forest turtle.

### 3.1.3 Geology

The following map shows the peak ground accelerations for earthquakes in Myanmar.

**Figure 40 – Peak ground accelerations for earthquakes in Myanmar**




There has been a magnitude 4 – 5 earthquake with an epicentre very close to the proposed terminal site. This is probably the severe historical earthquake recorded in 1762 at Naungdawgyi. No major

20th century earthquakes are recorded close to the site. Inland in the Arakan Mountains several earthquakes of similar scale have been recorded. Coastal and offshore earthquakes occur both north and south of the site. Three major quakes were recorded in the 1960s. Most of these earthquakes are of magnitude 4 – 5 but 4 earthquakes of magnitude 5 - 6 surround the site.

Kyauk Phyu[27] is expected to have a peak ground acceleration of 0.4 – 0.45g, as shown in the above graphic. This would cause severe shaking and moderate to heavy damage. Any LNG facility would need to be reinforced to protect it from this degree of seismic activity.

A major fault runs down the coast of western Myanmar about 50 - 70 km offshore, this is over the subduction of the Indian and Burma plates.

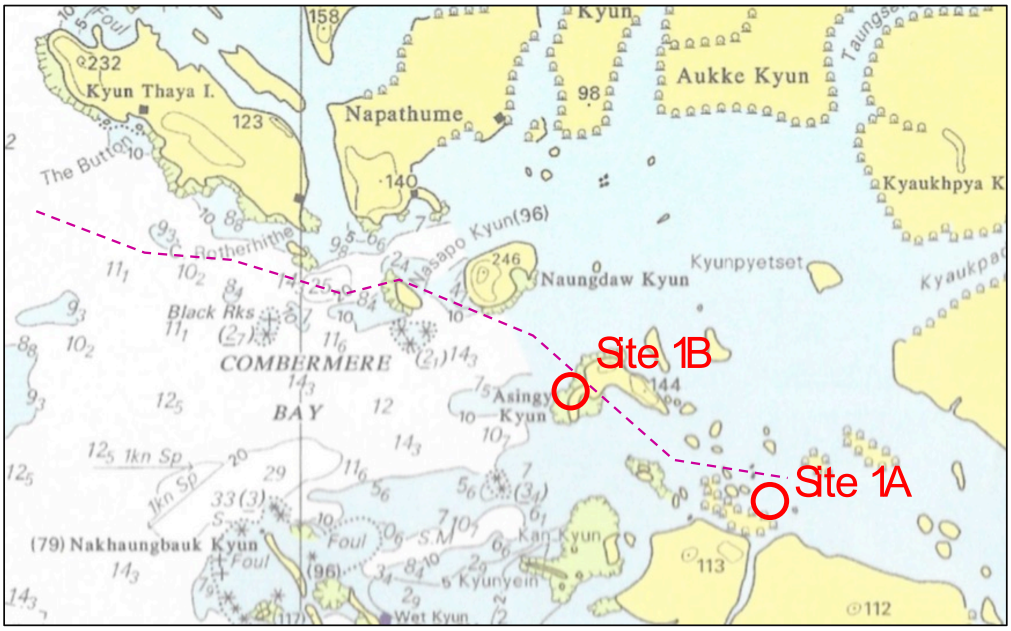
A second fault line appears to run down the Arakan Mountains but stops north of the site.

Site 1B is about 2 km from what appears to be an active volcanic area including the volcano Sai Krone. This is a mud volcano which produces mud and hot water periodically. Recent activity is evident with mud flows to the west of the volcano, away from the site 1B to the east.

### 3.1.4 Navigation

Based on a review of UK Admiralty Chart No. 817 and information gathered during the in-country visit the oil terminal has already created a deep water navigation channel between the Bay of Bengal and the terminal, dredged to a depth of 22 m and with appropriate navigational aids. This has been used by VLCCs (Very Large Crude Carriers) and therefore should be sufficient for LNG carriers. The chart and navigational channel are indicated below.

**Figure 41 – Navigation route**




Minor dredging is required as capital (initial) dredging for the channel and turning circle has already been completed by the oil terminal. The current channel exceeds the industry best practice (SIGTTO)

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[27] *Pailoplee S., "Seismic Hazard Analysis for Myanmar", Journal of Earthquake and Tsunami, November 2013*

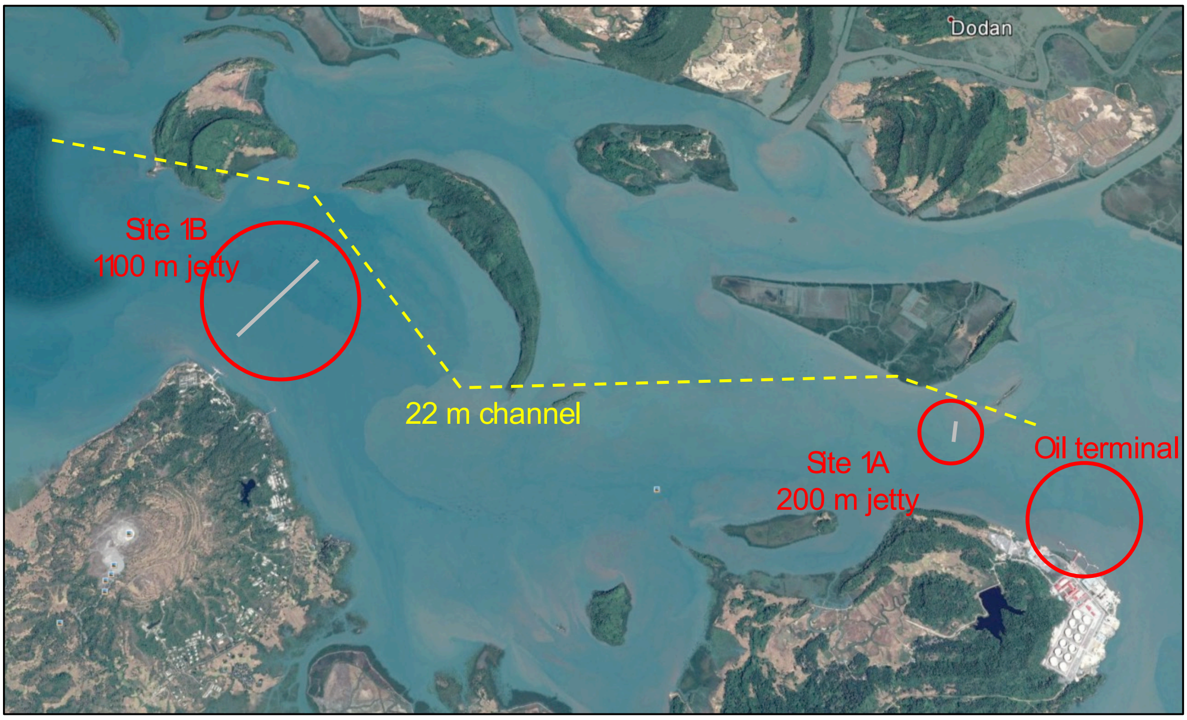
width and depth recommendations for LNG carriers. Some maintenance dredging may be required in future years but this could be co-funded with the oil terminal.

To ensure that the LNG carrier and/or FSRU is moored out of the navigation channel (at either Site 1 A or Site 1B) and not affected by surge events from the bow wake of passing oil tankers a berthing pocket will be required to be dredged between the existing channel and the proposed berth. A proposed dredge of an area of 500 m x 500 m from a depth of 14 m to 22 m results in a dredge volume of 2,000,000 $m^3$. This level of dredging is estimated to be minor for any jetty arrangement. No specific details of low visibility events have been found in public domain documents. Snow only occurs in the northern inland parts of Myanmar so is not considered a problem.

### *3.1.4.1 Jetty length*

The deep water channel runs close to land so the length of any jetty will be limited. The marine chart suggests that the jetty at site 1A would be about 200 m long while that at Site 1 B would have a length of about 1100 m, see figure below. The actual jetty length will be an optimisation between jetty construction costs and dredging costs (beyond the scope of this study).

**Figure 42 – Jetty lengths**




### *3.1.4.2 Marine traffic*

Oil tankers use the deep water navigation channel. No details of the number or movements has been identified. Public domain presentations[28] suggest that short sea and deep sea marine traffic in Myanmar is relatively low. Therefore it has been assumed that oil tankers operate at a similar density.

[28] *"Myanmar Maritime Quickscan", Netherland Marietem Land*

### 3.1.4.3 Towage

The oil terminal requires tugs to berth visiting oil tankers, so tugs are available at the terminal. MOGE stated that they have an ownership role in the tugs, but it is unknown whether the tugs would be available to assist LNG carrier berthing. This approach is considered normal.

Google Earth imagery indicates that there are/were 5 tugs moored at a lay-by berth adjacent to the Maday Oil Terminal.

**Figure 43 – Tugs at Maday Island oil terminal**


Again, no detail can be found as to the technical specification or availability of these tugs, but the following points are positive indictors:

- These tugs are each about 48m in length, which would suggest that they are capable of providing a bollard pull (BP) force of 45 to 60 tonnes when operated in the normal direct towage manner. Typically, a loaded LNGC would require about 180t to 240t of BP for safe berthing.
- Subject to further investigation about the capability and availability of these tugs, the early suggestion is that suitable towage resources are available at Kyauk Phyu, with a total BP of approximately 250t.
- Sufficient tugs are available but the bollard pull per tug is lower than that suggested for LNG carriers. However, the 5 existing tugs, when working together are adequate to handle LNG carriers.

### 3.1.4.4 Port Rules

Port rules would be anticipated for the oil port which would include most of the provisions required for LNG. However, no evidence of any port rules or port authority for the oil port has been identified in public domain documents.

## 3.1.5 Location 1 – Kyauk Phyu access to gas pipelines

The purpose of this section is to provide an analysis of the issues concerning access to Myanmar's high-pressure gas pipeline network, focussing on costs in the following areas.

- Overview of the site location and associated issues
- Review of offshore gas transmission pipeline costs.
- Review of onshore gas transmission pipeline costs.
- Gas network reinforcement costs.
- Concluding discussion.

### *3.1.5.1 Overview of the site location and associated issues*

There is a power station near Kyauk Phyu which is connected to the electricity distribution network by a single 230 kV feeder (about 200 MW) to the main north-south power transmission network. All the north-south power lines are running at capacity. Additional line capacity would take 2 – 3 years to build and up to 5 years to permit and plan. There is no advantage of generating power from gas at Kyauk Phyu. LNG must therefore be exported via the gas pipeline network.

The following diagram shows the location of Location 1 – Kyauk Phyu and the potential options considered during siting analysis for Site 1A and Site 1B both in relation to the gas transmission network and the local geography. Whilst the two potential sites 1A and 1B are roughly 10km apart, in terms of providing estimate of gas transmission pipeline connection costs the two options are very similar. For example, both sites will require a short length of subsea offshore gas transmission pipeline to connect to the mainland followed by a considerable length of onshore gas transmission pipeline, which shall be explored later in this section. Therefore, for the purposes of this analysis both sites will be treated as one and the same, clearly if a more detailed feasibility study was being carried out a great deal more detail would be included such as river crossings, road crossing and terrain mapping.

In terms of the local area, there are a number of potential issues that might make the construction of connecting gas transmission pipelines complex and complicated as follows:

- As previously mentioaned the Yoma Elephant range to the south could at some point be extended to the Thandwe-chaung and Tanlwe-ma-e-chaung areas. The Yoma Elephant range is key for wild Asian elephant and endangered and indigenous forest turtle. Therefore, if the Yoma Elephant range was to be extended such an extension could potentially impinge on the most direct route for the connecting pipeline if it would cross these areas.
- The current oil terminal built and operated by the Chinese has experienced tensions and difficulties with the local inhabitants and farmers. It is quite possible that the development of an LNG terminal in this location, even a relatively benign FSRU might not be well received.

**Figure 44 – Overview of Location 1 Kyauk Phyu for FSRU**

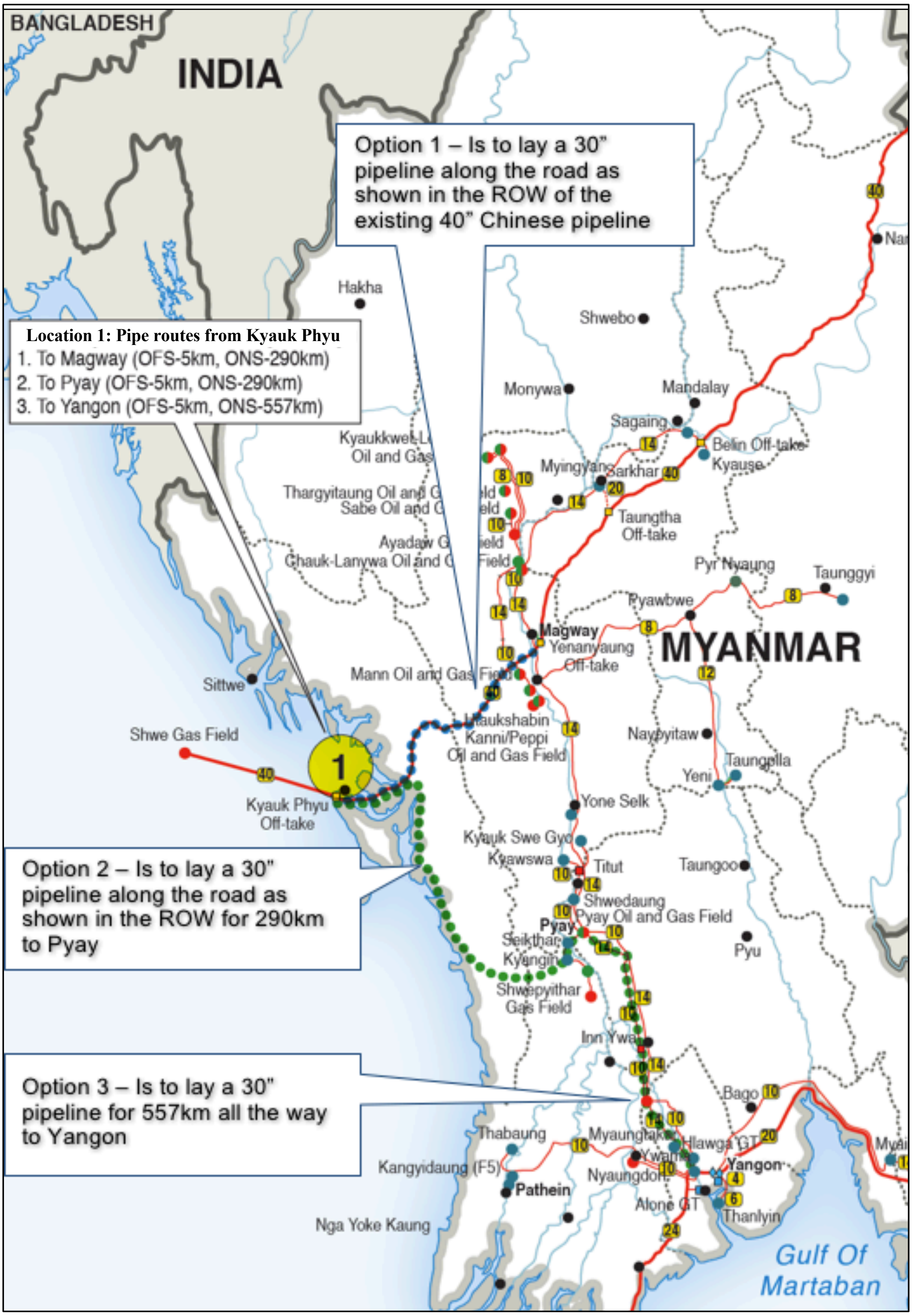

### 3.1.5.2 *Review of offshore gas transmission pipeline costs*

It is debateable whether one needs to include offshore connecting pipeline costs given the location of the FSRU and its vicinity to land. In fact, the connection of the FSRU to the mainland could almost be treated as a river crossing. Nevertheless, we have allowed for 5km of subsea pipeline.

### 3.1.5.3 *Review of onshore gas transmission costs*

In terms of connecting to the gas transmission network there are possible options as highlighted below on the map.

**Figure 45 – Potential RLNG connecting pipeline routes from Location 1 Kyauk Phyu**

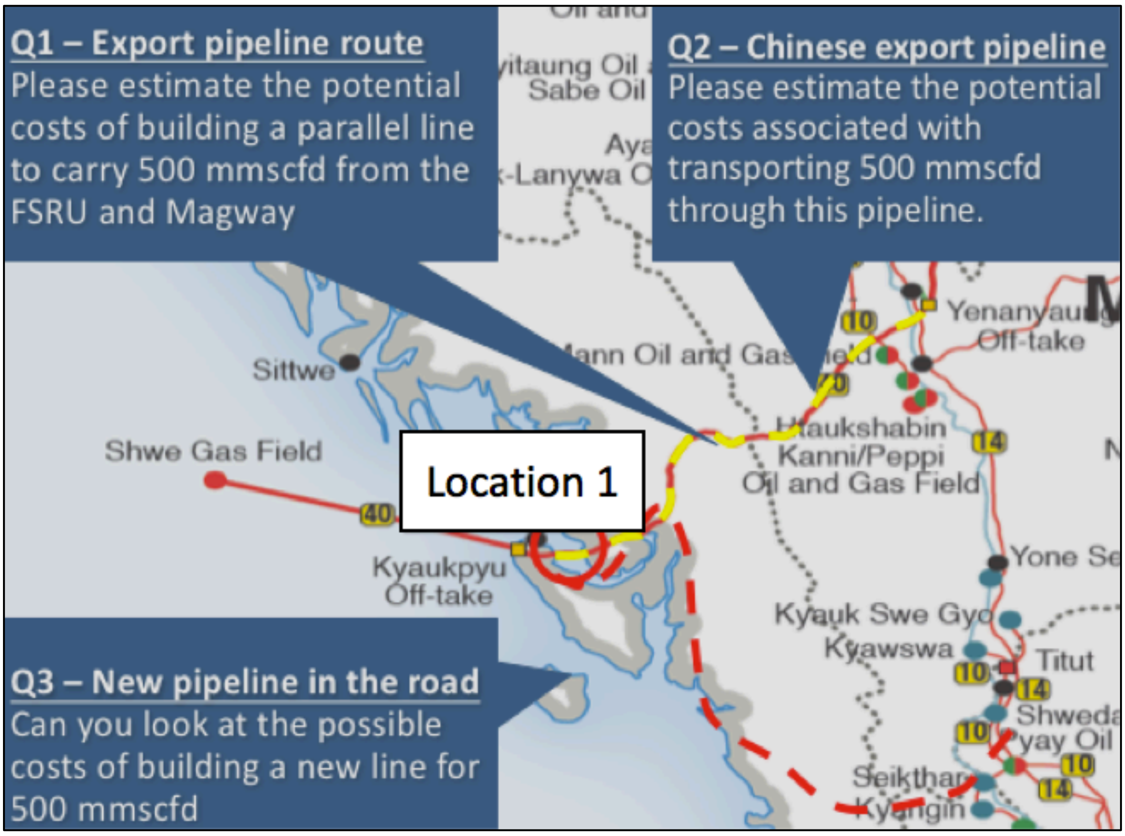


- Option 1 – Consists of laying a 290km of 30” high-pressure gas transmission pipeline to Magway in the same ROW as the has been previously used for the Chinese export gas pipeline. Whilst the pipeline route would be clear it would not be a risk-free option, with potential commercial and construction risks from constructing a new pipeline next to an existing pipeline. (NB: An alternative option would be to negotiate access to the Chinese export gas pipeline. In many ways this should be the lowest cost option since it would be using existing infrastructure if there was sufficient capacity in the existing pipeline, although it could be upgraded to release additional capacity. But the most important factor would be if the Chinese were willing to do a deal. It was noticeable from the discussion with MOGE and associated stakeholders that there was considerable reticence to engage in negotiations with the Chinese.
- Option 2 – This option also consists of laying 290km of 30” pipeline to Pyay the first major node of the gas network capable of absorbing up to 500mmscfd. The suggested route is in the road although this again would be quite challenging in terms of the route itself, the terrain and the potential space for a new pipeline.
- Option 3 – In addition to laying the 290km 30” pipeline to Pyay an alternative option would be to lay an additional 267km of 30” pipeline to take the RLNG to Yangon at an additional cost of $320.4million.

#### *3.1.5.4 Gas network reinforcement costs*

As part of the process of trying ascertain additional reinforcement costs associated with different options, the Project Team raised a number of questions with MOGE as highlighted in the following figure.

**Figure 46 – Additional questions raised in relation to Location 1 Kyauk Phyu**



In response to the questions raised by the Project Team highlighted above, MOGE replied that the Kyauk Phyu to China pipeline has a maximum capacity of 1 bscfd. Under normal operation 400 mmscfd of gas is transported to China with 70-100 mmscfd for use in Myanmar. Despite the fact that there is spare capacity in the pipeline, with the potential of a 'win-win' negotiation for both China and Myanmar, MOGE were reticent to open negotiations to access this spare capacity. It would appear that one reason for this reticence is the complex ownership structure of the pipeline.

#### *3.1.5.5 Discussion on gas pipelines*

In the light of the above the following table provides a summary of the estimated costs associated with connecting and delivering the RLNG into Myanmar's gas transmission network. Key points to note are as follows:

- The cheapest and easiest solution would be to access the export pipeline to China, however for reasons previously highlighted this has been excluded at this stage.
- Pipeline routes examined Kyaukpyu-Magway and Kyaukpyu-Pyay are very similar distances although the pipeline to Magway should be easier to lay as ROW currently exists.
- In addition, the Project Team have included the cost of laying a pipeline all the way to Yangon some 570km at an estimated cost of $684million.

**Table 18 – Summary of gas pipeline costs for Location 1 Kyauk Phyu**

| **Options 1 and 3 for delivery** | | |
|---|---|---|
| **Type of gas transmission infrastructure** | **Details of pipeline infrastructure** | **Cost ($ million)** |
| Offshore gas transmission pipeline | 5 km of 30" gas transmission pipeline at $1.8 million per km | 9.0 |
| Onshore gas transmission pipeline | 290 km of 30" gas transmission pipeline at $1.2 million per km | 348.0 |
| Additional reinforcement cost | Not known assumed to be zero[29] | 0.0 |
| **Total estimated cost for delivering RLNG into the Myanmar network** | | **357.0** |
| **Option 4 for delivery via a new 30" pipeline to Yangon** | | |
| **Type of gas transmission infrastructure** | **Details of pipeline infrastructure** | **Cost ($ million)** |
| Offshore gas transmission pipeline | 5 km of 30" gas transmission pipeline at $1.8 million per km | 9.0 |
| Onshore gas transmission pipeline | 557 km of 30" gas transmission pipeline at $1.2 million per km | 668.4 |
| Additional reinforcement cost | Not known assumed to be zero | 0.0 |
| **Total estimated cost for delivering RLNG into the Myanmar network** | | **677.4** |

[29] *It is recognised that there may not/are probably not zero. However in the absence of detailed data from MOGE the Project Team have assumed zero.*

### 3.1.6 Infrastructure

Internet sources suggest that the nearest town Kyuak Phyu (25–50,000 people) about 20 km from the site is currently unable to provide essential business services for foreign investors. At present, only the most basic financial, legal and logistical expertise is currently available.

There is little industry in Kyauk Phyu with fishing and agriculture the main employment. The highest level education facility in the town is a teacher training college.

A 100 bed hospital is located in Kyauk Phyu which has an emergency department. Internet based information suggests that the hospital and 4 smaller feeder hospitals are underfunded and poorly equipped.

There are 3 ports described at Kyauk Phyu, one in private hands and two operated by the Myanmar Port Authority. Berth lengths and depths are very limited and cranage and major logistics facilities are not present. Port side storage also appears to be limited. The nearest port of any size is Sittwe, 120 km to the north.

Kyauk Phyu has a domestic airport with links to Sittwe and Yangon.

There are plans to connect Kyauk Phyu to one of Myanmar's main highway routes but this does not seem to have happened to date. Roads are unpaved and their condition is such that many people choose to travel by boat. A railway link to China appears to be on hold or cancelled.

Rakhine State has suffered from long-simmering tensions between the predominantly Buddhist majority and Islamic minority.

## 3.1.7 Scoring

The traffic light scoring for Kyauk Phyu is shown in the following figure.

**Figure 47 – Location 1: Kyauk Phyu Traffic light scoring**

| | | Site 1: Kyauk Phyu | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Site 1 A Maday Island | | | | | | | Site 1 B Kyauk Phyu | | | | | | |
| | | Onshore terminal | FSRU on Jetty | Midwater FSRU | eepwater FSRU | FSU on Jetty | NGRV in eepwater | GBS | Onshore terminal | FSRU on Jetty | Midwater FSRU | eepwater FSRU | FSU on Jetty | NGRV in eepwater | GBS |
| GETTING LNG TO THE TERMINAL | | | | | | | | | | | | | | | |
| 1 | How much dredging is required to create a channel to the terminal? | | | | | | | | | | | | | | |
| 2 | What Jetty length is required to be able to moor a near shore FSRU/LNG Carrier? | | | | | | | | | | | | | | |
| OR | What Subsea pipeline length is required to connect a midwater or deepwater FSRU or LNGRV? | | | | | | | | | | | | | | |
| 3 | How much marine traffic is currently being experienced? | | | | | | | | | | | | | | |
| 4 | Are there local visibility limitations? | | | | | | | | | | | | | | |
| 5 | Are there any other factors that limit the site? | | | | | | | | | | | | | | |
| STORING LNG | | | | | | | | | | | | | | | |
| 1 | What is the wave environment like? | | | | | | | | | | | | | | |
| 2 | How variable is the wind/wave environment? | | | | | | | | | | | | | | |
| 3 | Might the LNG facility be impacted by extreme weather? | | | | | | | | | | | | | | |
| 4 | Will the site cause any destruction or exclusion to environmentally sensitive areas? | | | | | | | | | | | | | | |
| 5 | Will the site cause any destruction or exclusion to culturally and historically sensitive areas? | | | | | | | | | | | | | | |
| 6 | Will the site development and operation impact the local community in any detrimental way? | | | | | | | | | | | | | | |
| 7 | Will the site development and operation increase the risk of harm/fatality to the local community? | | | | | | | | | | | | | | |
| 8 | Are there risks to the LNG facility from geological events? | | | | | | | | | | | | | | |
| GETTING GAS TO MARKET | | | | | | | | | | | | | | | |
| 1 | Can LNG be vaporised in sufficient volume and in an environmentally acceptable way? | | | | | | | | | | | | | | |
| 2 | What is the onshore pipeline length? | | | | | | | | | | | | | | |
| 3 | What is the difficulty in laying the onshore pipeline? | | | | | | | | | | | | | | |
| 4 | What is the offshore pipeline length? | | | | | | | | | | | | | | |
| 5 | What is the difficulty in laying the offshore pipeline? | | | | | | | | | | | | | | |
| LOCAL INFRASTRUCTURE | | | | | | | | | | | | | | | |
| 1 | Is there sufficient towage available to berth the LNG carrier? | | | | | | | | | | | | | | |
| 2 | Is there currently any port rules and infrastructure appropriate to hydrocarbon importation at the proposed LNG | | | | | | | | | | | | | | |
| 3 | Is there sufficient infrastructure to accommodate workers and their families, expatriates and vendor personnel? | | | | | | | | | | | | | | |
| 4 | Is there emergency response and Health care capability? | | | | | | | | | | | | | | |
| 5 | Education and Skills? | | | | | | | | | | | | | | |
| 6 | Is there access to a major port with connecting roads? | | | | | | | | | | | | | | |
| 7 | Is there access to an international airport with road/rail links? | | | | | | | | | | | | | | |
| 8 | How adequate is the marine infrastructure? | | | | | | | | | | | | | | |

## 3.1.8 Technology & Site Selection

### 3.1.8.1 Site selection

This coastal area is defined by the Madegyan River. It is assumed that this river like most of those in Myanmar carries significant levels of soil and therefore siltation of the dredged pocket and channel will be an issue. Site 1A is closer to the river so will silt marginally faster. The body of water around both sites looks sufficient that cold recirculation of water will not be a problem. The Madegyan River flows will assist this but may be too small during the dry season.

Site 1A on Maday Island is preferred to site 1B at Careening Point for the following reasons:

- Presence of the mud volcano at Site 1B
- Substantially longer jetty at Site 1B
- Larger human population associated with the naval base at Site 1B
- Site 1A is closer to the Shwe pipeline corridor

#### *3.1.8.2 Viable Technology Options*

The wind and wave data does not require any form of berth protection (breakwater) or weathervaning capability.

A weathervaning mid-water solution benefits by being sited further away from populated areas and is less susceptible to geological damage. This is balanced by the need for considerable additional dredging. A weathervaning system is therefore rejected on an environmental impact and cost basis.

A jetty type arrangement is therefore proposed.

There is sufficient land available at Site 1A for an onshore terminal although the current proposed schedule mitigates against this.

A near shore FSRU on the jetty is possible and should have a faster schedule. An existing FSRU would be fastest followed by a conversion and then a new build.

A FSU would also be possible.

## 3.2 Location 2 – Nga Yoke Kaung

### 3.2.1 Introduction

The second Location considered is the middle Location situated in the general area of to Ngayok Bay in Ayeyarwady province, see diagram below. This site is closest to Yangon (largest power use location).

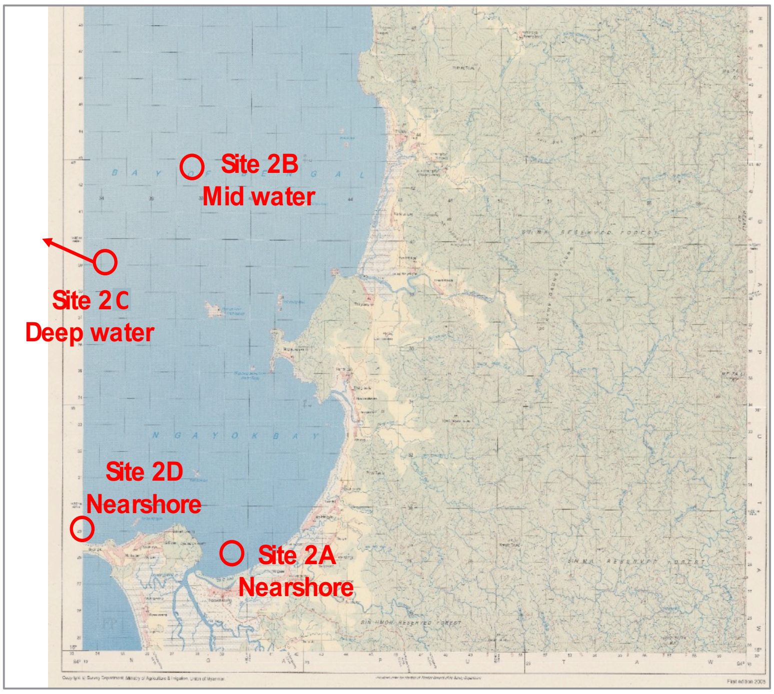
Four potential sites present themselves:

- Site 2A within the bay and close to the shoreline at the village of Kunthidaw.
- Site 2B, located in mid water outside of the protection of the bay on a tower yoke mooring.
- Site 2C, located in deep water outside of the protection of the bay on some form of buoy weathervaning mooring.
- Site 2D within the bay, at the very west (seaward) end of the south side of Nga Yoke Kuang Bay, just to the east of Goyangyi Island

There is no existing port at this location. A 300 MW coal fired power plant with a port has been suggested by Mitsubishi. This appears to have been withdrawn as a result of local protests.

**Figure 48 – Location of Sites 2A, 2B, 2C and 2D[30]**


*Overview map for Location 2*




*Location map for Location 2*

## 3.2.2 Weather

The metocean study has examined the inshore wave environment around the proposed terminal sites and a proposed pilot transfer station. The assessment is based on offshore waves over a 20-year period which have been propagated to the site.

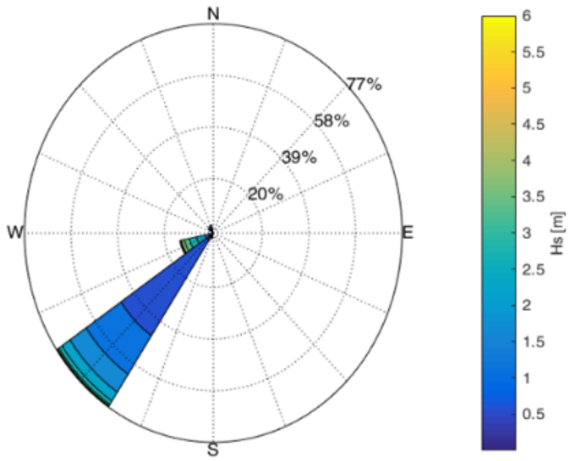
### 3.2.2.1 Waves

The offshore waves are almost wholly from the south western direction with a small variation towards west-southwest. At this site over a 30-year period the mean significant wave height (Hs) is 1.3m and a standard deviation of 0.8, as shown in the following figure.

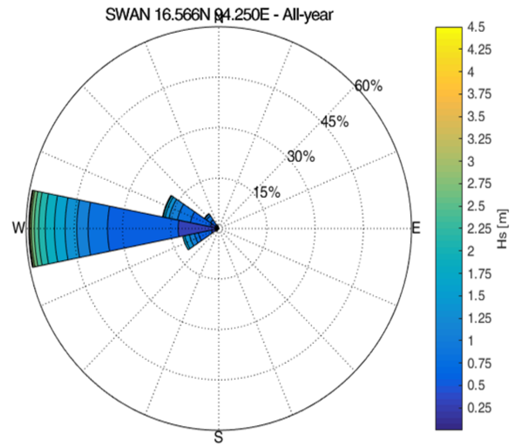
[30] *Overview map for Location 2*
*http://www.wineandvinesearch.com/myanmar/myanmar.png map for Location 2*
*Ministry of Agriculture and Irrigation, Survey Department, Government of Myanmar (Sheet No. 1694 06 Ayeyawady Division: Pathein District).*

**Figure 49 – Wave environment**

Site 2A, 2B & 2C



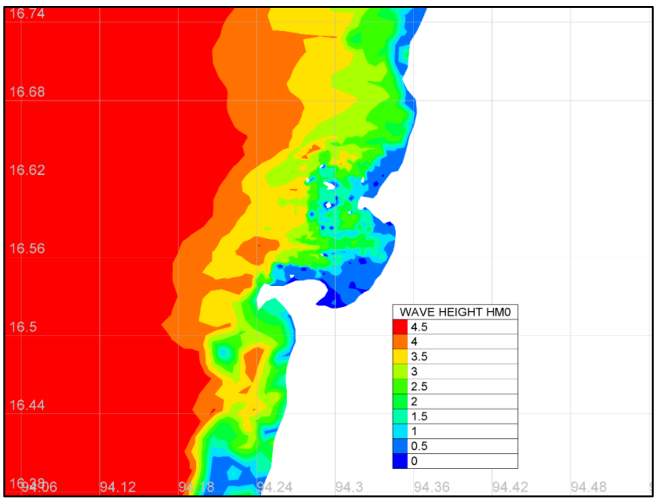

Site 2D




As a result of its location the proposed berth/mooring at sites 2A, B and C are directly exposed to south westerly winds (where it opens into the Bay of Bengal) while Site 2D is exposed to Westerly waves. The largest waves from both directions are predicted to have a height of 5.5 m Hs.

The following chart shows that even in a non-cyclonic storm the wave heights at a nearshore berth protected by the headland would be in the range 1 – 1.5 m. If not sheltered, elsewhere in the bay wave heights would reach 2.5 – 3 m. In deeper water offshore wave heights would be 3.5 to 4.5 m.

**Figure 50 – Inshore waves for non cyclonic storm**

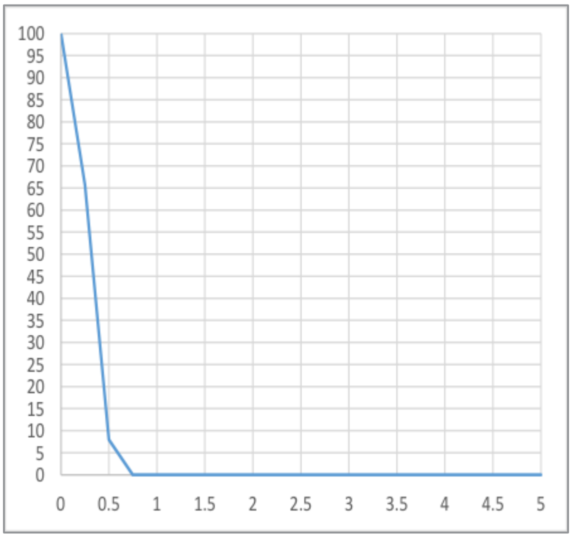



Wave protection of any LNG berth will be required unless the sheltered southern part of the bay is used, close into shore.

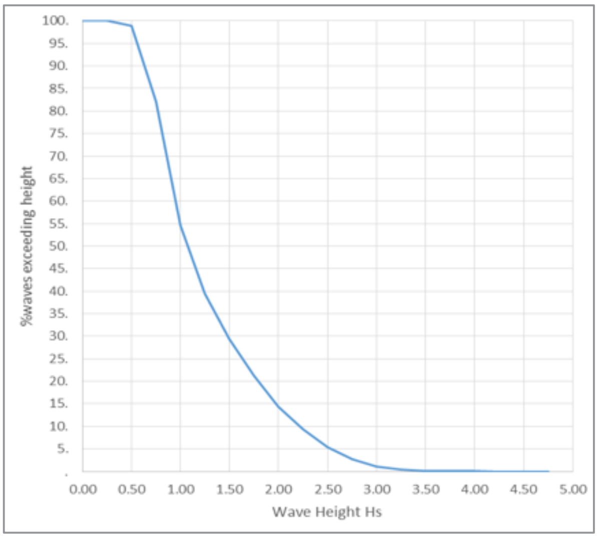
The metocean study has examined both the offshore (sites 2B and 2C) and inshore (sites 2A and 2D) wave environments. The wave exceedance curves for sites 2A, 2B/2C and 2D are as follows:

**Figure 51 – Wave height exceedance curves (Pilot station)**

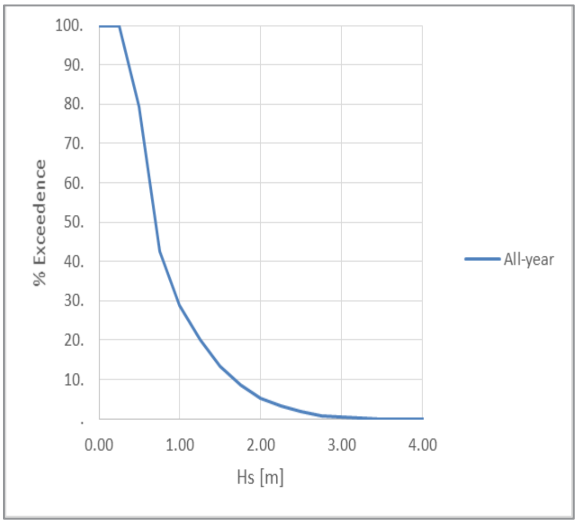
Site 2A




Site 2B and Site 2C



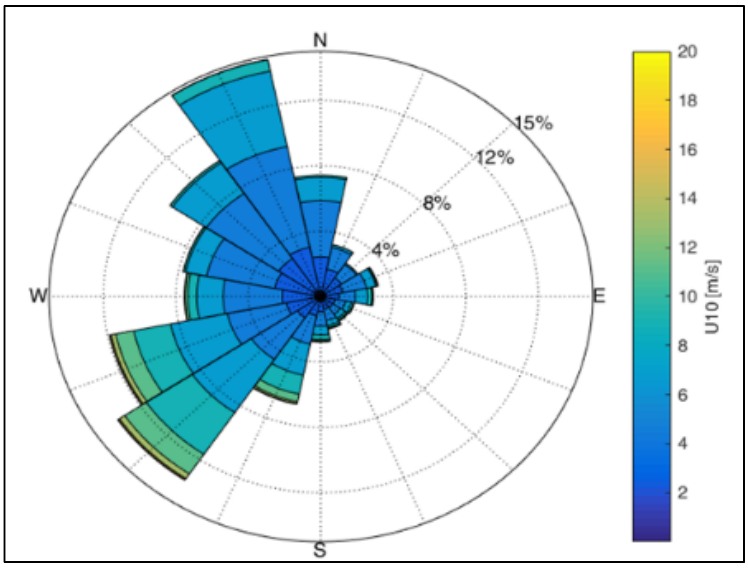

Site 2D



### 3.2.2.2 Wind

The metocean study examined offshore winds which can come from any westerly direction from north to south, with a mean hourly wind speed of 5.5 m/s over 30 years and standard deviation of 2.4, as shown in the following diagram.

**Figure 52 - Wind rose**




The headland would provide some protection to the south westerly winds but would be exposed to the north westerlys. The nearshore berths do not have sufficient depth to allow weathervaning and the space required would move the berths into a more exposed position. Site 2A needs to be oriented to the north-northwest to limit wind impacts on the moored vessels. Winds from a southerly direction are unusual but with the proposed berth orientation would be similar to SIGTTO limiting states for berthing. Site 2D is oriented north-south to maximise the shelter of the headland and minimise dredging.

Offshore the FSRU would need to weathervane to limit the impact of the winds. During north westerly winds the carrier would turn bow to the wind. Waves would still be from the south west and would therefore hit the carrier side on causing roll. The FSRU may need to manoeuvre using thrusters to find the least worst conditions, probably bow roughly westerly.

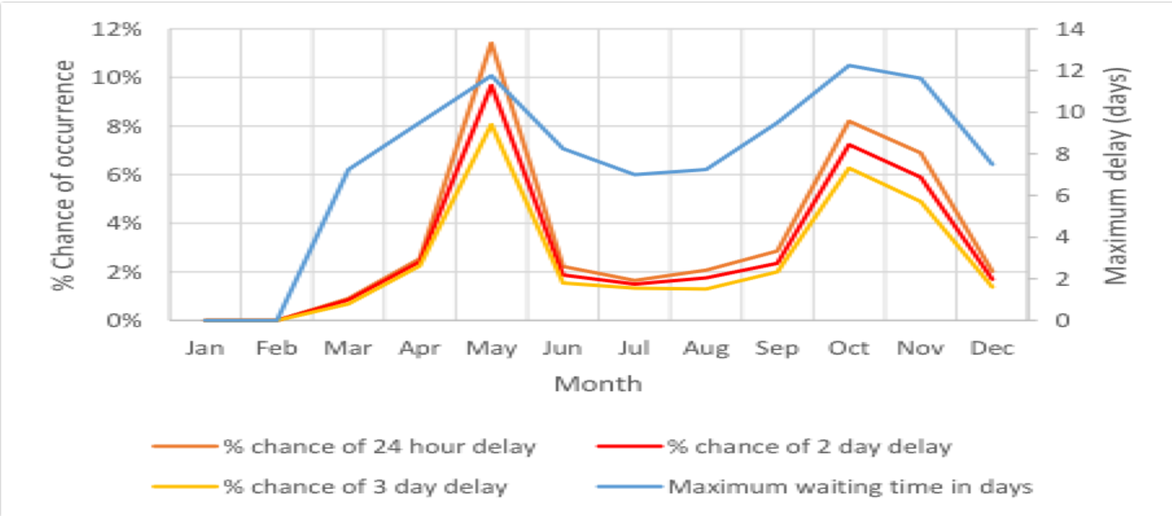
Carriers approaching the FSRU would do so into the wind with the FSRU acting as a temporary breakwater to reduce wind impacts. The combination of relatively high wind strengths and deep water would require more tug power to ensure successful berthing.

### 3.2.2.3 Storm durations

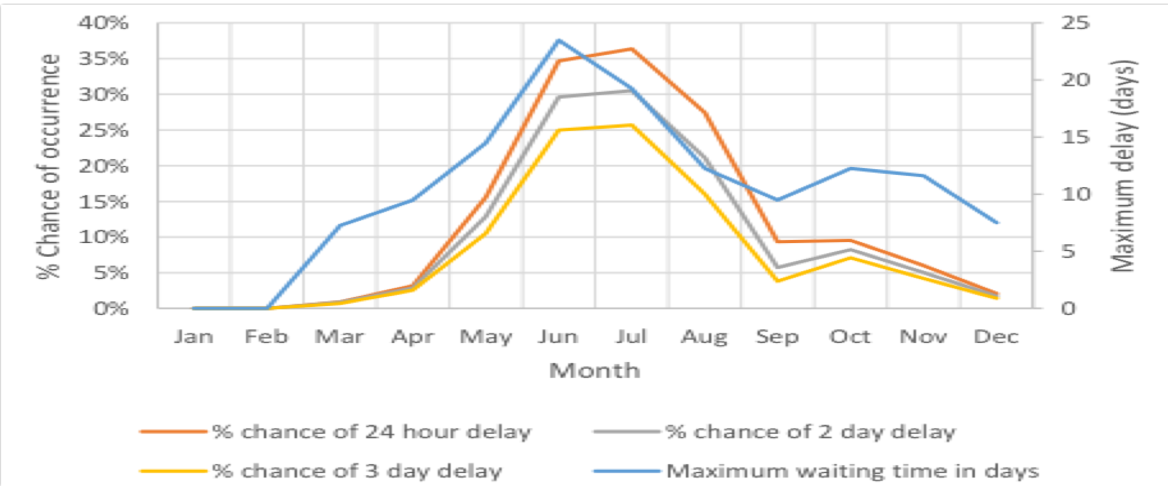
The following diagram shows the probability of different durations of weather that prevent a 24-hour window of waves less than 1.5 m Hs which are typically required to unload a LNG carrier.

**Figure 53 - Weather window durations and probabilities**

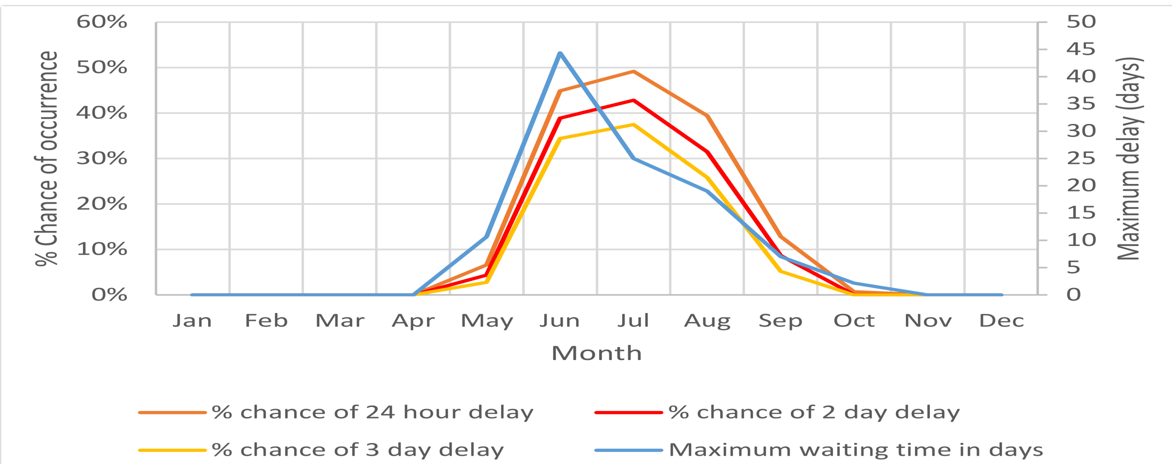
Nearshore Site 2A




Deepwater Site 2B / 2C




Site 2D



The above graphs show in blue and on the right-hand axis the maximum recorded duration when a 24 hour unloading window is not possible. For the nearshore site 2A this is about 8 days apart from in May, October and November when it increases to 12 days. Building in 12 days of excess storage capacity would cover all historical events of the last 30 years but could prove to be expensive. For the deep and mid water options (site 2B) maximum delay duration increases to about 23 days in June, is highly variable but is consistent with the near shore location at other times.

More typically lower levels of storage are used. The red-orange lines and the left hand axis look at the probability of a 24 hour window not being available in any month, for 1, 2 or 3 days duration. For the nearshore site 2A this is quite low (<2%) for all months except May and a secondary peak in the monsoon season of September to November. However during this latter period significant rainfall should have occurred allowing maximisation of hydroelectric generation and the reduction of any security of supply requirements from gas/LNG fired units.

Looking at the offshore sites 2B and 2C frequency of a delay is very high in May and June, up to 35%. The impact of storage is significant but reduces the delay frequency only to 25% for 3 days storage. The deep water option is not viable in May and June. As this is the peak of the dry season and hydroelectric power is minimal this site option should be eliminated.

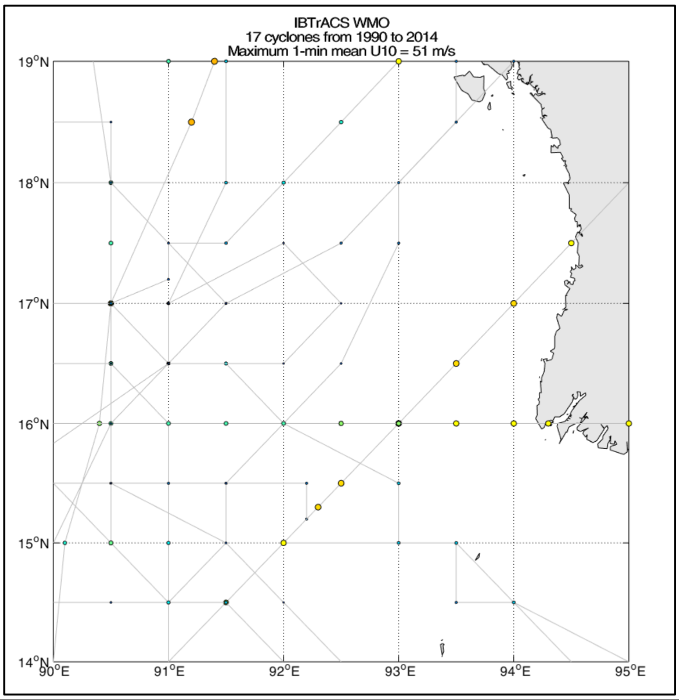
Site 2D also shows very high frequencies of delay. The site is very sensitive to wave height. Increasing the wave height from the standard 1.5 m Hs used above to 1.75 m Hs halves the delay frequency. Similarly increasing the wave height to 2 m Hs halves the delay frequencies again. Although the site looks non-viable at 1.5 m Hs the wave data and particularly the bathymetry are not accurate enough to be definitive about this affect. Site 2 may be sufficiently protected but this can only be confirmed by more definitive data and analysis.

The comments about the potential volume of LNG storage and its limitations on import options as made under Site 1 remain valid

#### 3.2.2.4 *Extreme Weather*

Cyclones are prevalent in central Myanmar and will impact this site.

**Figure 54 – Cyclone map**




| IBTrACS WMO data – Area 2 – Period: 1990-2014 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | All-year |
| Number of events [] | 0 | 0 | 1 | 1 | 8 | 0 | 0 | 0 | 0 | 5 | 2 | 0 | 17 |
| Maximum 1-min U10 [m/s] | 0 | 0 | 12 | 49 | 50 | 0 | 0 | 0 | 0 | 44 | 17 | 0 | 50 |
| Mean 1-min U10 [m/s] | 0 | 0 | 12 | 43 | 22 | 0 | 0 | 0 | 0 | 23 | 16 | 0 | 23 |

Historical cyclone activity analysis records 17 cyclones in 24 years in central Myanmar, almost 1 every other year. May is the most likely month for a cyclone and along with April is when the highest wind speeds are recorded. The headline might provide some protection to the nearshore site but is unlikely to be sufficiently large to significantly impact the analysis.

Flooding from cyclones is also recorded with less than 2000 people affected during August 2015 and again during cyclone Giri in 2010.

### 3.2.3 Environmental, Social & Cultural Impact

#### 3.2.3.1 *LNG carrier transit*

There is little survey data available but mangrove forest and coral are definitely present. Seagrass may also be present along most of the Arewaddy coastline. Destruction or damage to one of these habitats is expected for the nearshore sites because of dredging of the access channel.

Seagrass can be ingested by older, steam turbine driven, LNG carriers causing loss of power and therefore manoeuvrability. Tug operations would need to be more stringent at this site to mitigate this potential risk. For the floating terminal, the approach route would be through deep waters with no environmental impacts expected.

### 3.2.3.2 LNG facility

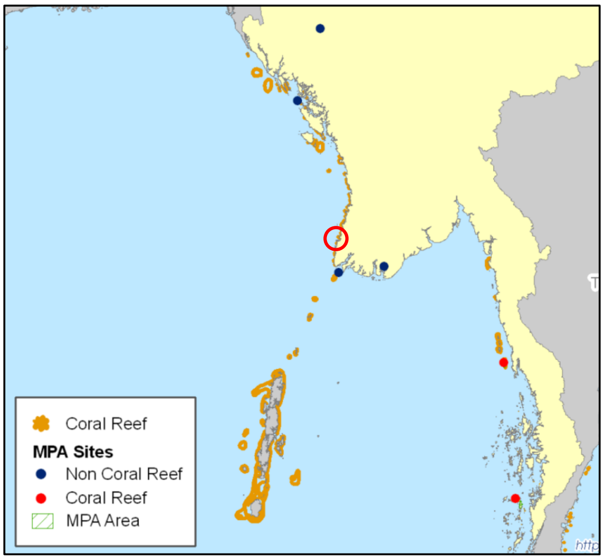
A 300 MW coal fired power plant and associated port was proposed by Mitsubishi but has been withdrawn as the result of protests by local people.

***Environmental***

There is little survey data available but mangrove forest and coral are definitely present. Seagrass may also be present along most of the Arewaddy coastline. Destruction or damage to one of these habitats is expected if dredging takes place for a berthing area and turning circle for a nearshore terminal. Dredging would produce turbulence and turbidity. Coral will be damaged.

FSRUs use seawater to vaporise the LNG. This water is returned cooler and containing biocide into the local sea. In a sheltered bay there may not be sufficient water movement to prevent recirculation of the cold water creating a larger area of damage. FSRUs can use heat from their engines to warm the seawater and prevent this temperature change but this is expensive in fuel costs. The biocide required will also damage the local ecology.

**Figure 55– Coral [31]Distribution in Myanmar**




A subsea pipeline from the offshore LNG facility would cause destruction of a small section of the reef. This could be mitigated by thrust boring beneath the coral and pulling the pipeline through the resulting channel. Without survey data on the extent of the coral no comments on the technical or economic feasibility of such an approach can be made.

Cold recirculation will not be a problem offshore as water movements are much more extensive. Biocide effects will be similar.

The tourist resorts of Chaung Tha and Ngwe Saung advertise snorkelling and swimming suggesting coral, around several islands (White Sand and Lover's, Bird). Diving is also offered from Gaw Yan Gyi.

[31] *Summary Report for MPAs in Myanmar*

There are no national parks defined in this part of the coastline that would be affected by an LNG development. However, the Thanihla Kyun (Diamond Island) wild life reserve just beyond Mawdin Point is the premier turtle reserve in Myanmar. Turtles are a high visibility, environmentally sensitive species to the world community and environmental pressure groups. Although 70 km to the south, other smaller populations are likely to be present further north, although public domain data suggests that they are more likely to spread east along the coastline towards Yangon.

***Social & Cultural***

There are seven small villages and hotel/resorts scattered around the bay. Four (Alegon, Nga Yoke Kaung, Sinhmon and Kyaukkegyi) could potentially be impacted by a jetty based LNG terminal at Site 2A. There is one settlement (unnamed), an extended collection of houses and farmland which will be affected by Site 2D. Any onshore terminal would involve loss of farmland and potentially relocation of farmers.

An offshore terminal would need some form of landfall compound but its impact on the local community would be minimal.

The area of the coast contains several popular beaches: Chaung Tha beach (popular with Yangonites) and Ngwe Saung (primarily foreigners and resorts). Snorkelling and eco-tourism into mangrove forest are popular activities. Income from tourism would be severely reduced or eliminated but might be replaced by services to the LNG facility.

***Hazard***

Of the seven small villages, Alegon, Nga Yoke Kaung, Sinhmon and Kyaukkegyi none lie within 500 m of the jetty at Site 2A with Nga Yoke Kaung being the closest and within 1000 m. The other villages lie within 1 – 2 km from the jetty or ship transit route. Similarly the unnamed village on Goyangyi Island is about 1000 m from the berth of Site 2D with a few houses/farms slightly closer.

There is no information available as to populations in these villages but they all appear to be small, a few hundred people at most.

***Pipeline***

There is a small, tourist based elephant camp described between the site and Pathein but should be avoidable. There is an existing pipeline easement between Pathein and Yangon and the new pipeline is assumed to be constructed within this.

### 3.2.4 Geology

There has been a magnitude 3 – 4 and a magnitude 4 – 5 earthquake with an epicentre very close to the proposed terminal site. There have been many earthquakes of this magnitude around the site both on the coast and inland in the Arakan Mountains. A few magnitude 5 - 6 earthquakes have been recorded and these become more prevalent south of the site within the Andaman Island chain.

Most of these earthquakes are of magnitude 4 – 5 but 4 earthquakes of magnitude 5 - 6 surround the site.

A major fault runs down the coast of western Myanmar past Location 1 and is projected to continue down past Location 2, following the tectonic plate boundary (India and Burma plates).

Nga Yoke Kaung is expected to have a peak ground acceleration of 0.4 – 0.45g. This would cause severe shaking and moderate to heavy damage. Any LNG facility would need to be reinforced to protect it from this degree of seismic activity.

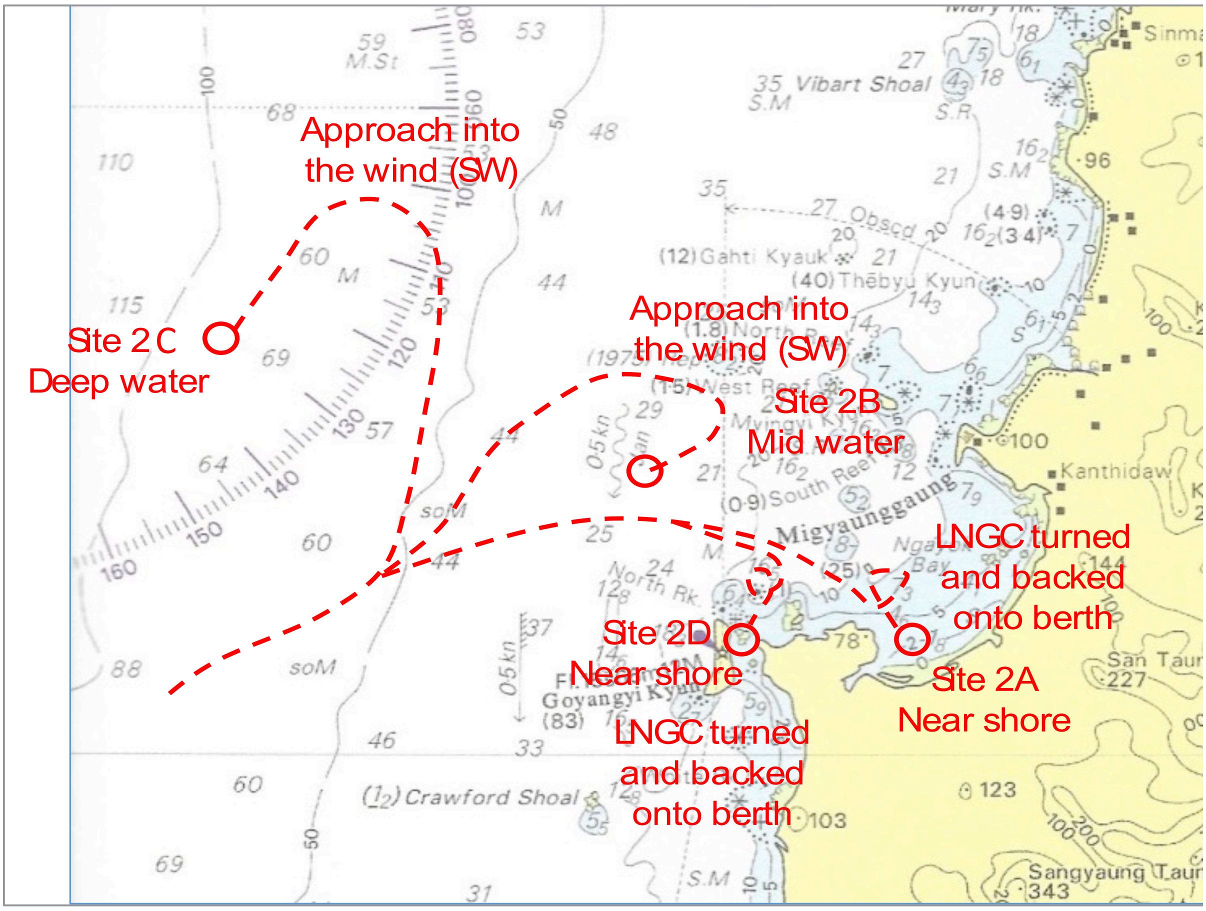
The area around Site 2D has caves visited by tourists and therefore suggests some form of Karst geology. This would predicate against an onshore terminal. A more detailed study is required to ensure site suitability.

## 3.2.5 Navigation

### *3.2.5.1 Navigation*

Based on a review of UK Admiralty Chart No. 818 a deep water navigation channel between the Bay of Bengal and the terminal would need to be dredged to a depth of 14 m culminating in a turning basin and berth pocket. Appropriate navigational aids will also be required. The chart and navigational route are indicated below.

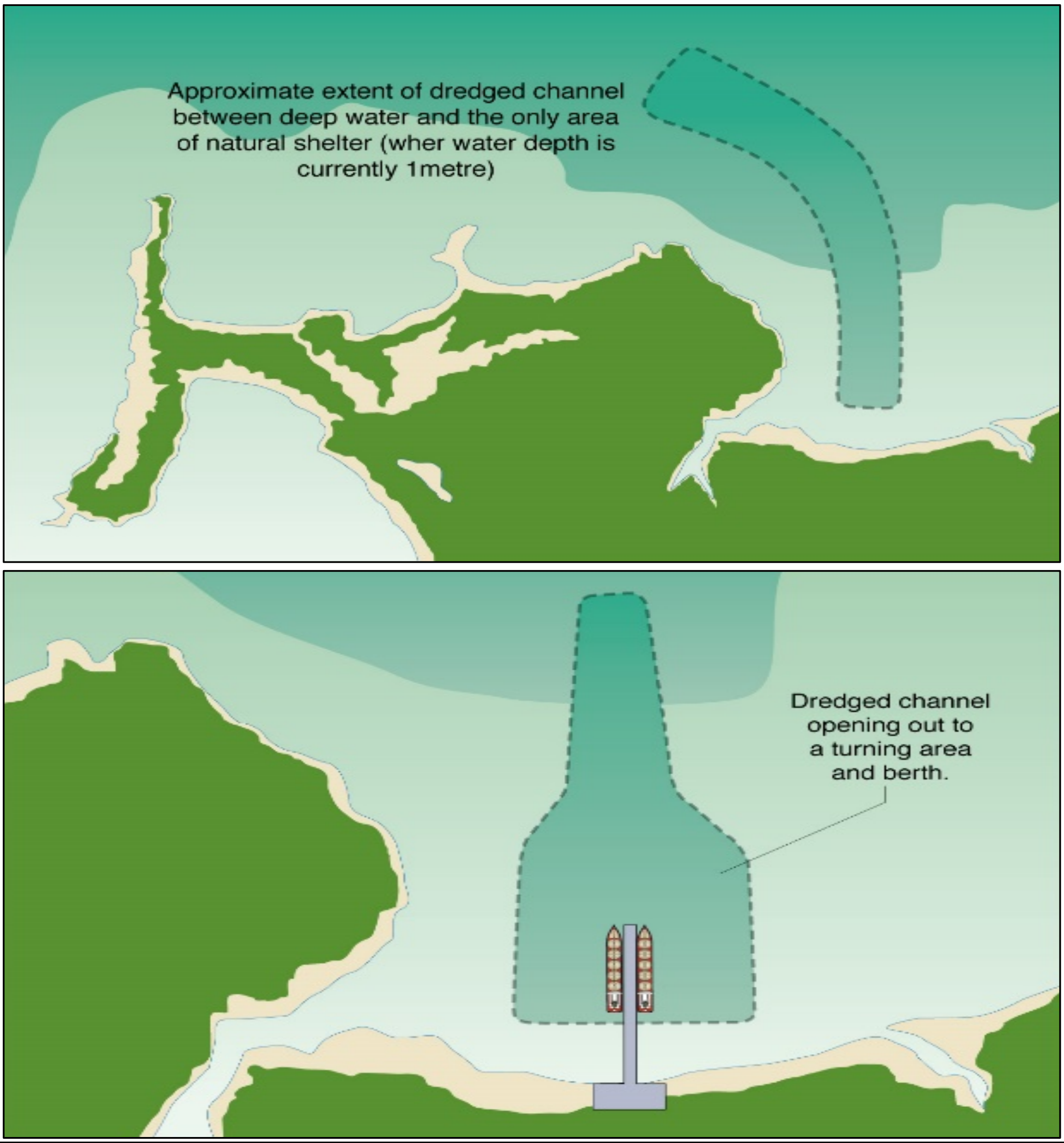
**Figure 56 – Navigation routes**



Site 2A, the near shore site will require major capital (initial) dredging. Site 2D will also require significant dredging. Minor maintenance dredging may be required to keep the channel open in subsequent years. There is no data available to quantify this.

The dredging requirements for Site 2A are shown in the following diagram, two proposed dredge areas are required:

**Figure 57 – Site 2A dredging requirements**




| | |
|---|---|
| Channel | 5,500 m long by 194 m wide from an average depth of 7 m to 14 m 7,469,000 $m^3$ total |
| Berth and turning circle | 500 m long by 500 m wide from an average depth of 1 m to 14 m 3,250,000 $m^3$ total |
| Total volume | 10,719,000 $m^3$. |

No dredging is required for the mid and deep water sites 2B and 2C.

The dredging requirements for Site 2D are shown as follows:

**Figure 58 – Site 2D indicative dredging requirements**

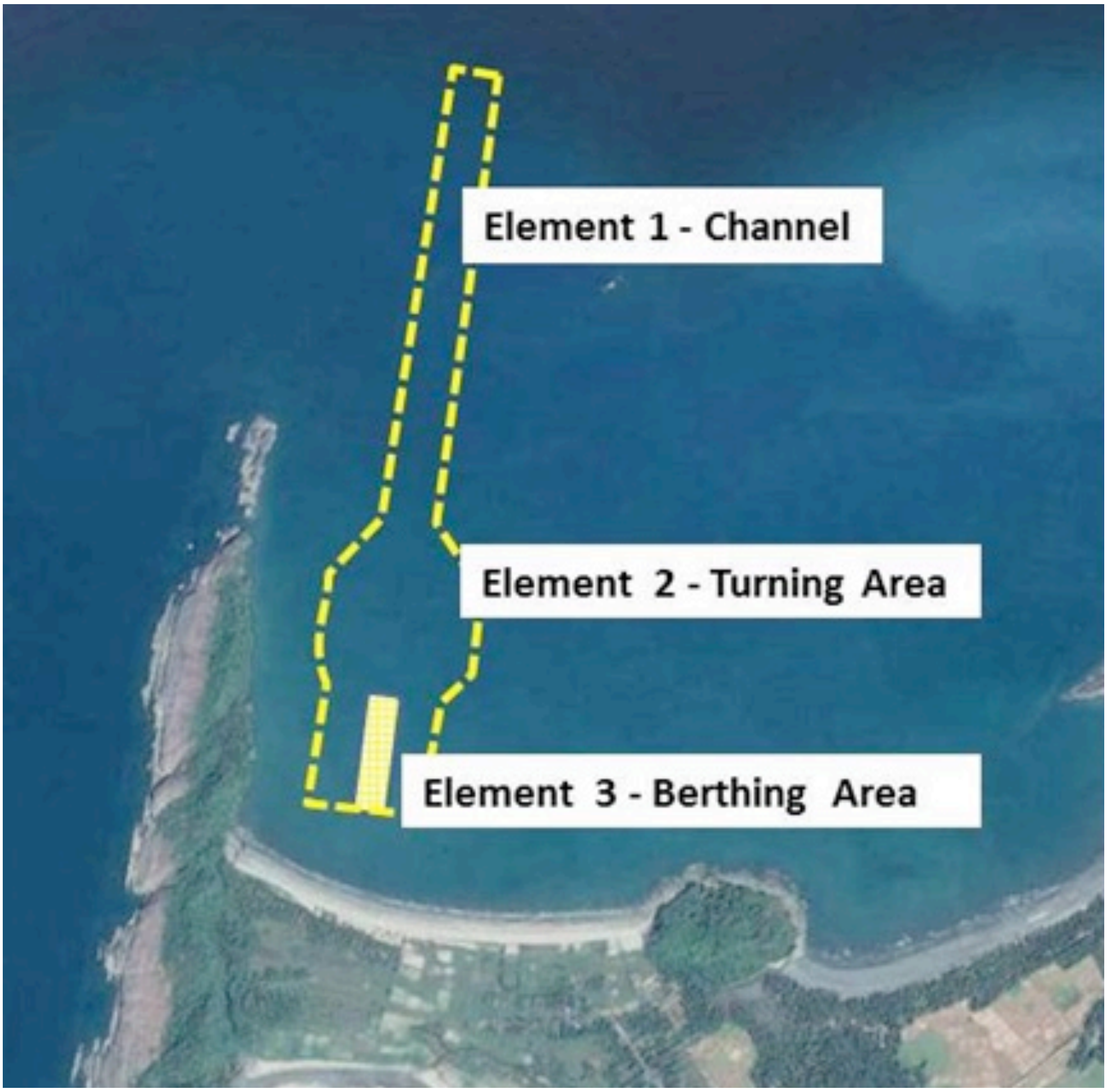
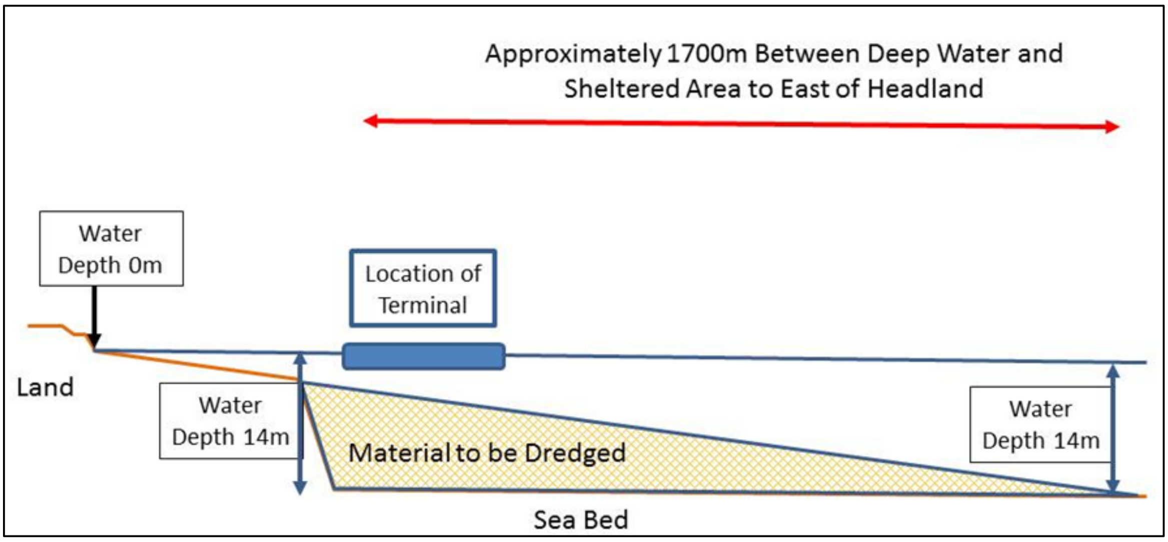


**Figure 59 – Site 2D schematic of dredging requirements**




The table below shows the calculation of dredging estimates to create a waterway navigable by the FSRU and LNGCs using an island jetty at Site 2D as shown. It is in three elements (channel, turning circle, and berthing area). For simplicity, it is assumed that a depth of 14m is required for each element.

**Table 19 – Summary of Site 2D dredging quantities**

| Element | Area To Be Dredged (Description) | Area To Be Dredged (Area in m2) | Current Estimated Mean Water Depth (m) | Required Water Depth (m) | Depth to be Dredged (m) | Volume of Dredged Material (m3) |
|---|---|---|---|---|---|---|
| 1 - Channel | 1500m channel x 217m wide | 325,500 | 9.0 | 14.0 | 5.0 | 1,627,500 |
| 2 - Turning Circle | 285m diameter circle | 255,278 | 3.0 | 14.0 | 11.0 | 2,808,058 |
| 3 - Berthing Area | (4 x Beam) x (1.5 x LOA) | 74,214 | 3.0 | 14.0 | 11.0 | 816,354 |
| **TOTAL ESTIMATE OF DREDGED MATERIAL in CUBIC METRES** | | | | | | **5,251,912** |

No specific details of low visibility events have been found in public domain documents. Snow only occurs in the northern inland parts of Myanmar so is not considered a problem.

### *3.2.5.2 Jetty length*

At Site 2A, to ensure shelter from wind and waves the berth must be located very close to shore which results in large amounts of dredging but a small jetty of perhaps 500 m. The actual jetty length will be an optimisation between jetty construction costs and dredging costs (beyond the scope of this study).

At Site 2D again the jetty needs to be close to shore to maximise shelter, an “Island” jetty head is proposed with no trestle link to the shoreline. The actual jetty location will be an optimisation between jetty construction costs and dredging costs (beyond the scope of this study).

#### 3.2.5.3 Subsea pipeline length

The midwater weathervaning FSRU is located in about 30 m of water and would use a turret yoke mooring. The subsea pipeline would be about 10 – 15 km offshore depending on the best onshore pipeline route. The deep water FSRU needs to be in a water depth of about 80 m to allow the turret mooring to be able to correct the position of the FSRU without overstressing the subsea pipeline. The subsea pipeline would be about 30 – 40 km offshore depending on the best onshore pipeline route and the angle and seabed conditions between the nearshore shelf and deep water.

#### 3.2.5.4 Marine traffic

No details of the number of movements or type of ship has been identified. The suggestion would only be local fishing vessels close to shore. Vessels heading to Sittwe, Kyauk Phyu oil port and Bangladesh might expect to pass close to shore but could be re-routed outside of the offshore FSRU exclusion zone.

#### 3.2.5.5 Towage

No tugs are available in the local area. Nearest towage is from Kyauk Phyu (400 km by sea). Yangon at about (450 km) appears to have a single tug the Mhan Sung 3 which appears to spend much of its time in the port. No details of the tug can be found but it appears sufficiently large to be able to offer a 40 ton bollard pull. The tug is not under classification so may be in poor condition. Alone this tug is insufficient for LNG towage requirements.

#### 3.2.5.6 Port Rules

There is no existing port and therefore no port rules.

### 3.2.6 Gas Pipeline

The purpose of this section is to provide an analysis of the issues concerning access to Myanmar's high-pressure gas pipeline network, focussing on costs in the following areas.

- Overview of the site location and associated issues
- Review of offshore gas transmission pipeline costs.
- Review of onshore gas transmission pipeline costs.
- Gas network reinforcement costs.
- Concluding discussion.

#### 3.2.6.1 Overview of the site location and associated issues

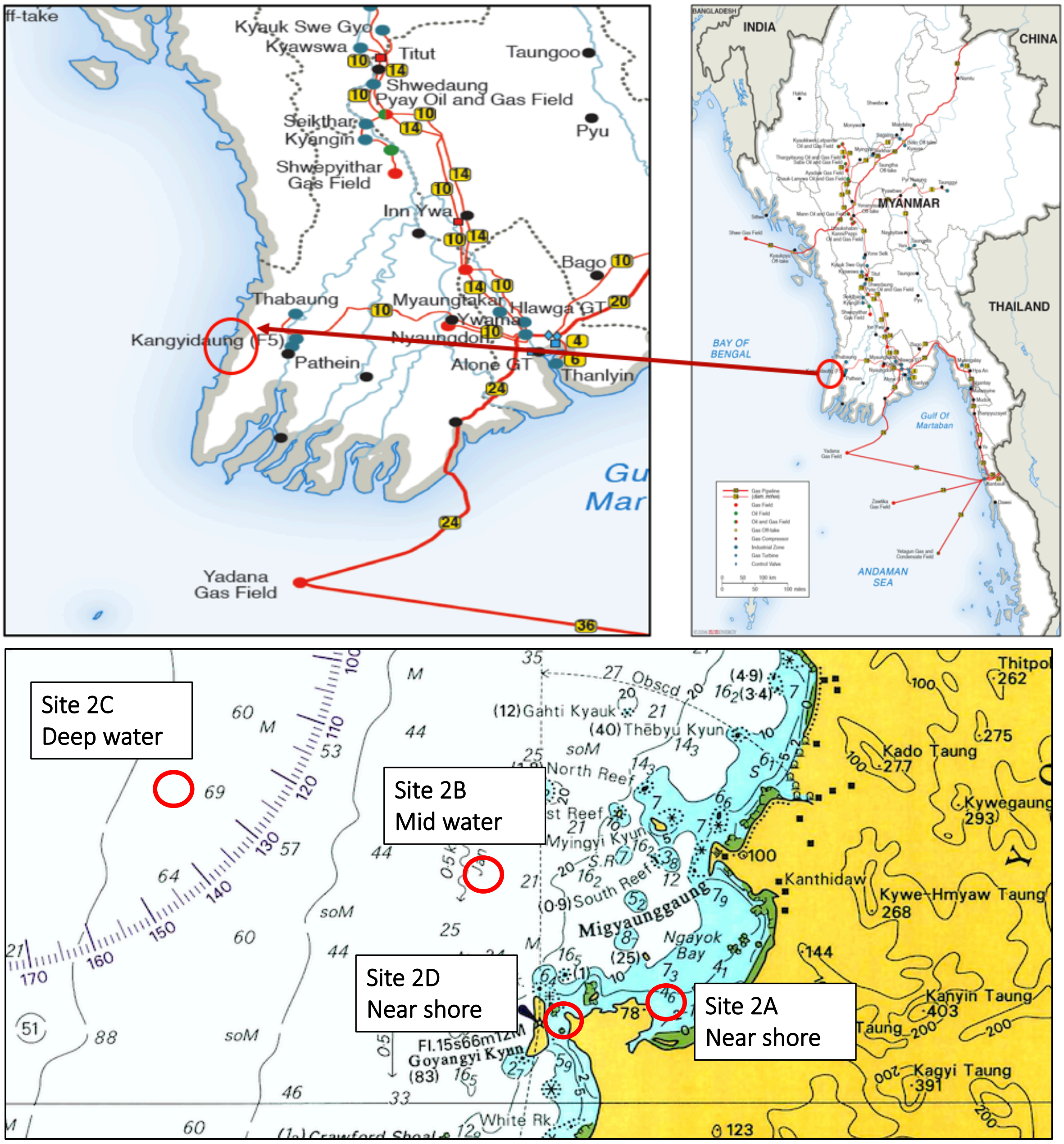
A 66kV power line has recently been laid between Pathein and the coast near Nga Yoke Kaung. This could be upgraded. This would carry about 300 MW unless reinforced or upgraded. Pathein is connected to Yangon by a 230 kV transmission line. A power station at Pathein would also be possible. A new power plan with a new 230 kV power line is planned for Kyarlat near the landfall of the Yadana pipeline to use an additional 50 mmscfd from the field. This is anticipated to be operational between 2020 and 2025.

The following diagram shows Location 2 – Nga Yoke Kaung and the potential options considered during siting analysis Site 2A, 2B, 2C and 2D in relation to the gas transmission network and the local geography. This is one of the more challenging potential locations from a marine perspective as evinced by the diversity between the four options, with the Sites 2A and 2D, 2B and 2C at distances of 1-2km, 10-15 km and 30-40 km respectively from the coast. This means that Site 2A and 2D would only need a short subsea high-pressure gas pipeline to transport the RLNG to the coast where Sites 2B and 2C would require subsea pipelines of 10-15 km and 30-40 km respectively. For the purposes of this analysis subsea gas transmission pipeline lengths will be assumed to be the shortest distance between two points, similarly onshore gas transmission pipeline will use the most obvious route. Clearly if a more detailed feasibility study was being carried out a great deal more detail would be included such as river crossings, road crossing and terrain mapping etc.

In terms of the local area, there are a number of potential issues that might make the construction of connecting gas transmission pipelines complex and complicated as follows:

- This part of Myanmar is popular with tourists and therefore if the FSRU was located close to the shore we can assume this might have a potential impact on the tourist industry.
- As previously highlighted dredging and offshore pipeline construction work has potential to do significant damage to local marine ecology. In particular, this area of Myanmar is well known for its coral and therefore its damage/destruction should be avoided.

**Figure 60 – Overview of Location 2 Nga Yoke Kaung and proposed site options for FSRUs**



#### 3.2.6.2 Review of offshore gas transmission pipeline costs

In the light of the above the following table provides a summary of the estimated costs associated with constructing subsea gas transmission pipelines connecting the FSRU with the mainland for the four site options 2A, 2B, 2C and 2D. Key assumptions used are as follows:

- The shortest distance from the FSRU to the coast is assumed, with no significant obstacles.
- Costs based on 30" high-pressure gas transmission pipeline, to allow for some expansion above 500 mmscfd.
- Where the marine team have provided distances offshore as ranges the average distance has been used.

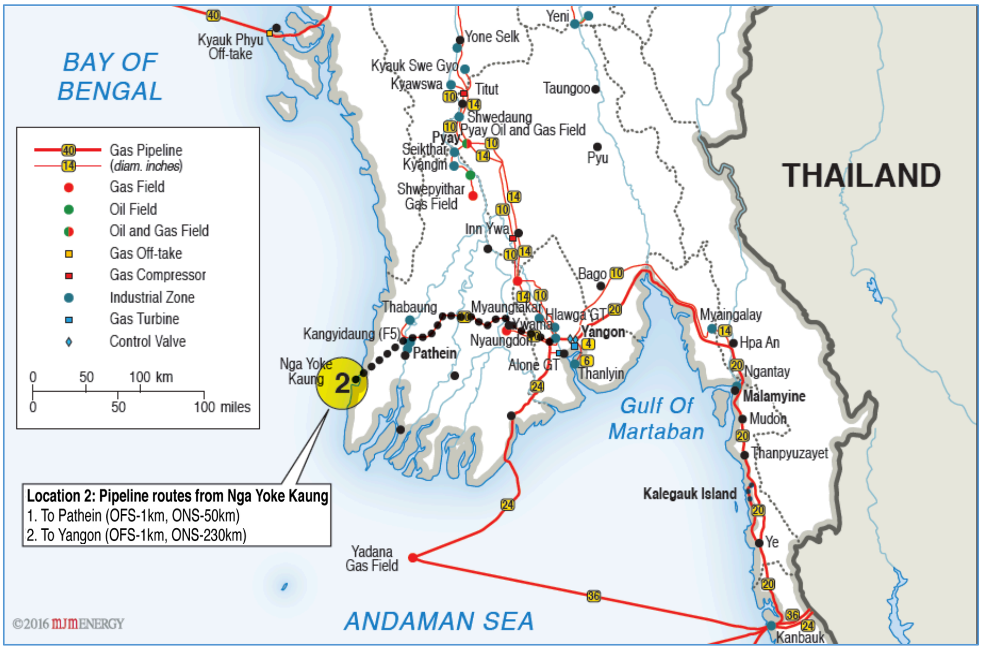
**Table 20 – Summary of offshore gas transmission pipeline costs for Location 2 Nga Yoke Kaung**

| Site description | Offshore gas transmission pipeline | Cost ($ million) |
|---|---|---|
| Site 2A | 1.0 km of 30" offshore gas transmission pipeline at $1.8 million per km | 1.8 |
| Site 2B | 12.5 km of 30" offshore gas transmission pipeline at $1.8 million per km | 22.5 |
| Site 2C | 35 km of 30" offshore gas transmission pipeline at $1.8 million per km | 63.0 |
| Site 2D | 1.0 km or 30" offshore gas transmission pipeline at $1.8 million per km | 1.8 |

#### 3.2.6.3 Review of onshore gas transmission costs

In terms of connecting to the gas transmission network following discussions with MOGE it would appear that the most likely option as highlighted below on the map is a new 30" pipeline via Pathein to Yangon. Since the pipeline from Yangon from Pathein to Thabaung is only 10" and has a limited operating pressure and capacity. Therefore, the RLNG will need to be delivered as close as possible to Yangon via a new 30" onshore high-pressure pipeline. However, a possible alternative would be to stop the pipeline at Pathein if used in conjunction with a power generation project. This would reduce the onshore pipeline required to around 50km.

**Figure 61 – Potential RLNG connecting pipeline routes from Location 2 Nga Yoke Kaung**




In terms of the proposed pipeline route shown above the key points to note are as follows:

- Part 1 – This part of the pipeline will be laid in a new ROW from the coast to Pathein, where it will join the existing ROW for the Yangon to Pathein 10" pipeline. Depending on the final route chosen it is estimated approximately 50 km of 30" will be required in the new ROW[32].
- Part 2 – This section of the new pipeline will follow the route and the ROW of the existing pipeline. It is estimated that the length of Part 2 of this pipeline is approximately 180km. It might even be possible to replace this 10" pipeline with the new 30" pipeline, although the construction of the new pipeline will not be without challenges, since MOGE believe the pipeline route is already very congested.

### *3.2.6.4 Gas network reinforcement costs*

It is expected that the Myanmar gas network will not require any additional reinforcement work since the newly constructed gas transmission pipeline delivering the RLNG to Yangon will be delivering directly into a gas demand centre.

### *3.2.6.5 Concluding discussion*

In the light of the above the following table provides a summary of the estimated costs associated with connecting and delivering the RLNG into Myanmar's gas transmission network.

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[32] *It should be noted that this route is based on the most straight forward route. If the pipeline route was to follow the road it would be about 100 km.*

**Table 21 – Summary of gas pipeline costs for Location 2 Nga Yoke Kaung**

| Gas pipeline costs to Yangon | | |
|---|---|---|
| **Type of gas transmission infrastructure** | **Details of pipeline infrastructure** | **Cost ($ million)** |
| Offshore gas transmission pipeline (Site 2A) | 1.0 km of 30" offshore gas transmission pipeline at $1.8 million per km | 1.8 |
| Offshore gas transmission pipeline (Site 2B) | 12.5 km of 30" offshore gas transmission pipeline at $1.8 million per km | 22.5 |
| Offshore gas transmission pipeline (Site 2C) | 35 km of 30" offshore gas transmission pipeline at $1.2 million per km | 63.0 |
| Offshore gas transmission pipeline (Site 2D) | 1.0 km of 30" offshore gas transmission pipeline at $1.8 million per km | 1.8 |
| Onshore gas transmission pipeline | 230 km of 30" gas transmission pipeline at $1.2 million per km | 276.0 |
| Additional reinforcement cost | Not known assumed to be zero | 0.0 |
| **Total estimated cost for delivering RLNG into the Myanmar network** | **Site 2A Total = $277.8 million**<br>**Site 2B Total = $298.5 million**<br>**Site 2C Total = $339.0 million**<br>**Site 2D Total = $277.8 million** | |
| **Gas pipeline costs to Pathein** | | |
| **Type of gas transmission infrastructure** | **Details of pipeline infrastructure** | **Cost ($ million)** |
| Offshore gas transmission pipeline (Site 2A) | 1.0 km of 30" offshore gas transmission pipeline at $1.8 million per km | 1.8 |
| Offshore gas transmission pipeline (Site 2B) | 12.5 km of 30" offshore gas transmission pipeline at $1.8 million per km | 22.5 |
| Offshore gas transmission pipeline (Site 2C) | 35 km of 30" offshore gas transmission pipeline at $1.2 million per km | 63.0 |
| Offshore gas transmission pipeline (Site 2D) | 1.0 km of 30" offshore gas transmission pipeline at $1.8 million per km | 1.8 |
| Onshore gas transmission pipeline | 50 km of 30" gas transmission pipeline at $1.2 million per km | 60.0 |
| Additional reinforcement cost | Not known assumed to be zero | 0.0 |
| **Total estimated cost for delivering RLNG into the Myanmar network** | **Site 2A Total = $ 61.8 million**<br>**Site 2B Total = $ 82.5 million**<br>**Site 2C Total = $123.0 million**<br>**Site 2D Total = $277.8 million** | |

### 3.2.7 Infrastructure

The nearest city is Pathein (315,000 people). It is about about 85 km from the proposed LNG site. Despite its size there are contradictory internet sources that suggest that Pathein is currently unable to provide essential business services for foreign investors. Only the most basic financial, legal and logistical expertise is currently available. There is no industry in Kga Yoke Kaung with fishing and agriculture (sesames, groundnuts, jute, maize, pulses, tobacco, chilies etc) the main employment. Pathein, is a rice-milling and export centre and has light industries. However, Pathein has three universities; Pathein University, GTC Technical University and a Computer IT University. There is also a teacher training college. The Technical University may be able to educate potential workers with appropriate skills. Pathein has several hospitals including a 200 bed general hospital.

Although fishing appears a major industry there is no port at Kga Yoke Kaung. Pathein is the most important delta port outside of Yangon. It lies about 75 miles inland and is only accessible to ships of 600 GRT and a draft of less than 7 m. The port is operated by the Myanmar Port Authority. Berth lengths and depths are very limited and cranage and major logistics facilities are not present. Port side storage also appears to be limited. The nearest ports of any size are around Yangon, 190 km by road to the east. Panthein has a domestic airport with links to Yangon. Pathein is the terminus of a branch off the main railway line which connects it to Hinthada, Letpadan and Yangon.

The closest road to Nathahu or Kanthidaw is described as a secondary road/cart track (unpaved). The nearest paved road is to Ngwe Saung which is a secondary national highway (paved). From Pathein the road network improves towards Yangon.

### 3.2.8 Scoring

The traffic light scoring for Site 2 Nga Yoke Kuang is shown in the following table.

## Table 22 – Nga Yoke Kuang traffic light scoring for Sites 2A, B and C

| | | Nearshore Site 2A | | | | | | | Offshore Sites 2B & 2C | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Onshore terminal | FSRU on Jetty | Midwater FSRU | Deepwater FSRU | FSU on Jetty | LNGRV in Deepwater | GBS | Onshore terminal | FSRU on Jetty | Midwater FSRU | Deepwater FSRU | FSU on Jetty | LNGRV in Deepwater | GBS |
| **GETTING LNG TO THE TERMINAL** | | | | | | | | | | | | | | | |
| 1 | How much dredging is required to create a channel to the terminal? | | | | | | | | | | | | | | |
| 2 | What Jetty length is required to be able to moor a near shore FSRU/LNG Carrier? | | | | | | | | | | | | | | |
| OR | What Subsea pipeline length is required to connect a midwater or deepwater FSRU or LNGRV? | | | Not Possible | | | Not Possible | | | | | | | | |
| 3 | How much marine traffic is currently being experienced? | | | | | | | | | | | | | | |
| 4 | Are there local visibility limitations? | | | | | | | | | | | | | | |
| 5 | Are there any other factors that limit the site? | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| **STORING LNG** | | | | | | | | | | | | | | | |
| 1 | What is the wave environment like? | | | | | | | | | | | | | | |
| 2 | How variable is the wind/wave environment? | | | | | | | | | | | | | | |
| 3 | Might the LNG facility be impacted by extreme weather? | | | Not Possible | | | Not Possible | | | | | | | | |
| 4 | Will the site cause any destruction or exclusion to environmentally sensitive areas? | | | | | | | | | | | | | | |
| 5 | Will the site cause any destruction or exclusion to culturally and historically sensitive areas? | | | | | | | | | | | | | | |
| 6 | Will the site development and operation impact the local community in any detrimental way? | | | | | | | | | | | | | | |
| 7 | Will the site development and operation increase the risk of harm/fatality to the local community? | | | | | | | | | | | | | | |
| 8 | Are there risks to the LNG facility from geological events? | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| **GETTING GAS TO MARKET** | | | | | | | | | | | | | | | |
| 1 | Can LNG be vaporised in sufficient volume and in an environmentally acceptable way? | | | | | | | | | | | | | | |
| 2 | What is the onshore pipeline length? | | | Not Possible | | | Not Possible | | | | | | | | |
| 3 | What is the difficulty in laying the onshore pipeline? | | | | | | | | | | | | | | |
| 4 | What is the offshore pipeline length? | | | | | | | | | | | | | | |
| 5 | What is the difficulty in laying the offshore pipeline? | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| **LOCAL INFRASTRUCTURE** | | | | | | | | | | | | | | | |
| 1 | Is there sufficient towage available to berth the LNG carrier? | | | | | | | | | | | | | | |
| 2 | Is there currently any port rules and infrastructure appropriate to hydrocarbon importation at the proposed LNG site? | | | | | | | | | | | | | | |
| 3 | Is there sufficient infrastructure to accommodate workers and their families, expatriates and vendor personnel? | | | | | | | | | | | | | | |
| 4 | Is there emergency response and Health care capability? | | | Not Possible | | | Not Possible | | | | | | | | |
| 5 | Education and Skills? | | | | | | | | | | | | | | |
| 6 | Is there access to a major port with connecting roads? | | | | | | | | | | | | | | |
| 7 | Is there access to an international airport with road/rail links? | | | | | | | | | | | | | | |
| 8 | How adequate is the marine infrastructure? | | | | | | | | | | | | | | |

**Table 23 - Nga Yoke Kuang traffic light scoring for Site 2D**

| | | Onshore terminal | FSRU on Jetty | Midwater FSRU | Deepwater FSRU | FSU on Jetty | LNGRV in Deepwater | GBS |
|---|---|---|---|---|---|---|---|---|
| **GETTING LNG TO THE TERMINAL** | | | | | | | | |
| 1 | How much dredging is required to create a channel to the terminal? | | | | | | | |
| 2 | What Jetty length is required to be able to moor a near shore FSRU/LNG Carrier? | | | | | | | |
| OR | What Subsea pipeline length is required to connect a midwater or deepwater FSRU or LNGRV | | | Not possible | | | Not possible | |
| 3 | How much marine traffic is currently being experienced? | | | | | | | |
| 4 | Are there local visibility limitations? | | | | | | | |
| 5 | Are there any other factors that limit the site? | | | | | | | |
| | | | | | | | | |
| **STORING LNG** | | | | | | | | |
| 1 | What is the wave environment like? | | | | | | | |
| 2 | How variable is the wind/wave environment? | | | | | | | |
| 3 | Might the LNG facility be impacted by extreme weather? | | | Not possible | | | Not possible | |
| 4 | Will the site cause any destruction or exclusion to environmentally sensitive areas? | | | | | | | |
| 5 | Will the site cause any destruction or exclusion to culturally and historically sensitive areas? | | | | | | | |
| 6 | Will the site development and operation impact the local community in any detrimental way? | | | | | | | |
| 7 | Will the site development and operation increase the risk of harm/fatality to the local community? | | | | | | | |
| 8 | Are there risks to the LNG facility from geological events? | | | | | | | |
| | | | | | | | | |
| **GETTING GAS TO MARKET** | | | | | Onshore pipeline | | | |
| 1 | Can LNG be vaporised in sufficient volume and in an environmentally acceptable way? | | | | | | | |
| 2 | What is the onshore pipeline length? | | | | | | | |
| 3 | What is the difficulty in laying the onshore pipeline? | | | | | | | |
| 4 | What is the offshore pipeline length? | | | | | | | |
| 5 | What is the difficulty in laying the offshore pipeline? | | | | | | | |
| | | | | | | | | |
| **LOCAL INFRASTRUCTURE** | | | | | | | | |
| 1 | Is there sufficient towage available to berth the LNG carrier? | | | | | | | |
| 2 | Is there currently any port rules and infrastructure appropriate to hydrocarbon importation at the proposed LNG site? | | | | | | | |
| 3 | Is there sufficient infrastructure to accommodate workers and their families, expatriates and vendor personnel? | | | | | | | |
| 4 | Is there emergency response and Health care capability? | | | Not possible | | | Not possible | |
| 5 | Education and Skills? | | | | | | | |
| 6 | Is there access to a major port with connecting roads? | | | | | | | |
| 7 | Is there access to an international airport with road/rail links? | | | | | | | |
| 8 | How adequate is the marine infrastructure? | | | | | | | |

## 3.2.9 Technology & Site Selection

### *3.2.9.1 Site selection*

The wind and wave data requires a very sheltered site location within the bay, berth protection or weathervaning capability. A breakwater would be difficult to construct as it could change water movement patterns within the bay resulting in scour or siltation. A sheltered location within the bay requires very significant dredging. Either a breakwater or dredging would damage coral and other marine life. The cost of both dredging and a breakwaters would be significant.

The only positive of the nearshore location, Site 2A, is the lack of marine traffic.

Given the costs and the significant impact on the environment and local people. The nearshore site is not considered acceptable.

The wave environment at both offshore positions (Site 2B and 2D) can be rough and significant downtime is anticipated. The current level of metocean study is insufficient to categorically reject this concept at this stage but its viability looks poor. Much of this downtime is when Myanmar needs electricity from gas most. This is expected to make the import option uneconomic.

The only mitigation would be large volumes of additional storage on the FSRU but as previously described this makes the project bespoke with an increase in schedule and investment and a reduced probability of a lease solution.

The two offshore sites i) mid-water (<50m) and ii) deep water (>80 m) solutions are rejected.

The nearshore site 2D suffers from all the issues of Site 2A but at a lesser degree of scale. Dredging remains significant and its potential impact on coral and tourism important. Visual impact may also be an issue. Site 2D is challenging but may be viable.

#### *3.2.9.2 Viable Technology Options*

None

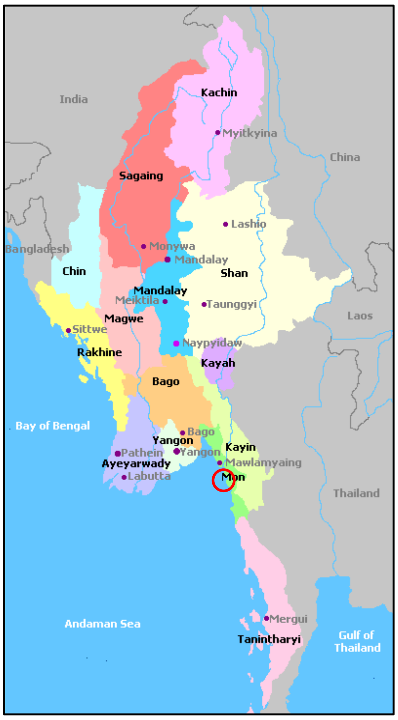
## 3.3 Location 3 – Kalegauk Island

### 3.3.1 Introduction

The third Location considered is the southern Location situated in Mon state between the townships of Ye and Thanbyuzayat, as shown in the figure below. This Location is close to Mawlamyine, a power generation centre and relatively close to Yangon (largest power use location). Gas transmission pipelines run south - north along this coastal strip connecting with Myanmar – Thailand pipelines from the Yetagon, Yadana and Zawitka fields at Kangbauk and the power generation plants at Mawlamyine before going onto Yangon. Mawyawaddy Navy Command holds 3,525 acres of land on Kalegauk Island for a potential naval base. A deep water port is also planned.

The LNG facility could be located anywhere along the east coast of the island.

**Figure 62 – Location 3**[33]




*Overview map for Location 3*


*Detailed map for Location 3*

[33] *Overview map for Location 3*
*http://www.wineandvinesearch.com/myanmar/myanmar.png Location map for Location 3*
*Ministry of Agriculture and Irrigation, Survey Department, Government of Myanmar (Sheet No. 1597 10 Mon State: Mawlamyine District)*

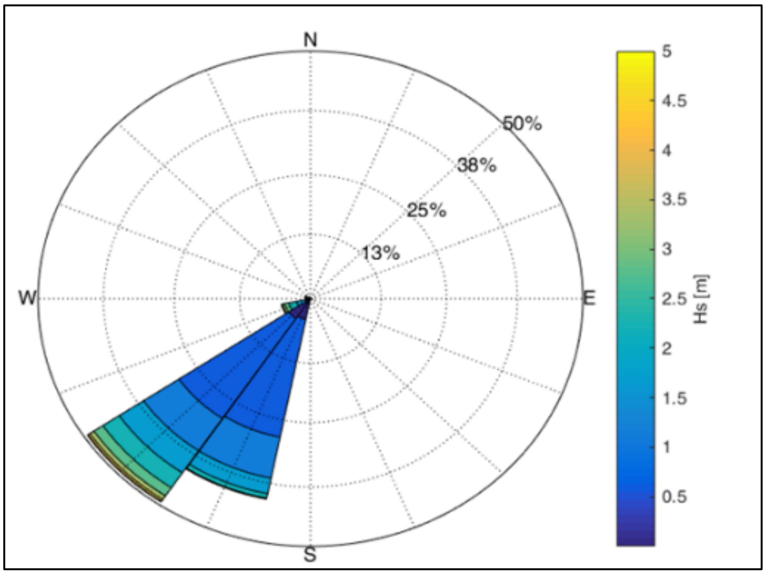
## 3.3.2 Weather

The metocean study has examined the inshore wave environment around the proposed terminal locations and a proposed pilot transfer station. The assessment is based on offshore waves over a 20 year period which have been propagated to the proposed locations.

### *3.3.2.1 Waves*

The offshore waves are almost wholly from the south-western direction with a small variation towards south-southwest. At this location over a 30 year period the mean significant wave height (Hs) is 1.1m and a standard deviation of 0.7, as shown in the following chart.

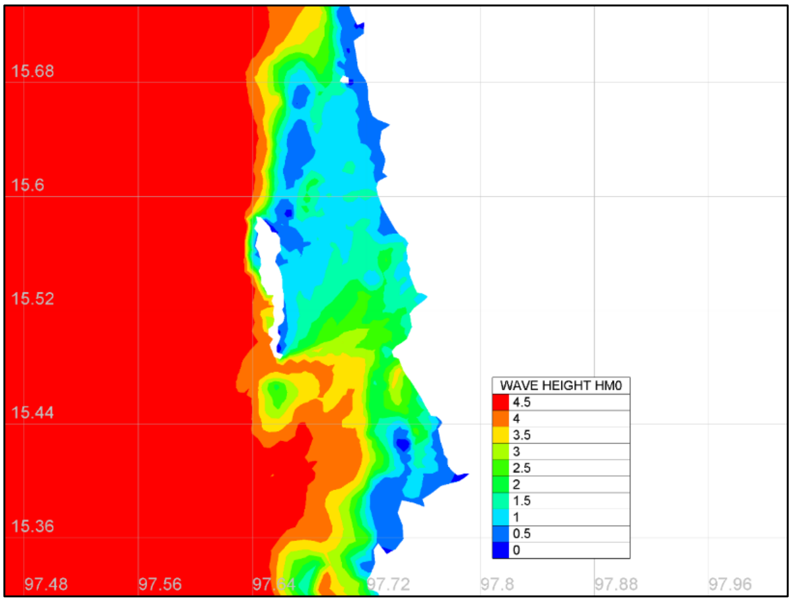
**Figure 63 – Wave environment**




Any specific site located on the east coast of the island will block these south westerly waves.

The following shows that even in a non-cyclonic storm the wave heights at a nearshore berth protected by the island would be in the range 1 – 1.5 m. If located off the shore line with reduced sheltering wave heights would reach 2.5 – 3 m.

**Figure 64 – Inshore waves for non-cyclonic storm**

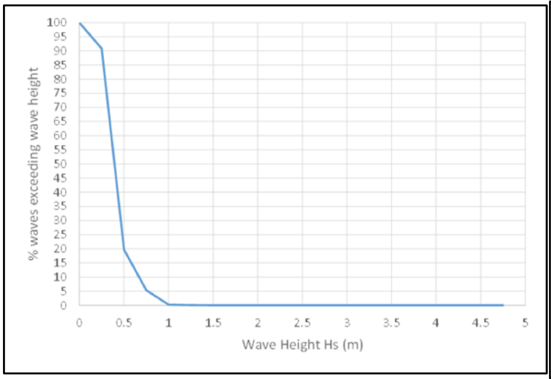



Wave protection will not be required.

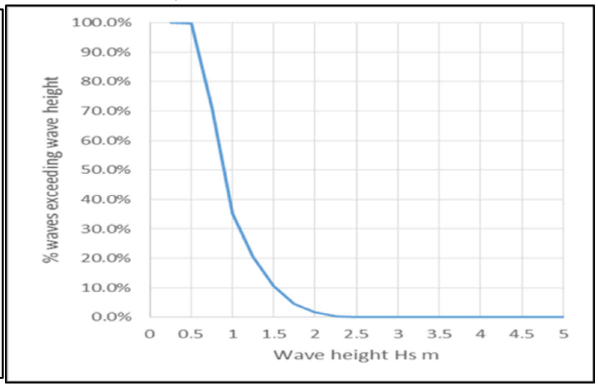
The metocean study has examined the inshore wave environment around the terminal Site 3A and a pilot transfer station. The wave exceedance curves for the various sites are as follows:

**Figure 65 – Wave height exceedance curve**

At Berth Site 3A




At Pilot Station/Offshore Site 3B




Pilots can consistently board LNG carriers in waves with heights of 1.75 m and less 98.4% of the time at this location.

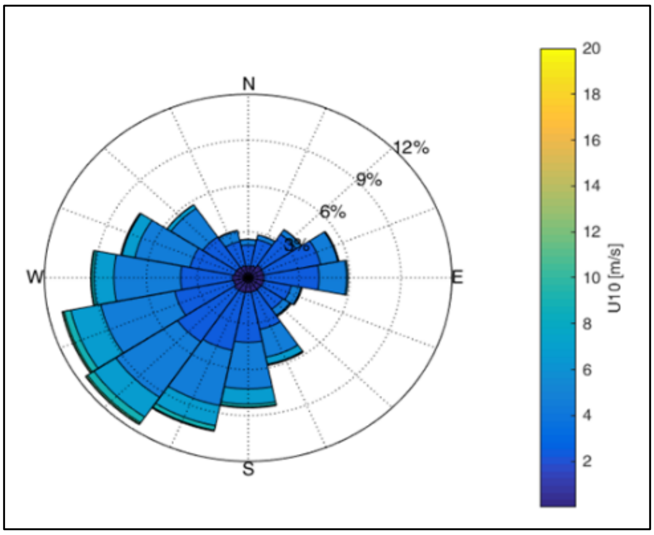
At no time in the year is the berthing wave height of 1.5 m Hs exceeded. The location is very sheltered. A site to the west of Kalegauk Island could be envisaged for a tower yoke mooring or a buoy mooring. As there is no deep water in the Gulf of Martaban a tower yoke mooring system has been assumed (Site 3B). The wave height exceedance curve based on the pilot station is shown above.

At a mooring limit of 1.5 – 2.0 m Hs, mooring and offloading of the LNG carrier can be consistently achieved. Wave heights are higher this side of the island and there is the potential for storms with higher wave heights.

### 3.3.2.2 Wind

The metocean study examined offshore winds which can come from a southerly to westerly quadrant, with a mean hourly wind speed of 5 m/s over 30 years and standard deviation of 2.4, as shown in the following chart.

**Figure 66 – Wind rose**

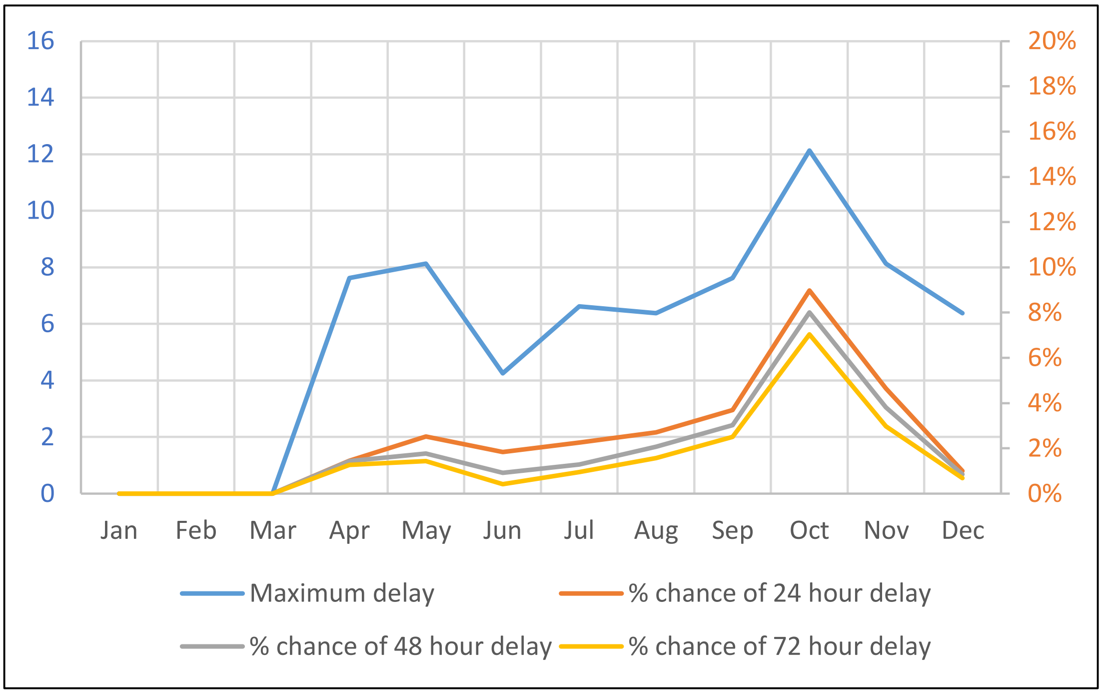



The island consists of a series of hills will elevations as high as 197 m which should provide considerable shelter to vessels moored close to the island. The marine chart suggests that there are sizeable currents in the area of the Site 3A running north–south. These will have a greater impact than winds so best orientation would be bow to current (north) meaning wind primarily impacts the south of the LNGC / FSRU. The berth would meet the SIGTTO limiting states for berthing and operation. An offshore FSRU (Site 3B) would be best oriented bow to the south west and weathervaning to limit the impact of the winds is unlikely to be required. The size of the hills on Kalegauk Island would continue to provide some, limited protection. Carriers approaching the berth or FSRU would do so into the wind, for example from the North.

### 3.3.2.3 Storm durations

The following graphs show the probability of different durations of weather that prevent a 24 hour window of waves less than 1.5 m Hs for the nearshore location (Site 3A) and 2 m Hs for the offshore location (Site 3B) which are typically required to unload a LNG carrier.

**Figure 67 – Weather window durations and probabilities (Site 3A)**




The graph for the deeper water location (Site 3B) shows that 8 days of storage would be sufficient apart from in October when it increases to 12 days. The probability of needing additional storage is about twice as high as for the sheltered site to the east of the island. Building in 12 days of excess storage capacity would cover all historical events of the last 30 years but could prove to be expensive.

More typically lower levels of storage are used. The red-orange lines and the left hand axis look at the probability of a 24 hour window not being available in any month, for 1, 2 or 3 days duration. This is quite low (<3%) for the monsoon season of September to November for both sites. However during this period significant rainfall should have occurred allowing maximisation of hydroelectric generation and the reduction of any security of supply requirements from gas/LNG fired units.

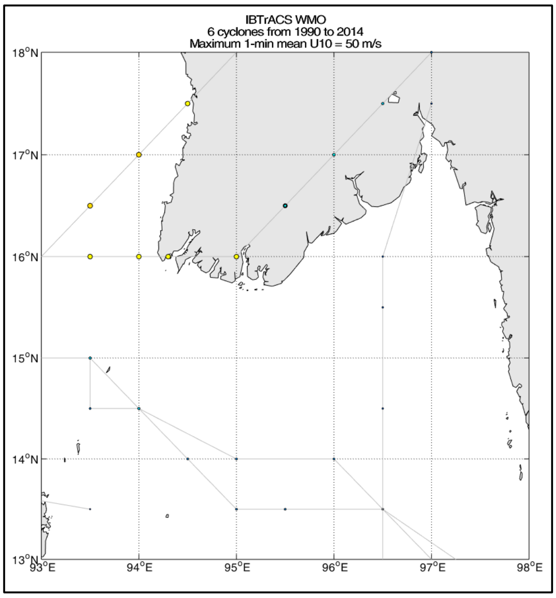
Security of supply is a political question for MOGE/Myanmar to decide. However, the graph shows a significant impact of about 3% exceedance of moving from 1 to 3 days storage. Often 2 days is to provide some degree of weather window. Two or three days of storage would provide a useful mitigation as long as no technology step changes occur that would add substantial addition cost.

The comments about the potential volume of LNG storage and its limitations on import options as made under Location 1 remain valid.

#### *3.3.2.4 Extreme Weather*

Cyclones tend to track up the Andaman Island chain and do not frequently enter the Andaman Sea. However cyclones do occasionally impact this area.

**Figure 68 – Cyclone map**




| IBTrACS WMO data – Area 3 – Period: 1990-2014 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | All-year |
| Number of events [] | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 6 |
| Maximum 1-min U10 [m/s] | 0 | 0 | 0 | 49 | 44 | 0 | 0 | 0 | 0 | 22 | 17 | 0 | 49 |
| Mean 1-min U10 [m/s] | 0 | 0 | 0 | 38 | 28 | 0 | 0 | 0 | 0 | 18 | 17 | 0 | 25 |

Historical cyclone activity analysis records 6 cyclones in 24 years, 1 every 4 years. May is the most likely month for a cyclone and along with April is when the highest wind speeds are recorded.

There was a flood in August 2011 after a torrent of rain (12.6 inches on 1 August 2011). 2,000 houses were flooded and some schools and markets were closed because of it.

## 3.3.3 Environmental, Social & Cultural Impact

#### *3.3.3.1 LNG carrier transit*

No issues/impacts expected.

#### *3.3.3.2 LNG facility*

***Environmental***

There is little survey data available. Mangrove may be present at the shoreline (Site 3A). Destruction or damage to these habitats is highly possible as a result of the dredging activity and dredge disposal which would produce turbulence and turbidity. There are no national parks defined in this part of the coastline that would be affected by a LNG development. Coastal fishing is important in Mon State with the townships/villages around Thanbyuzayat and Ye producing dried fish and fish sauce. Dredging could damage the local fishery on a short – medium timescale.

FSRUs use seawater to vaporise the LNG. This water is returned cooler and containing biocide into the local sea. There are significant currents on the east side of the island so water recirculation is probably not an issue. The biocide required will damage the local ecology which appears to be a local fishing ground.

***Social & Cultural***

There are four small villages on Kalegauk Island (no details identified) and therefore near Site 3A. The only two where names have been identified are Da min zeik Atet and Da min zeik Auk. There is no information available on populations in these villages but they all appear to be small, a few hundred people at most. The village distribution only allows a small area of land where an LNG terminal would not impact the existing people/settlements. This area contains woodland rather than farmland. If a larger land area is required or more detailed surveys requires the LNG facility to be located elsewhere, relocation of one of the smaller villages may be required.

Myanbet Pagoda complex is sited on the mainland directly opposite the southern end of Kalegauk Island. Visual impact may be affected by a moored LNG carrier/FSRU. Site 3B would be sufficiently offshore to prevent any local impacts. Visual impact may be apparent.

***Hazard***

There are two small areas on the island where all four settlements are 1 – 1.5 km distant from any LNG facility. The northern area contains a single farm and the southern area is habitation free. There is no information available as to the populations of these villages but they all appear to be small, a few hundred people at most.

##### *3.3.3.3 Pipeline*

There is an existing pipeline running from Kanbuak where it connects with the offshore fields and the Thai border to Yangon via Mawlamyine. This pipeline is old and undersized and has been partly upgraded over the last few years. Upgrading will continue when funds are available. An easement therefore already exists and the new pipeline is assumed to be constructed within this. A subsea pipeline will be required to connect Kalegauk Island with these pipelines on the mainland. If the area between the island and the mainland is an important fishery the pipeline could be trenched and buried to allow continued fishing without restriction. There is also the potential to lay a new subsea gas pipeline directly across the Gulf of Martaban directly towards Yangon.

### 3.3.4 Geology

There have been no recorded earthquakes in the vicinity of Kalegauk Island. There have been several Magnitude 4 – 5 earthquakes in the Andaman Sea to the west, approximately south of Yangon. These earthquakes run along the Sagaing plate boundary. The Sagaing Fault is a major strike-slip structure that cuts through the centre of Myanmar broadly dividing the country into a western half including Locations 1 and 2 moving north with the Indian plate, and an eastern half including Location 3 attached to the Eurasian plate. The Indian plate continues to move north at about 35 mm per year putting a sideways pressure onto the Eurasian plate in Myanmar. The Sagaing fault line lies offshore of the island to the west. Inland to the east there is also a significant active fault line. Both are relatively far from the Location 2.

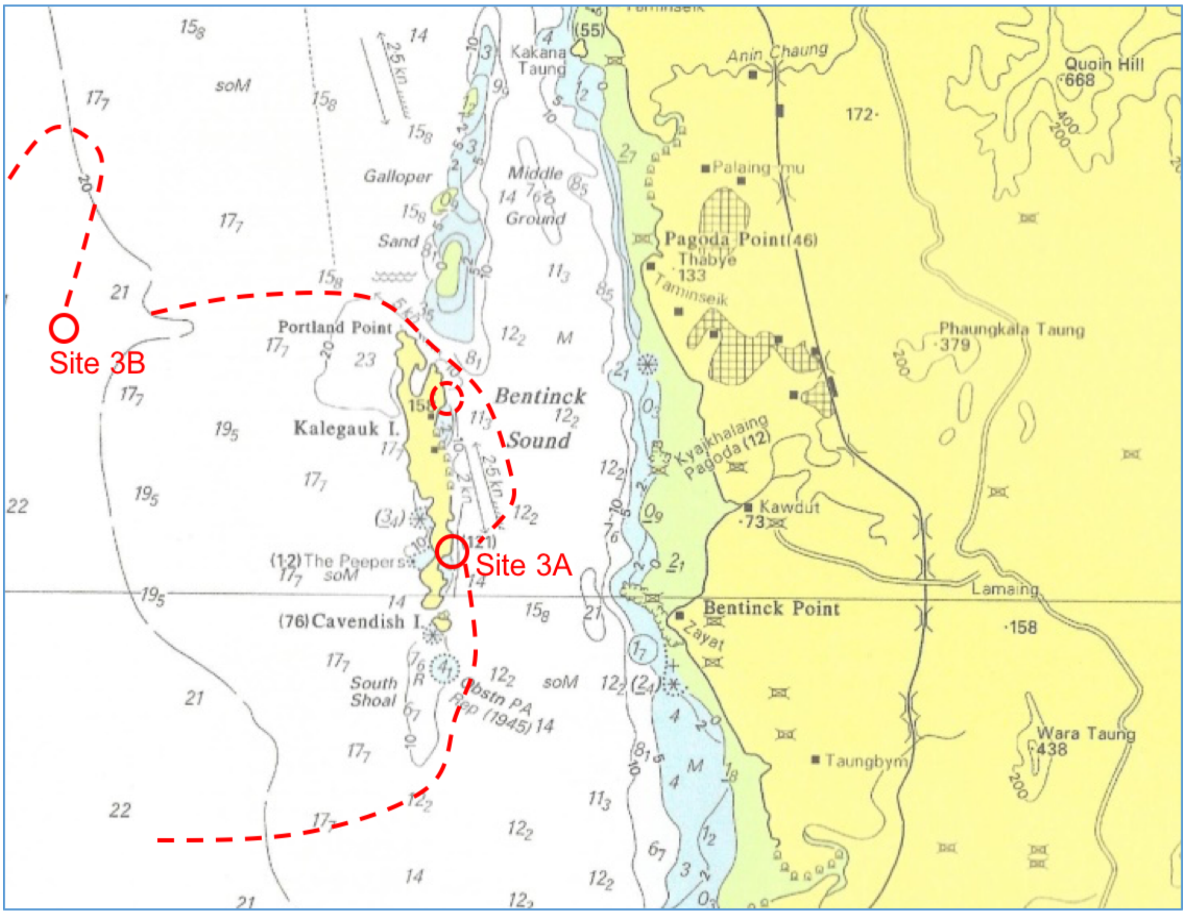
Kalegauk Island is expected to have a peak ground acceleration of < 0.2g. This would cause strong shaking and light damage. Any LNG facility would need some additional design to protect it from this degree of seismic activity.

## 3.3.5 Navigation

### 3.3.5.1 Navigation

UK Admiralty Chart No. 826, shows that Kalegauk Island is separated from the mainland by a stretch of deep water about 5 miles wide (Bentinck Sound), which can be entered from both the north and the south directions. Within Bentinck Sound, the minimum charted water depths are 11.3m from the northerly direction, and 12.2m from the southerly direction. Subject to a proper bathymetric survey, it may be possible to dredge a channel to a depth of 14m. Dredging would be significant but less than that proposed for an onshore site at Nga Yoke Kaung. Appropriate navigational aids will also be required. The chart and navigational channel are indicated in the following chart.

**Figure 69 – Navigation route**



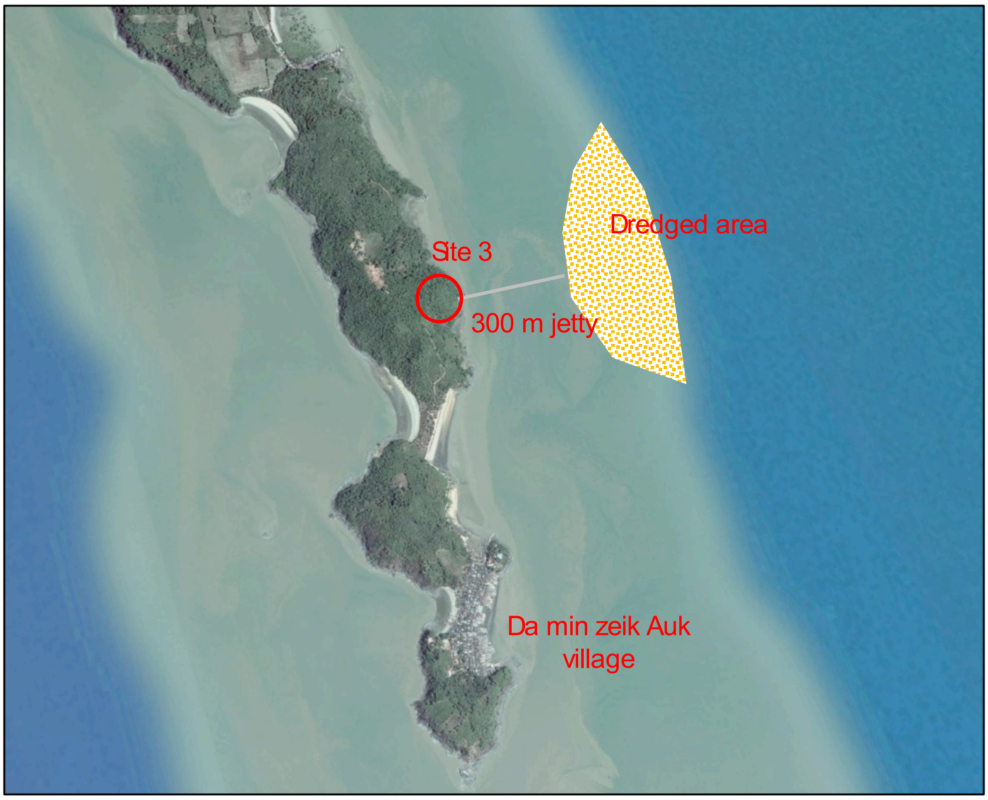

If tidal movements are considered, Table 23, the natural water depth will always be increased by between 0.9m and 5.5m, unless there are exceptional tidal conditions. That being the case, navigational access via the southern end of Bentinck Sound is possible at all times other than at low water on spring tides. The statistical probability of an LNGC arrival at this state of tide is very low and, if it did occur, the ship need only wait a few hours until the tide rises to give the required water depth for berthing.

**Table 24 – Tidal Conditions**

| Heights in Metres Above Chart Datum | | | | |
|---|---|---|---|---|
| Tidal Condition | Mean High Water Spring Tides | Mean High Water Neap Tides | Mean Low Water Neap Tides | Mean Low Water Spring Tides |
| Tidal Height, m | 5.5 | 3.9 | 2.5 | 0.9 |

The LNG carrier and FSRU will need to remain afloat at all times so a berth pocket would need to be dredged in all scenarios. A slightly larger dredged area would be preferred to ensure the LNG carrier could standoff during emergency scenarios. Dredging would be very much reduced from the full channel option. The expected dredging requirements are shown in Figure 59. A berth pocket 500 m long by 500 m wide from an average depth of 12.2 m to 14 m, a total of 450,000 $m^3$.

**Figure 70 – Dredging requirements**




The dredging described above is capital (initial) dredging. The Gulf of Martaban, the local area of the Andaman Sea receives silt from all the major rivers of Myanmar. The local seabed is described on the chart as mud or soft mud which tends to support this behaviour. Significant maintenance dredging is likely to be required to keep the channel open in subsequent years.

Site 3B is in deep water and will not require dredging.

No specific details of low visibility events have been found in public domain documents. Snow only occurs in the northern inland parts of Myanmar so is not considered a problem.

#### 3.3.5.2 Jetty length

To ensure shelter from wind and waves and to maximise the depth of water the berth should be located very close to shore for Site 3A which results in a small jetty of perhaps 300 m. The actual jetty length will be an optimisation between jetty construction costs and dredging costs (beyond the scope of this study). Site 3B will use a tower yoke mooring so does not have a jetty.

#### 3.3.5.3 Marine traffic

No details of the number of movements or type of ship has been identified, which suggests only local fishing vessels close to shore.

#### 3.3.5.4 Towage

Port services such as tugs would have to be brought in from another location. The nearest port is Moulmein (also known as Mawlamyine) approximately 50 nautical miles (5 hours transit time) away. However the trade at that port is largely small coastal vessels and large ships have to unload at anchor into barges. Investigations indicate that the port has only 1 tug of 550 horsepower, which is wholly inadequate for LNGCs. Yangon port is 120 miles away (about 10 hours transit time) where one tug has been identified.

#### 3.3.5.5 Port Rules

There is no existing port and therefore no port rules.

### *3.3.6* Kalegauk Island access to gas pipelines

The purpose of this section is to provide an analysis of the issues concerning access to Myanmar's high-pressure gas pipeline network, focussing on costs in the following areas.

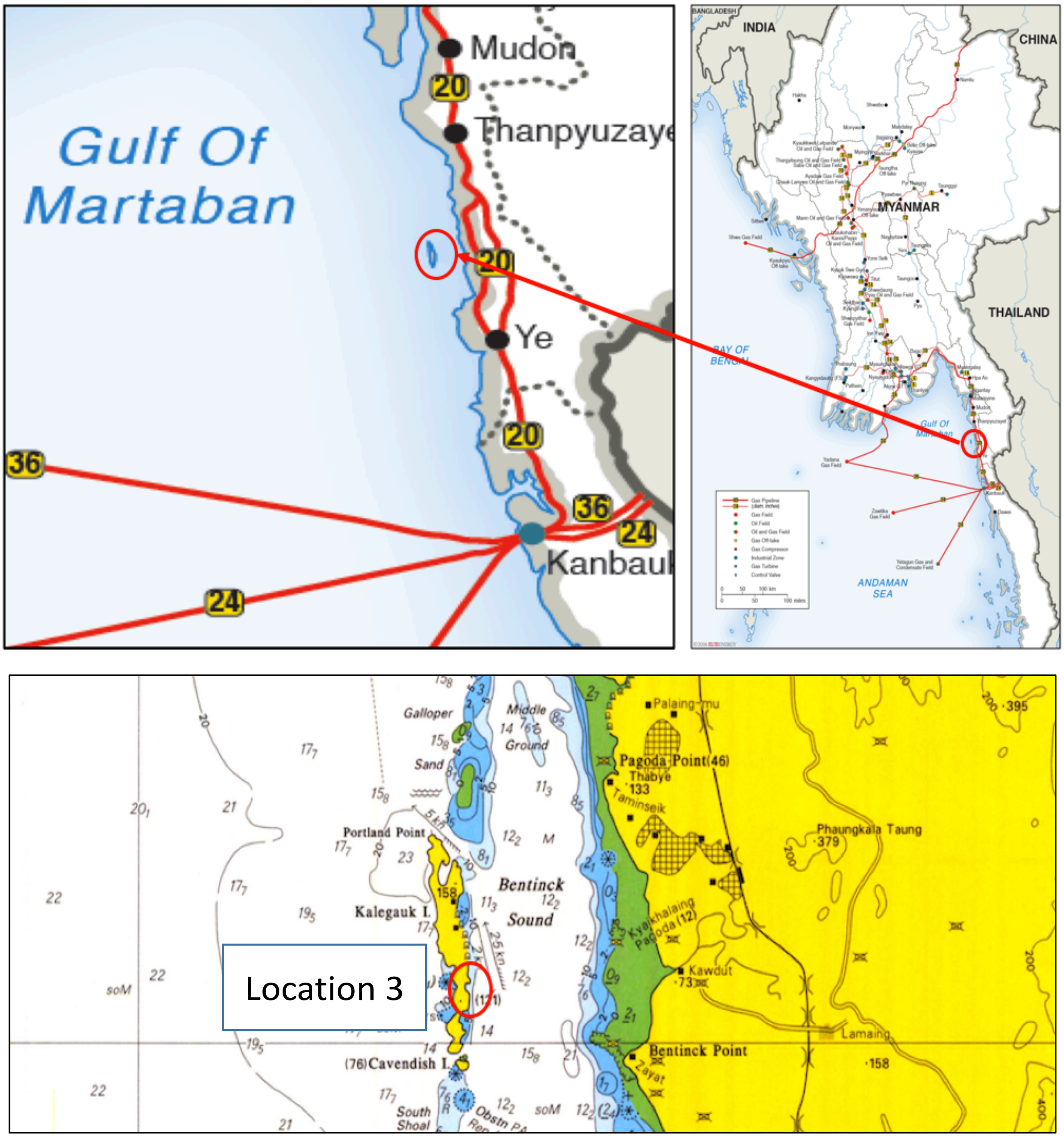
- Overview of the location and associated issues.
- Review of offshore gas transmission pipeline costs.
- Review of onshore gas transmission pipeline costs.
- Gas network reinforcement costs.
- Concluding discussion.

#### 3.3.6.1 Overview of the location and associated issues

There is a power station at Mawlamyine which is connected to the electricity distribution network by a single 230 kV feeder to the Yangon area and eventually to Thailand. The power line is designed to work north to south and is perceived as a current bottleneck in the power grid. A major project to build a line south to Dawei via Mawlamyine and alongside the gas pipeline to Kambauk is under consideration. The capacity of the line may be increased from the current 230 kV plans. This line is at least 5 years in the future with an earliest start date of 2018 resulting in a 2020/21 delivery date. There is little potential power load in the Kalegauk Island area so there is no advantage of generating significant power in the area. LNG should therefore be exported via a gas pipeline network.

The following diagram shows Location 3 – Kalegauk Island and the potential options considered during the siting analysis.

**Figure 71 – Overview of Location 3 Kalegauk Island for FSRU**



In terms of the local area, there could be limited impact on project costs and timing if Tanintharyin national park is to be avoided. In addition, the Project Team have found some references to turtles in the area, which will require further work should this be chosen.

However, the analysis of Location 3 is slightly different to Locations 1 and 2 for the following reasons.

- There is the potential of a direct subsea connection to Yangon.
- The impact of high onshore pipeline costs from the gas landed on the coast from Kalegauk Island to Yangon.

As shall be seen later in this section comparing high capex projects onshore with high capex offshore does pose certain challenges.

#### *3.3.6.2 Review of offshore gas transmission pipeline costs*

In the light of the above the analysis compares two options as follows:

- Site 3A (Onshore option) – This consists of a short subsea pipeline linking the FSRU, which is located near Kalegauk Island with the mainland. Since Bentinck Sound is approximately 8 km wide, we have allowed a total of 10 km offshore connecting pipeline. In addition, there will be a long connecting pipeline / reinforcement to the outskirts of Yangon.
- Site 3B (Offshore option) – This consists or a direct subsea pipeline from the FSRU to Yangon of around 170 km.

**Table 25 – Summary of offshore gas transmission pipeline costs for Location 3 Kalegauk Island**

| Site description | Offshore gas transmission pipeline | Cost ($ million) |
|---|---|---|
| Site 3A (Onshore option, short connection to shore with onshore connection to gas grid.) | 10.0 km of 30” offshore gas transmission pipeline at $1.8 million per km | 18.0 |
| Site 3B (Offshore option consisting of direct subsea connection to Yangon.) | 170.0 km of 30” offshore gas transmission pipeline at $1.8 million per km | 306.0 |

#### *3.3.6.3 Review of onshore gas transmission costs*

In theory there are two possible options for connecting the RLNG that is delivered via the short subsea pipeline to the coast, to Myanmar’s gas transmission network. Since one or both 20 inch pipelines which are roughly 8 km apart as shown on the following map, should in theory be able to receive the RLNG.

However, when the Project Team asked MOGE whether the RLNG could be accommodated by one or both of these 20 inch pipelines it was informed that these pipelines were in a poor state of repair and were unable to accept additional supplies of gas. Therefore, when considering the cost of onshore connecting pipeline the Project Team have examined the option of laying 400 km of 30 inch high-pressure gas pipeline from the landing point near Kawdut to the outskirts of Yangon. However, a possible alternative or intermediate step might be to only lay the 30” pipeline as far as Mawlamyine reducing the pipeline length from 400km to around 125km.

Figure 72 – Potential connecting pipeline point on 20 inch pipeline for Location 3 Kalegauk Island

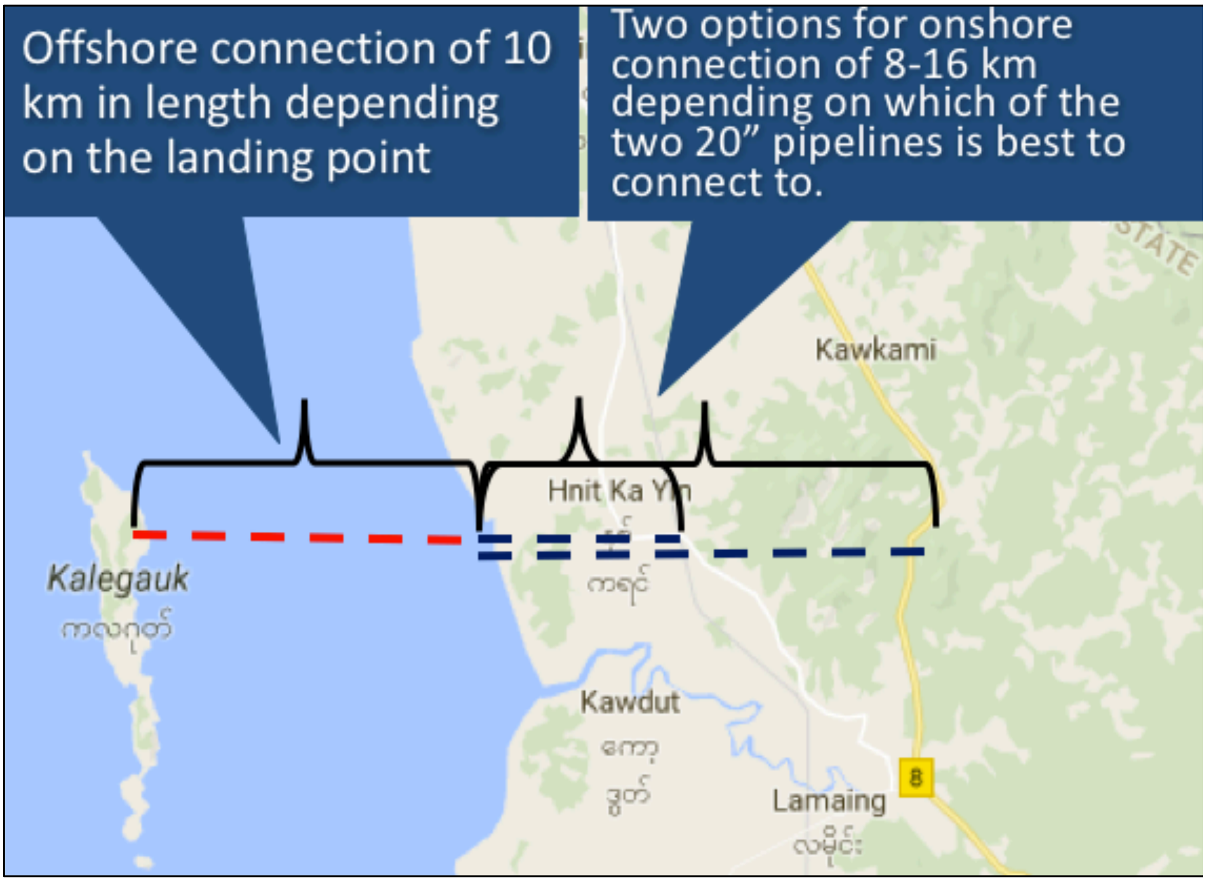


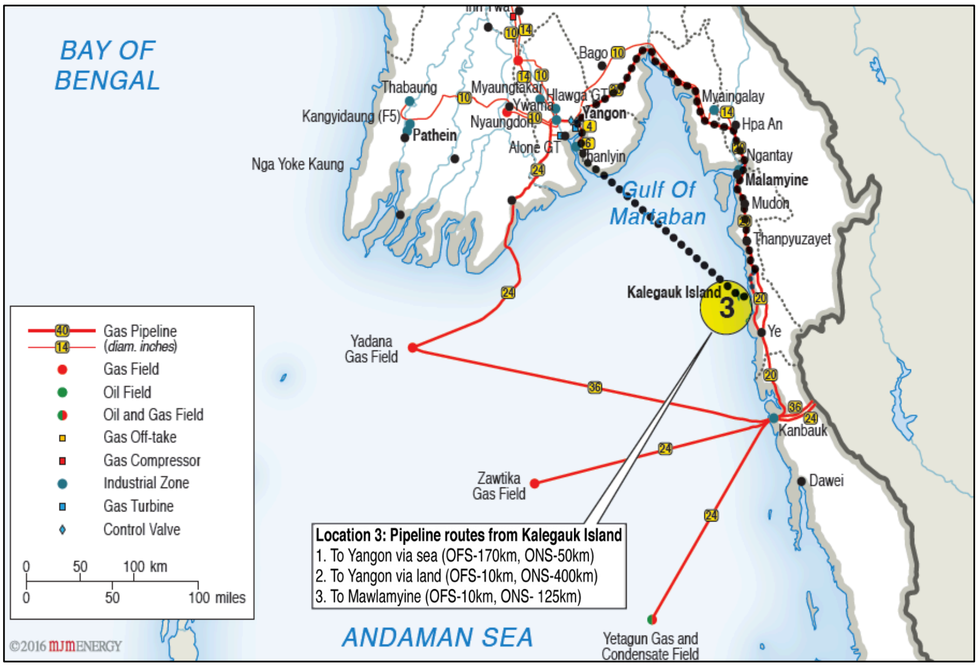

Table 26 – Summary of onshore gas transmission pipeline costs for Location 3 Kalegauk Island

| Site description | Onshore gas transmission pipeline | Cost ($ million) |
|---|---|---|
| Site 3A – (Onshore option consisting of short connection to shore together with direct onshore pipeline to Yangon.) | 400 km of 30" onshore gas transmission pipeline at $1.2 million per km | 480.0 |
| Site 3A – (Onshore option consisting of short connection to shore together with direct onshore pipeline to Mawlamyine.) | 125 km of 30" onshore gas transmission pipeline at $1.2 million per km | 150.0 |

#### *3.3.6.4 Gas network reinforcement costs*

As part of the process of trying ascertain additional reinforcement costs associated with different options, the Project Team raised a number of questions with MOGE as highlighted in the following figure.

**Figure 73 – Additional questions raised in relation to Location 3 Kalegauk Island**




**Questions raised**

1. Can MOGE estimate the potential costs of receiving 500mmscfd of RLNG at or near to Ye in terms of upgrading the gas transmission pipeline from Ye to Yangon?
2. Can MOGE consider the potential implications of laying a 500mmscfd subsea gas pipeline from Kalegauk Island to Yangon?

In response to the questions raised by the Project Team highlighted above, MOGE confirmed the following:

- The pipeline to Mawlamyine has a maximum capacity of 100 MMCFD due to the low pressures at which it operates. In addition, it is not possible to install compressors to increase pressures further due to the poor condition of the pipeline.
- Whilst MOGE is undertaking pipeline repairs and replacements this is very slow at the rate of 10-30 miles per year depending on budget availability.
- From Mawlamyine to Yangon, the maximum capacity is 25 MMCFD unless further compression is installed.

As highlighted previously what this means is that there is little or no spare capacity to accommodate new supplies, without significant additional investment in pipeline infrastructure or the location of a major power generation load near the landing point of the RLNG. This leaves two possible options as follows:

- Build a new onshore pipeline from Ye to Yangon – If RLNG is going to be absorbed into Myanmar's gas network and transported to Yangon, it would require around 400 km of 30" high-pressure gas transmission pipeline to transport RLNG to the city of Yangon. In practice this might be less as the supplies provided by the RLNG displace existing supplies on the route to Yangon.
- Build a new subsea pipeline from Kalegauk Island to Yangon – It is roughly 225 km to Yangon from Kaleguak Island. Whilst Yangon would benefit from this additional gas, the benefits of developing the onshore gas pipeline network from Ye to Yangon would be lost.

#### 3.3.6.5 Concluding discussion

In the light of the above the following table provides a summary of the estimated costs associated with connecting and delivering the RLNG into Myanmar's gas transmission network. It should be noted that these options are really quite different with different challenges as follows:

- ***Site 3A2(Onshore pipeline to Yangon)* –** Whilst this is the more expensive option with an estimated total cost of $498 million there will be a huge potential network benefit associated with building a 400 km high-pressure gas pipeline to Yangon.
- ***Site 3A2(Onshore pipeline to Mawlamyine only)* –** This is basically identical to Site 3A2(Onshore pipeline to Yangon) in all respects except the pipeline to Mawlamyine is considerably shorter at an estimated 125km
- ***Site 3B2 (Subsea pipeline to Yangon)*** – This option involves the construction of around 170 km of subsea pipeline. Clearly this option enables the RLNG to be delivered into the centre of Yangon which is the main demand centre in the region. Also, whilst the Project Team have estimated the cost of a subsea pipeline at $1.8 million per km based on average of the data received from Myanmar and international data, this cost still seems rather low.

Table 27 – **Summary of gas pipeline costs for Site 3A Kalegauk Island**

| **Site 3A2 *(Onshore pipeline to Yangon)* – Costs for 30" pipeline from Kalegauk Island to Yangon** | | |
|---|---|---|
| **Type of gas transmission infrastructure** | **Details of pipeline infrastructure** | **Cost ($ million)** |
| Offshore gas transmission pipeline | 10 km of 30" gas transmission pipeline at $1.8 million per km | 18.0 |
| Onshore gas transmission pipeline | 400 km of 30" gas transmission pipeline at $1.2 million per km | 480.0 |
| **Total estimated cost for delivering RLNG into the Myanmar network** | | **498.0** |
| **Site 3A2 *(Onshore pipeline to Mawlamyine only)* – Costs for 30" pipeline from Kalegauk Island to Mawlamyine** | | |
| **Type of gas transmission infrastructure** | **Details of pipeline infrastructure** | **Cost ($ million)** |
| Offshore gas transmission pipeline | 10 km of 30" gas transmission pipeline at $1.8 million per km | 18.0 |
| Onshore gas transmission pipeline | 125 km of 30" gas transmission pipeline at $1.2 million per km | 150.0 |
| **Total estimated cost for delivering RLNG into the Myanmar network** | | **168.0** |

Table 28 – **Summary of gas pipeline costs for Site 3B2(Subsea pipeline to Yangon)**

| Type of gas transmission infrastructure | Details of pipeline infrastructure | Cost ($ million) |
|---|---|---|
| Offshore gas transmission pipeline | 170 km of 30" gas transmission pipeline at $1.8 million per km | 306.0 |
| Onshore gas transmission pipeline | 50 km of 30" gas transmission pipeline at $1.2 million per km | 60.0 |
| Additional reinforcement cost | nil | 0.0 |
| **Total estimated cost for delivering RLNG into the Myanmar network** | | **366.0** |

Finally, using the five key questions from the Traffic Light Tool, both options score reasonably well although they are quite expensive.

### 3.3.7 Infrastructure

There are two villages described on the island, Da min zeik Atet and Da min zeik Auk, one at each end of the island, although Google earth satellite photos suggest there are also two smaller settlements between the two. None of these settlements are large enough to show up on maps.

The nearest mainland town is Zayat (<10,000 people) at about 10 km with no roads connecting to this town shown.

The nearest larger settlements are Ye (population 40,000) about 40 km to the south and Thanbyuzayat (probably near 25,000) about 50 km to the north. Both have access to the principal national road (although described in poor condition) and Mawlamyine-Dawei railway. Ye also has an air strip and a seaport. The state capital Mawlamyine lies about 100 km to the north.

Ye's economy is mainly based on areca nuts (the seed of the areca palm), rubber and fishing so relevant vocational training is considered to be poor. In Myanmar terms, Mon State is relatively well developed. Schooling at a basic and perhaps intermediate level is anticipated in Ye. All higher level institutions are in Mawlamyine.

There is a 300 bed general hospital with some specialist departments in Mawlamyine. Ye has a 100 bed hospital but data suggests that historically it has performed poorly. Thanbyuzayat has a 25 bed hospital that has a positive record.

Ye has a small port. No details have been found so it has been assumed that this is probably for fishing vessels. Mawlamyine has a larger commercial port operated by the Myanmar Port Authority. Berth lengths and depths are very limited and cranage and major logistics facilities are not present. Port side storage also appears to be limited. The port is effectively tidal as vessels need to cross a shoal. The nearest port of any size are around Yangon, 220 km to the west.

Ye has a domestic airport with links to Yangon.

The main railway line passes north to south down the coast through both Thanbyuzayat and Ye.

A major road follows the railway before turning inland and heading to the Thai border. Roads to the coast opposite Kalegauk Island are not indicated on maps so are presumed to be small and unpaved.

No details have been found of other infrastructure in this area which is described as rarely visited by foreigners and closed to non-Myanmar people prior to 2013.

### 3.3.8 Scoring

The traffic light scoring for Kalegauk Island is shown in the following table.

## Table 29 – Location 3 Kalegauk Island traffic light scoring

| | | Near shore Site 3A | | | | | | | Offshore Site 3B | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Onshore terminal | FSRU on Jetty | Midwater FSRU | Deepwater FSRU | FSU on Jetty | LNGRV in Deepwater | GBS | Onshore terminal | FSRU on Jetty | Midwater FSRU | Deepwater FSRU | FSU on Jetty | LNGRV in Deepwater | GBS |
| GETTING LNG TO THE TERMINAL | | | | | | | | | | | | | | | |
| 1 | How much dredging is required to create a channel to the terminal? | | | | | | | | | | | | | | |
| 2 | What Jetty length is required to be able to moor a near shore FSRU/LNG Carrier? | | | | | | | | | | | | | | |
| OR | What Subsea pipeline length is required to connect a midwater or deepw FSRU or LNGRV | | | | | | | | | | | | | | |
| 3 | How much marine traffic is currently being experienced? | | | | | | | | | | | | | | |
| 4 | Are there local visibility limitations? | | | | | | | | | | | | | | |
| 5 | Are there any other factors that limit the site? | | | | | | | | | | | | | | |
| STORING LNG | | | | | | | | | | | | | | | |
| 1 | What is the wave environment like? | | | | | | | | | | | | | | |
| 2 | How variable is the wind/wave environment? | | | | | | | | | | | | | | |
| 3 | Might the LNG facility be impacted by extreme weather? | | | | | | | | | | | | | | |
| 4 | Will the site cause any destruction or exclusion to environmentally sensi areas? | | | | | | | | | | | | | | |
| 5 | Will the site cause any destruction or exclusion to culturally and historic sensitive areas? | | | | | | | | | | | | | | |
| 6 | Will the site development and operation impact the local community in a detrimental way? | | | | | | | | | | | | | | |
| 7 | Will the site development and operation increase the risk of harm/fatality the local community? | | | | | | | | | | | | | | |
| 8 | Are there risks to the LNG facility from geological events? | | | | | | | | | | | | | | |
| GETTING GAS TO MARKET | | Onshore pipeline | | | | | | | Subsea pipeline | | | | | | |
| 1 | Can LNG be vaporised in sufficient volume and in an environmentally acceptable way? | | | | | | | | | | | | | | |
| 2 | What is the onshore pipeline length? | | | | | | | | | | | | | | |
| 3 | What is the difficulty in laying the onshore pipeline? | | | | | | | | | | | | | | |
| 4 | What is the offshore pipeline length? | | | | | | | | | | | | | | |
| 5 | What is the difficulty in laying the offshore pipeline? | | | | | | | | | | | | | | |
| LOCAL INFRASTRUCTURE | | | | | | | | | | | | | | | |
| 1 | Is there sufficient towage available to berth the LNG carrier? | | | | | | | | | | | | | | |
| 2 | Is there currently any port rules and infrastructure appropriate to hydrocarbon importation at the proposed LNG site? | | | | | | | | | | | | | | |
| 3 | Is there sufficient infrastructure to accommodate workers and their famil expatriates and vendor personnel? | | | | | | | | | | | | | | |
| 4 | Is there emergency response and Health care capability? | | | | | | | | | | | | | | |
| 5 | Education and Skills? | | | | | | | | | | | | | | |
| 6 | Is there access to a major port with connecting roads? | | | | | | | | | | | | | | |
| 7 | Is there access to an international airport with road/rail links? | | | | | | | | | | | | | | |
| 8 | How adequate is the marine infrastructure? | | | | | | | | | | | | | | |

## 3.3.9 Technology & Site Selection

### *3.3.9.1 Site selection*

Silt from Thanlwin and Sittoung Rivers will infill the dredged pocket and channel.

The southern Site 3 is slightly preferred to the northern site because a farmstead will need to be relocated.

### *3.3.9.2 Viable Technology Options*

The wind and wave data does not require any form of berth protection (breakwater) or weathervaning capability.

A weathervaning mid-water solution benefits by being sited further away from populated areas and is less susceptible to geological damage. This is balanced by the need for considerable additional dredging. A weathervaning system is therefore rejected on an environmental impact and cost basis.

A jetty type arrangement is therefore proposed.

The southern site 3 may just have sufficient land available for an onshore terminal although the current proposed schedule mitigates against this.

A near shore FSRU on the jetty is possible and should have a faster schedule. An existing FSRU would be fastest followed by a conversion and then a new build.

A FSU would also be possible.

## 3.4 The Discounted Expenditure Analysis

The qualitative (traffic light) site selection processes have produced 15 possible site-technology combinations. These are summarised in the following table. All of these options could be examined using the discounted expenditure model described in the following chapter. However, this scope is limited to the analysis of 3 sites. Therefore the 15 options need to be reduced to three by shortlisting for further analysis.

**Table 30 – Site and technology combination**

| Site | Option | Site scores by colour | | | | Shortlisting |
|---|---|---|---|---|---|---|
| | | Green | Yellow | Orange | Red | |
| Site 1A | 1A1 Onshore terminal | 6 + 1 | 6 + 7 | 3 | 2 | Implementation schedule too long |
| | 1A2 FSRU | 6 + 1 | 6 + 7 | 3 | 2 | Shortlist |
| | 1A3 FSU | 6 + 1 | 6 + 7 | 3 | 2 | |
| Site 2A | 2A Nearshore | 2 | 9 + 2 | 5 + 1 | 2 + 5 | Not viable |
| | 2B Mid water | 2 | 9 + 2 | 3 + 1 | 3 + 5 | Not viable |
| | 2C Deep water | 2 | 9 + 2 | 3 + 1 | 3 + 5 | Not viable |
| | 2D Nearshore | 3 | 8 + 2 | 6 + 1 | 1 + 5 | Challenging |
| Site 3A Onshore pipeline | 3A1 Onshore terminal | 7 | 10 | 1 + 4 | 0 + 4 | Implementation schedule too long |
| | 3A2 FSRU (jetty) | 7 | 10 | 1 + 4 | 0 + 4 | Shortlist |
| | 3A3 FSU | 7 | 10 | 1 + 4 | 0 + 4 | Reject because of near shore space limitations |
| Site 3A Offshore pipeline | 3A4 Onshore terminal | 7 | 10 | 1 + 4 | 0 + 4 | Implementation schedule too long |
| | 3A5 FSRU (jetty) | 7 | 10 | 1 + 4 | 0 + 4 | Similar to Site 3B |
| | 3A6 FSU | 7 | 10 | 1 + 4 | 0 + 4 | Reject because of near shore space limitations |
| Site 3B | 3B1 FSRU (tower yoke) and onshore gas pipeline | 5 | 11 | 2 + 4 | 0 + 4 | Similar to site 3A |
| Site 3B | 3B2 FSRU (tower yoke) and offshore gas pipeline | 4 | 10 | 2 + 4 | 0 + 4 | Shortlist |

Onshore sites 1A1, 3A1 and 3A4 are not preferred as the construction schedule exceeds Myanmar's expectations. In addition, the contract duration of 5 – 10 years does not optimise the return on these investments.

Sites 3A3 and 3A6 are rejected based on the limited amount of space available on Kalegauk Island. Two FSUs will be required to handle the amount of LNG. This configuration requires two berths, in effect at least doubling (plus separation distance) the length of the facility. The only possible site is relatively close to habitation and therefore risks would increase.

Location 1 could accommodate either an FSRU or two FSUs. The selection will depend on the amount of supply security that MOGE wishes to have. In discussions, security of supply did not appear to be a major issue to MOGE and so the single berth FSRU option has been preferred. Sites 3A2, 3A5, 3B1 and 3B2 are very similar. The choice is primarily about two different parameters deep water vs sheltered shallow water and onshore vs offshore pipelines. Two cases have been chosen to highlight these differences. These are 3A2 and 3B2. Cases 3A5 and 3B1 could equally well be chosen but the subsea pipeline option is more logically combined with the offshore FSRU.

The selected sites for economic assessment using the discounted expenditure model are:

- Location 1 – Site 1A2 (Jetty mounted FSRU at Kyauk Phyu).
- Location 2 – Site 2D (Jetty mounted FSRU at Nga Yoke Kuang).
- Location 3 – Sites 3A2 (Jetty mounted FSRU at Kalegauk Island with onshore gas pipeline).
- Location 3 – Site 3B2 (Tower yoke mounted FSRU at Kalegauk Island with offshore gas pipeline).

These are examined below.

### 3.4.1 Jetty mounted FSRU at Kyauk Phyu (1A2)

#### *3.4.1.1 Description*

A current "industry standard" FSRU of 170,000$m^3$ is moored on a fixed jetty of 200 m length next to Shwe pipeline oil terminal. Some minor dredging is performed to create a berth pocket out of the deep water channel. Gas from the FSRU is vaporised at an average rate of 250 mmscfd (50% of 500 mmscfd) using an open loop sea water system and injected into a new 30 inch overland gas pipeline to Pyay following the existing road.

The following physical parameters were used.

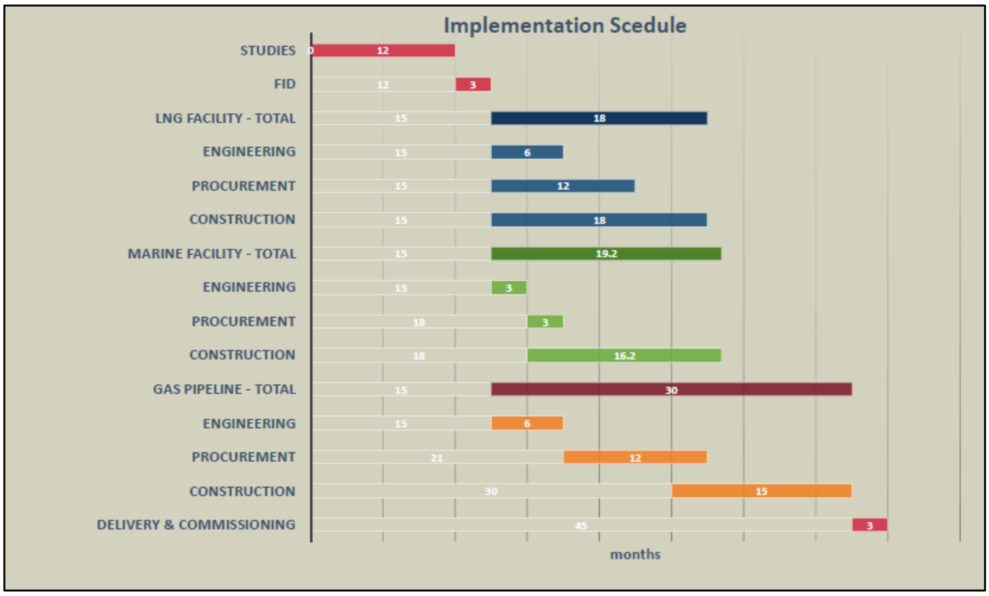
**Table 31 – Summary data inputs for the analysis for Site 1A2**

| **PHYSICAL PARAMETRS:** | | **Data** |
|---|---|---|
| LNG facility size | | 170,000 $m^3$ stored with 500 mmscfd vaporiser capacity |
| LNG facility type | | FSRU |
| Location | | Nearshore |
| Ownership | | Lease |
| geology | | <0.4 g acceleration |
| Jetty length | | 200 m |
| Breakwater | | Not required |
| Dredging | | 2,000,000 $m^3$ |
| Gas pipeline | | 5 km of 30 inch offshore + 557 km of 30 inch onshore |
| Design LNG ship | | 163,000 $m^3$ |
| **FINANCIAL AND ECONOMIC PARAMETERS:** | | **Data** |
| Project start year | | 2017 |
| LNG import term | | 10 years |
| Discount rate | | 10% |
| Lease rate | | 140,000 US$/day |
| Fuel oil cost | | 470 US$/ton 380 cs Singapore |
| Electricity cost | | 0.05 US$/kWh (70 kyats/kWh) |
| Tug cost | | US$ 15,000/day each (no mobilisation costs) |
| **CAPITAL COSTS: Description of key areas** | | **Value** |
| FSRU | | 0 US$ million (lease) |
| Jetty | | 138 US$ million |
| Dredging | | 10 US$ million |
| Gas pipeline | | 677.6 US$ million |
| Local infrastructure | | 0 US$ million |
| TOTAL | | 825.06 US$ million |
| Note 1 : No BOT/BOOT purchase payment was assumed at the end of the contract life. | | |
| **OPERATING COSTS: Description of key areas** | | **Operating costs** |
| FSRU lease | | 51 US$ million pa |
| Fixed costs | Labour | 3 US$ million pa |
| | Insurance | 2 US$ million pa |
| | Inspection and maintenance | 2 US$ million pa |
| | Supporting infrastructure | 2 US$ million pa |
| Variable costs | Fuel oil | 6.48 US$ million pa |
| | Electricity | 0 US$ million pa |
| | Towage | 1.6 US$ million pa |
| TOTAL | | 68.08 US$ million pa |
| **Notes** | | |
| 1. The above calculation is based on a 557km connecting pipeline to Yangon. If Site 1A2 was to opt for the shorter 290km onshore connection to either Pyay or Magway the CAPEX costs would be reduced by $320.4 million, with an equivalent reduction in the DCF figure. | | |

### *3.4.1.2 Schedule to implementation*

The following design/construction schedule has been estimated with a total completion time of 48 months.

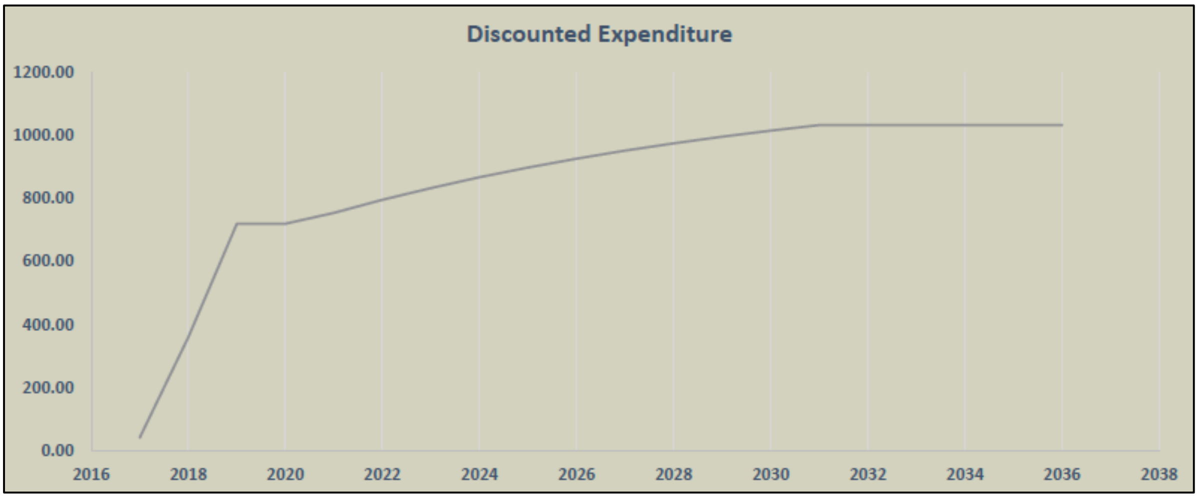
**Figure 74 – Estimated design/construction schedule for Site 1A2**




### *3.4.1.3 Discounted Expenditure*

The above parameters have been combined into a discounted expenditure figure of: 1,062 US$ million, which is shown in the following chart.

**Figure 75 – Breakdown of the discounted expenditure for Site 1A2**



## 3.4.2 Jetty mounted FSRU at Nga Yoke Kaung (2D)

### *3.4.2.1 Description*

A current “industry standard” FSRU of 170,000$m^3$ is moored on an island jetty about 200m offshore. Some dredging is performed to create a berth pocket out of the deep water channel. Gas from the FSRU is vaporised at an average rate of 250 mmscfd (50% of 500 mmscfd) using an open loop sea water system and injected into a new 30 inch overland gas pipeline to Yangon via Pathein.

The following physical parameters were used.

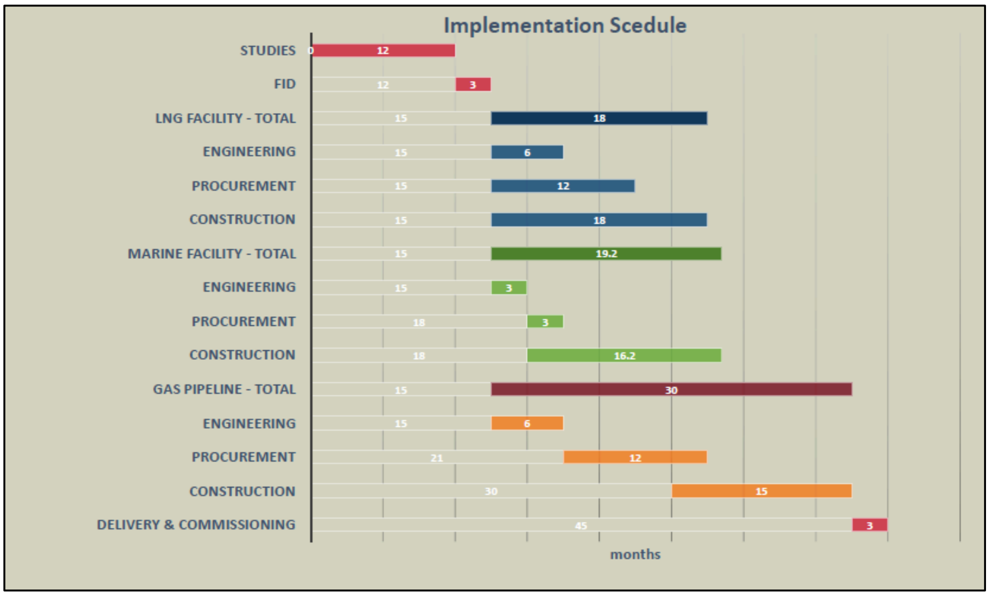
**Table 32 – Summary data inputs for the analysis for Site 2D**

| | | |
|---|---|---|
| **PHYSICAL PARAMETRS:** | | **Data** |
| LNG facility size | | 170,000 $m^3$ stored with 500 mmscfd vaporiser capacity |
| LNG facility type | | FSRU |
| Location | | Nearshore |
| Ownership | | Lease |
| geology | | <0.4 g acceleration |
| Jetty length | | 0 m |
| Breakwater | | Not required |
| Dredging | | 5,200,000 $m^3$ |
| Gas pipeline | | 1 km of 30 inch offshore + 230 km of 30 inch onshore |
| Design LNG ship | | 163,000 $m^3$ |
| **FINANCIAL AND ECONOMIC PARAMETERS:** | | **Data** |
| Project start year | | 2017 |
| LNG import term | | 10 years |
| Discount rate | | 10% |
| Lease rate | | 140,000 US$/day |
| Fuel oil cost | | 470 US$/ton 380 cs Singapore |
| Electricity cost | | 0.05 US$/kWh (70 kyats/kWh) |
| Tug cost | | US$ 15,000/day each ( 4 days mobilisation)) |
| **CAPITAL COSTS: Description of key areas** | | **Value** |
| FSRU | | 0 US$ million (lease) |
| Jetty | | 46 US$ million |
| Dredging | | 26 US$ million |
| Gas pipeline | | 278 US$ million |
| Local infrastructure | | 0 US$ million |
| TOTAL | | 350 US$ million |
| Note 1 : No BOT/BOOT purchase payment was assumed at the end of the contract life. | | |
| **OPERATING COSTS: Description of key areas** | | **Operating costs** |
| FSRU lease | | 51 US$ million pa |
| Fixed costs | Labour | 3 US$ million pa |
| | Insurance | 2 US$ million pa |
| | Inspection and maintenance | 2 US$ million pa |
| | Supporting infrastructure | 2 US$ million pa |
| Variable costs | Fuel oil | 6.5 US$ million pa |
| | Electricity | 0 US$ million pa |
| | Towage | 14.6 US$ million pa |
| TOTAL | | 81.1 US$ million pa |
| **Notes** | | |
| 1. The above calculation is based on a 230km connecting pipeline to Yangon. If Site 2D was to opt for the shorter 50km onshore connection to Pathein the CAPEX costs would be reduced by $204 million, with an equivalent reduction in the DCF figure. | | |

### 3.4.2.2 *Schedule to implementation*

The following design/construction schedule has been estimated with a total completion time of 48 months.

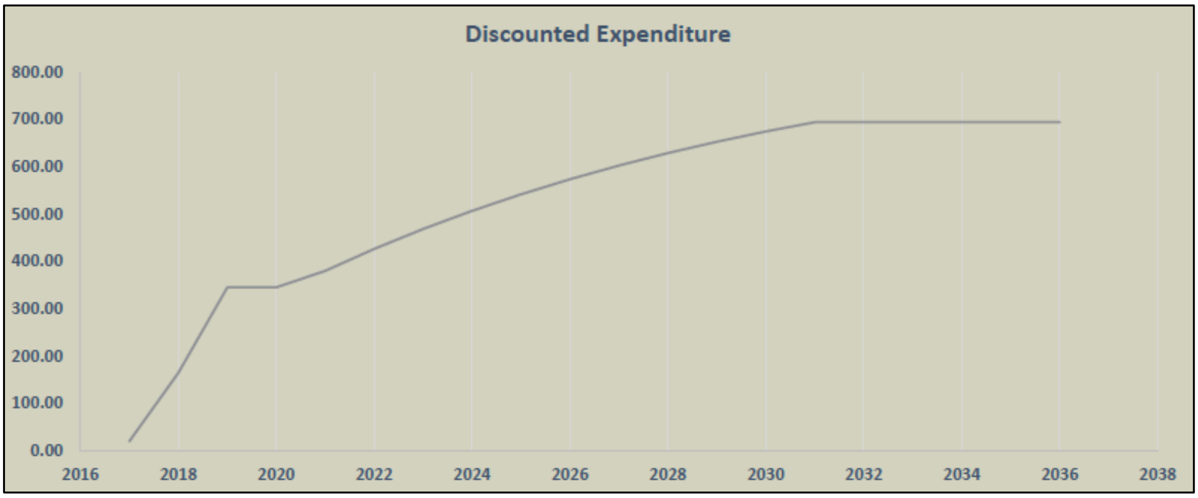
**Figure 76 – Estimated design/construction schedule for Site 2D**




### 3.4.2.3 *Discounted Expenditure*

The above parameters have been combined into a discounted expenditure figure of: 682 US$ million, which is shown in the following chart.

**Figure 77 – Breakdown of the discounted expenditure for Site 2D**



## 3.4.3 Jetty mounted FSRU at Kalegauk Island with onshore pipeline Site 3A2

### *3.4.3.1 Description*

A current "industry standard" FSRU of 170,000m$^3$ is moored on a jetty to the east of Kalegauk Island (Site 3A). Gas is vaporised at an average rate of 250 mmscfd (50% of 500 mmscfd) using an open loop sea water system and injected into a short subsea pipeline to the mainland and then via a 400km pipeline onshore to the immediate south east of Yangon as summarised in the following table.

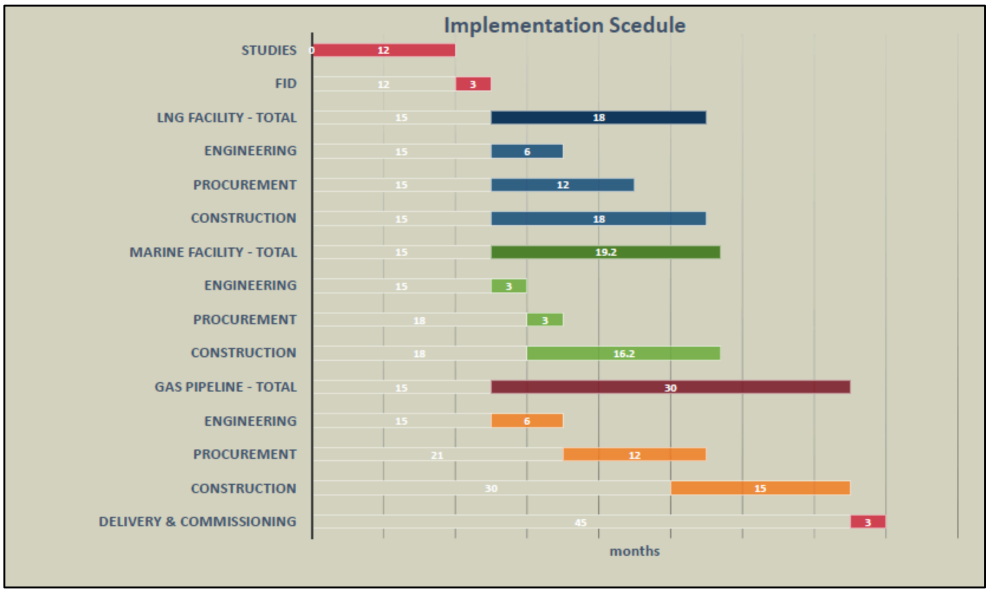
**Table 33 – Summary of physical parameter data used in analysis for Site 3A2**

| **PHYSICAL PARAMETRS:** | | **Data** |
|---|---|---|
| LNG facility size | | 170,000 m$^3$ stored with 500 mmscfd vaporiser. |
| LNG facility type | | FSRU |
| Location | | Nearshore |
| Ownership | | Lease |
| geology | | <0.2 g acceleration |
| Jetty length | | 300 m |
| Breakwater | | Not required |
| Dredging | | 500,000 m$^3$ |
| Gas pipeline | | 10 km 30 inch subsea pipeline + 400 km onshore |
| Design LNG ship | | 163,000 m$^3$ |
| **FINANCIAL AND ECONOMIC PARAMETERS:** | | **Data** |
| Project start year | | 2017 |
| LNG import term | | 10 years |
| Discount rate | | 10% |
| Lease rate | | 140,000 US$/day |
| Fuel oil cost | | 470 US$/ton 380 cs Singapore |
| Electricity cost | | 0.05 US$/kWh (70 kyats/kWh) |
| Tug cost | | US$ 15,000/day each plus 4 days mobilisation |
| **CAPITAL COSTS: Description of key areas** | | **Value** |
| FSRU | | 0 US$ million (lease) |
| Jetty | | 167 US$ million |
| Dredging | | 2.5 US$ million |
| Gas pipeline | | 498 US$ million |
| Local infrastructure | | 0 US$ million |
| TOTAL | | 667.5 US$ million |
| Note 1: No BOT/BOOT purchase payment was assumed at the end of the contract life. | | |
| **OPERATING COSTS: Description of key areas** | | **Operating costs** |
| FSRU lease | | 51 US$ million pa |
| Fixed costs | Labour | 3 US$ million pa |
| | Insurance | 2 US$ million pa |
| | Inspection and maintenance | 2 US$ million pa |
| | Supporting infrastructure | 2 US$ million pa |
| Variable costs | Fuel oil | 6.5 US$ million pa |
| | Electricity | 0 US$ million pa |
| | Towage | 14.6 US$ million pa |
| TOTAL | | 81.1 US$ million pa |
| **Notes** | | |
| 1. The above calculation is based on a gas pipeline to Yangon. If an intermediate solution was developed with the onshore pipeline stopping at Mawlamyine only 125km from where RLNG is landed from the FSRU a saving of around $330million would be possible. | | |

### 3.4.3.2 *Schedule to implementation*

The following design/construction timescale has been estimated, with the total implementation time of 48 months.

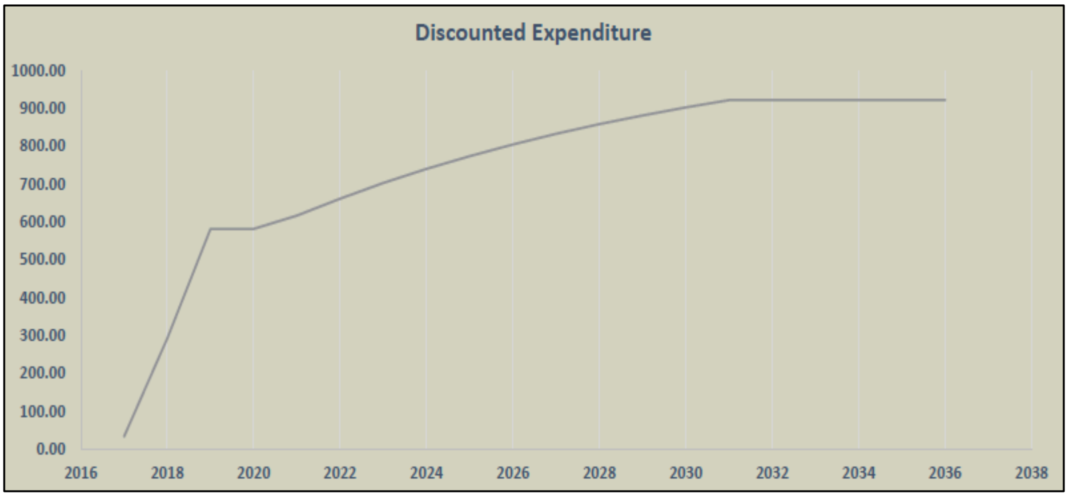
**Figure 78 – Estimated design/construction schedule for Site 3A2**




### 3.4.3.3 *Discounted Expenditure*

The above parameters have been combined into a discounted expenditure figure of 949.1US$ million. The breakdown over time of this figure is shown in the following chart.

**Figure 79 – Breakdown of the discounted expenditure for Site 3A2**



## 3.4.4 Tower Yoke mounted FSRU at Kalegauk Island with offshore pipeline Site 3B2

### 3.4.4.1 Description

A current "industry standard" FSRU of 170,000m$^3$ is moored on a weathervaning tower yoke mooring in 20 m of water off the west coast of Kalegauk Island. Gas from the FSRU is vaporised at an average rate of 225 mmscfd (50% of 450 mmscfd) using an open loop sea water system and injected into a new subsea pipeline direct to Yangon. On landing a short onshore pipeline connects the gas into the existing network to the south east of Yangon. The following physical parameters were used.

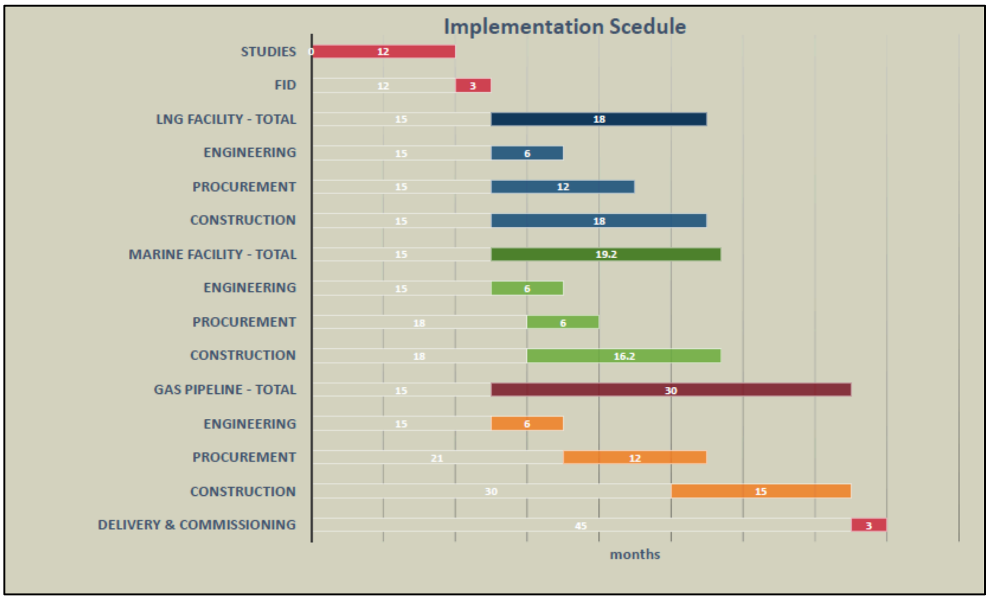
**Table 34 – Summary of physical parameter data used in analysis for Site 3B2**

| **PHYSICAL PARAMETRS:** | | **Data** |
|---|---|---|
| LNG facility size | | 170,000 m3 stored with 500 mmscfd vaporiser |
| LNG facility type | | FSRU |
| Location | | Mid water (Tower Yoke) |
| Ownership | | Lease |
| geology | | <0.2 g acceleration |
| Jetty length | | Not required |
| Breakwater | | Not required |
| Dredging | | Not required |
| Gas pipeline | | 170km 30 inch subsea pipeline + 50 km onshore |
| Design LNG ship | | 163,000 m$^3$ |
| **FINANCIAL AND ECONOMIC PARAMETERS:** | | **Data** |
| Project start year | | 2017 |
| LNG import term | | 10 years |
| Discount rate | | 10% |
| Lease rate | | 140,000 US$/day |
| Fuel oil cost | | 470 US$/ton 380 cs Singapore |
| Electricity cost | | 0.05 US$/kWh (70 kyats/kWh) |
| Tug cost | | US$ 15,000/day each plus 2 days mobilisation |
| **CAPITAL COSTS: Description of key areas** | | **Value** |
| FSRU | | 0 US$ million (leased) |
| Tower Yoke Mooring | | 81 US$ million |
| Dredging | | 0 US$ million |
| Gas pipeline | | 366 US$ million |
| Local infrastructure | | 0 US$ million |
| TOTAL | | 447 US$ million |
| Note 1 : No BOT/BOOT purchase payment was assumed at the end of the contract life. | | |
| **OPERATING COSTS: Description of key areas** | | **Operating costs** |
| FSRU lease | | 51 US$ million pa |
| Fixed costs | Labour | 3 US$ million pa |
| | Insurance | 2 US$ million pa |
| | Inspection and maintenance | 2 US$ million pa |
| | Supporting infrastructure | 2.2 US$ million pa |
| Variable costs | Fuel oil | 6.48 US$ million pa |
| | Electricity | 0 US$ million pa |
| | Towage | 14.5 US$ million pa |
| TOTAL | | 81.1 US$ million pa |

#### 3.4.4.2 Schedule to implementation

The following design/construction schedule has been estimated with a total completion time of 48 months.

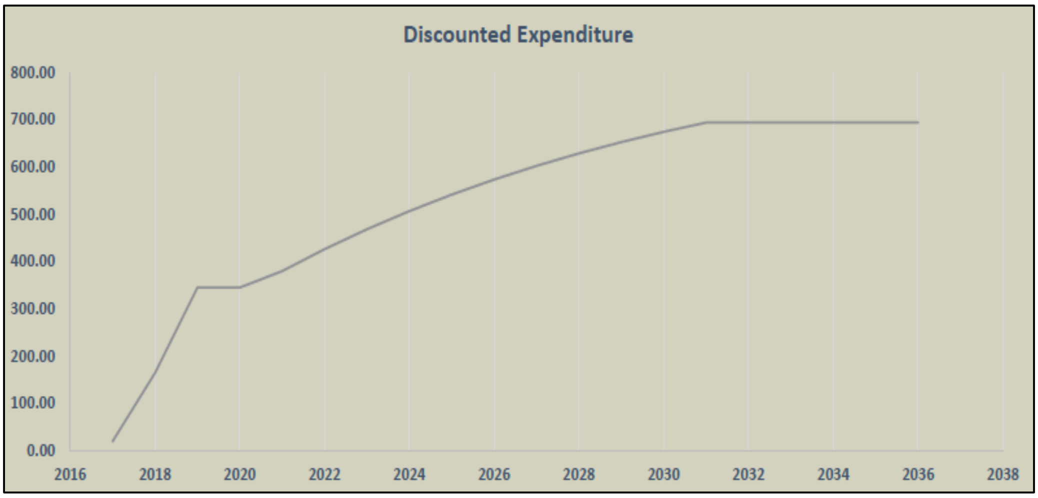
**Figure 80 - Estimated design/construction schedule for Site 3B2**




#### 3.4.4.3 Discounted Expenditure

The above parameters have been combined into a discounted expenditure figure of 802 US$ million. The breakdown over time of this figure is shown in the following chart.

**Figure 81 – Discounted expenditure model for Site 3B2**



## 3.5 Discussion of results

The discounted expenditure model has been run for the 4 sites and indicates the following:

- The majority of the capital expenditure is in the gas pipeline connection as the FSRU is leased.
- The marine facilities have a similar implementation schedule to the LNG facility.

The results from the 4 sites are as follows:

**Table 35 – Summary of discounted expenditure analysis**

<table>
<tr><th>Site</th><th>Schedule (Months)</th><th>Capital Investment (US$ million)</th><th>Operating Expense (US$ million per annum)</th><th>Discounted Expenditure (DEX) (US$ million)</th></tr>
<tr><td>Site 1A2</td><td>48</td><td>826</td><td>68</td><td>1,062</td></tr>
<tr><td colspan="5">The above calculation is based on a 557km connecting pipeline to Yangon. FSRU lease payment included in Operating Expense. If Site 1A2 was to opt for the shorter 290km onshore connection to either Pyay or Magway the CAPEX costs would be reduced by $320.4 million, with an equivalent reduction in the DCF figure.</td></tr>
<tr><td>Site 2D</td><td>48</td><td>350</td><td>81</td><td>682</td></tr>
<tr><td colspan="5">The above calculation is based on a 230km connecting pipeline to Yangon. FSRU lease payment included in Operating Expense. If Site 2D was to opt for the shorter 50km onshore connection to Pathein the CAPEX costs would be reduced by $204 million, with an equivalent reduction in the DCF figure.</td></tr>
<tr><td>Site 3A2</td><td>48</td><td>668</td><td>81</td><td>949</td></tr>
<tr><td colspan="5">The above calculation is based on a gas pipeline to Yangon. FSRU lease payment included in Operating Expense. If an intermediate solution was developed with the onshore pipeline stopping at Mawlamyine only 125km from where RLNG is landed from the FSRU a saving of around $330million would be possible.</td></tr>
<tr><td>Site 3B2</td><td>48</td><td>447</td><td>81</td><td>802</td></tr>
<tr><td colspan="5">FSRU lease payment included in Operating Expense.</td></tr>
</table>

Based on the above analysis two sites emerge as possibilities.

- Site 2D – Is the cheapest site overall although development of this site may be hindered by environmental concerns.
- Site 3B2 on a tower yoke mooring to the west of Kalegauk Island is the lowest discounted cost. The difference between this site and site 3A2 is that a direct subsea pipeline is used across the Gulf of Martaban to Yangon. The long onshore pipeline from Kalegauk Island (Site 3A2) dominates the capital cost. If the existing pipeline was reinforced using other sources of funds then this project option would reduce dramatically in price. If the option 3A5 was substituted, i.e. the sheltered site to the east of Kalegauk Island and is combined with a direct subsea pipeline it is anticipated that its economics would be similar to Site 3B2.

From a weather point of view site 3A5 would have more a consistent and lower wave climate to operate in which would improve uptime and reduce any additional storage requirements based on security of supply arguments.

There are potential political issues which need to be resolved at Kalegauk

- At Kalegauk Island the ongoing dispute between residents and the Myanmar Navy needs further examination.
- The onshore site may be compromised by the development of deep water ports.

These political issues may add cost to the project but are more likely to delay implementation.

# 4 Conclusions and Recommendations

As highlighted in the introduction, this report in conjunction with the Site Prioritisation Tool (SPT) (on an Excel platform), make up the main deliverables for this project in keeping with the TOR. In particular, the three main areas of work have consisted of the following:

- Task 1(a) – Siting analysis to assess potential locations of LNG import facilities in Myanmar.
- Task 1(b) – Preparation of prioritisation framework and accompanying analytical tool for LNG import options and locations.
- Task 1(c) – Overview of the LNG markets that Myanmar may access with a view of procuring LNG to be physically swapped with gas export partners.

Therefore, using the above framework from the TOR our conclusions and recommendations are provided below.

## 4.1 Conclusions

Please note that for the sake of completeness and ease of reading we have included the results from the reports on Location 4 and Location 5 in these Conclusions and Recommendations. Please refer to the relevant reports for the detailed analysis.

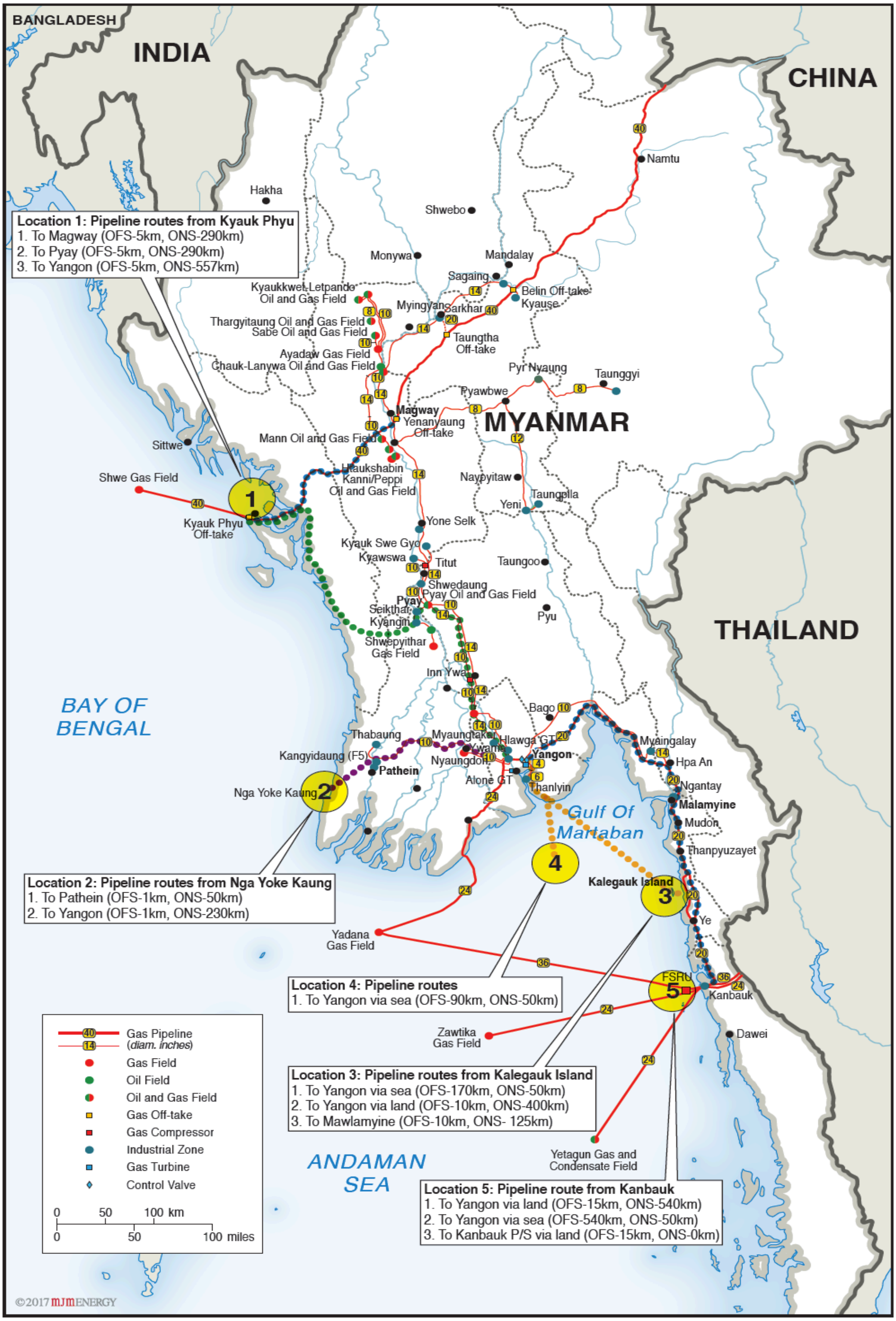
### 4.1.1 Task 1(a) Siting Analysis

The siting analysis has narrowed down the potential options from three broad geographical locations, to fifteen possible options, to seven potentially credible sites. This was achieved through a combination of identifying suitable technologies, understanding the impact of local site metocean conditions, reviewing local conditions in relation to infrastructure (pipeline and marine) and costing the various options. The result of this analysis is summarised in the following table.

**Table 36 Summary of discounted expenditure analysis for Site 1A2, 2D, 3A2, 3B2, 4, 5A, and 5B**

<table>
<tr><th>Site</th><th>Schedule (Months)</th><th>Capital Investment (US$ million)</th><th>Operating Expense (US$ million per annum)</th><th>Discounted Expenditure (DEX) (US$ million)</th></tr>
<tr><td>Site 1A2</td><td>48</td><td>826</td><td>68</td><td>1,062</td></tr>
<tr><td colspan="5">The above calculation is based on a 557km connecting pipeline to Yangon. FSRU lease payment included in Operating Expense. If Site 1A2 was to opt for the shorter 290km onshore connection to either Pyay or Magway the CAPEX costs would be reduced by $320.4 million, with an equivalent reduction in the DEX figure.</td></tr>
<tr><td>Site 2D</td><td>48</td><td>350</td><td>81</td><td>682</td></tr>
<tr><td colspan="5">The above calculation is based on a 230km connecting pipeline to Yangon. FSRU lease payment included in Operating Expense. If Site 2D was to opt for the shorter 50km onshore connection to Pathein the CAPEX costs would be reduced by $204 million, with an equivalent reduction in the DEX figure.</td></tr>
<tr><td>Site 3A2</td><td>48</td><td>668</td><td>81</td><td>949</td></tr>
<tr><td colspan="5">The above calculation is based on a gas pipeline to Yangon. FSRU lease payment included in Operating Expense. If an intermediate solution was developed with the onshore pipeline stopping at Mawlamyine only 125km from where RLNG is landed from the FSRU a saving of around $330million would be possible.</td></tr>
<tr><td>Site 3B2</td><td>48</td><td>447</td><td>81</td><td>802</td></tr>
<tr><td colspan="5">FSRU lease payment included in Operating Expense.</td></tr>
<tr><td>Site 4</td><td>48</td><td>312.8</td><td>81</td><td>649</td></tr>
<tr><td colspan="5">The above calculation is based on an FSRU, a finger jetty and a direct offshore pipeline connection to Yangon. FSRU lease payment included in Operating Expense. However, due to the exposed nature of the site the it would be necessary to include a breakwater to mitigate the exposed nature of the site, the cost of which could be quite variable.</td></tr>
<tr><td>Site 5A</td><td>45</td><td>855</td><td>15</td><td>808</td></tr>
<tr><td colspan="5">The above calculation is based on a joint project with PTT (Thailand) consisting of the purchase and conversion of a 10-year old LNGC (included in Capital Investment), a tower yoke mooring, a new 15 km, shared 30” subsea pipeline (MOEE 56.25%, PTT et al 43.75%) which makes landfall adjacent to the existing pipelines and a 540 km 30” onshore pipeline to Yangon wholly owned by MOEE.</td></tr>
<tr><td>Site 5B</td><td>45</td><td>640</td><td>15</td><td>621</td></tr>
<tr><td colspan="5">Site 5B is similar to Option with the RLNG from the FSRU being injected into two new subsea pipelines. One connecting into the existing Myanamar-Thailand lines at Kanbauck (wholly funded by PTT) and the second, a 265 km, 30” subsea pipeline making landfall to the south east of Yangon wholly funded by MOEE or private investors.</td></tr>
</table>

**Figure 82 – Overview of the five main locations examined for MOGE**



### 4.1.2 Task 1(b) Site Prioritisation Tool

The SPT has been developed and consists of three stages

- ***SPT-Stage 1 (Concept selection***) – Where SPT-Stage 1 asks a series of generic questions in relation to gas demand, timing, security of supply and ownership that whilst not site specific the answers to these questions will influence site selection. SPT-Stage 1 then uses this data to identify a suggested LNG import technology option such as an FSRU or land-based LNG import terminal, although the user can override this suggestion with their own preferred choice. The output from SPT-Stage 1 is then summarised in a simple chart.
- ***SPT-Stage 2 (Qualitative site selection)*** – The output from SPT-Stage 1 is then fed into SPT-Stage 2. Having made a technology choice, the user is then asked a series of questions that fall under the following four categories: (1) Getting LNG to the LNG facility; (2) Storing the LNG shipments; (3) Getting LNG out; and (4) Area Local infrastructure. The user's responses are analysed and scored using the traffic light methodology. The output will provide a more detailed visual indication of whether the site is suitable or not.
- ***SPT-Stage 3 (Discounted expenditure selection)*** – Whilst SPT-Stage 2 is by definition qualitative and high level, SPT-Stage 3 has been devised by the Project Team to compare the financial, operational and commercial aspects of the different site selection options. Fundamentally, the approach taken is a Net Present Value (NPV) model. However, in the absence of income data, SPT-Stage 3 is based solely on a discounted expenditure approach.

The spreadsheet model has been developed with simplicity of use in mind, therefore, many of the default settings and cost settings could be recalibrated with costs local to Myanmar where appropriate.

### 4.1.3 Task 1(c) Gas Swaps

This report is now in a separate document.

## 4.2 Recommendations

In terms of recommendations each of the seven sites highlighted warrant additional work as follows:

***(1) Site 1A2 (Jetty mounted FSRU at Kyauk Phyu) –*** Whilst this site scores well in all categories, the pipeline connection cost is high, although the overall cost and associated construction risks could be reduced if access could be obtained to the Chinese pipeline. Therefore, we recommend firstly that MOGE consider discussions with the Chinese on TPA and secondly, in order to fully understand the implications of laying a new pipeline in the Shwe pipeline ROW, that MOGE undertake a feasibility study of laying a new 30-inch pipeline.

***(2) Site 2D (Jetty mounted FSRU at Nga Yoke Kaung) –*** Whilst the option is one of the closer options to Yangon it is also sensitive in terms of environment and social issues. Further work would need to be undertaken on both the environmental issues and pipeline costs to Yangon.

***(3) Site 3B2 (Tower yoke mounted FSRU at Kalegauk Island with offshore gas pipeline) –*** This option will be sensitive to subsea pipeline construction costs. Therefore, given the disparity between MOGE's initial offshore pipeline costs and international benchmarks we recommend that MOGE undertake a feasibility study of the long offshore subsea pipeline costs from Kalegauk Island to Yangon.

(4) ***Site 3A2 (Jetty mounted FSRU at Kalegauk Island with onshore gas pipeline) –*** With costs in order of $948million this project is one of the more expensive options, although the actual pipeline costs may be less depending upon how the new connecting pipeline and the local gas network interconnect. Therefore, we recommend that MOGE undertake a commercial and operational study of the proposed connecting pipeline to establish a more accurate estimate of its cost.

(5) ***Site 4 (FSRU, with a finger jetty and a direct offshore pipeline connection to Yangon) –*** Whilst Site 4 has the lowest discounted cost, these estimates come with high levels of uncertainty in relation to the cost offshore pipeline and the breakwater. Therefore, we recommend that MOGE undertake a technical costing study of both the offshore pipeline and the breakwater.

(6) ***Site 5A (A shared project with PPT (Thailand) using a refurbished LNGC, tower yoke and a land-based pipeline to Yangon) –*** This project only really becomes viable if cost sharing with PTT becomes a reality, which seems unlikely. If the project were to go ahead, we recommend that MOGE undertake a feasibility study of laying a new 30-inch pipeline to Yangon, since a large proportion of the cost is captured by this pipeline.

(7) ***Site 5B (A shared project with PPT (Thailand) using a refurbished LNGC, tower yoke and an offshore pipeline to Yangon) –*** The issues are similar to Site 5A. If the project were to go ahead, we recommend that MOGE undertake a feasibility study for laying a new 30-inch subsea pipeline to Yangon, since a large proportion of the cost is captured by this pipeline.

(8) ***General recommendation on managing system reinforcement*** – in addition to the above we also recommend that MOGE considers its policy in relation to system reinforcement and where the costs of infrastructure development are allocated. For example, if some of the onshore connecting gas pipeline costs are absorbed by the local gas network because of the obvious system benefits then Site 3A2 may look more favourable.

# ANNEXES

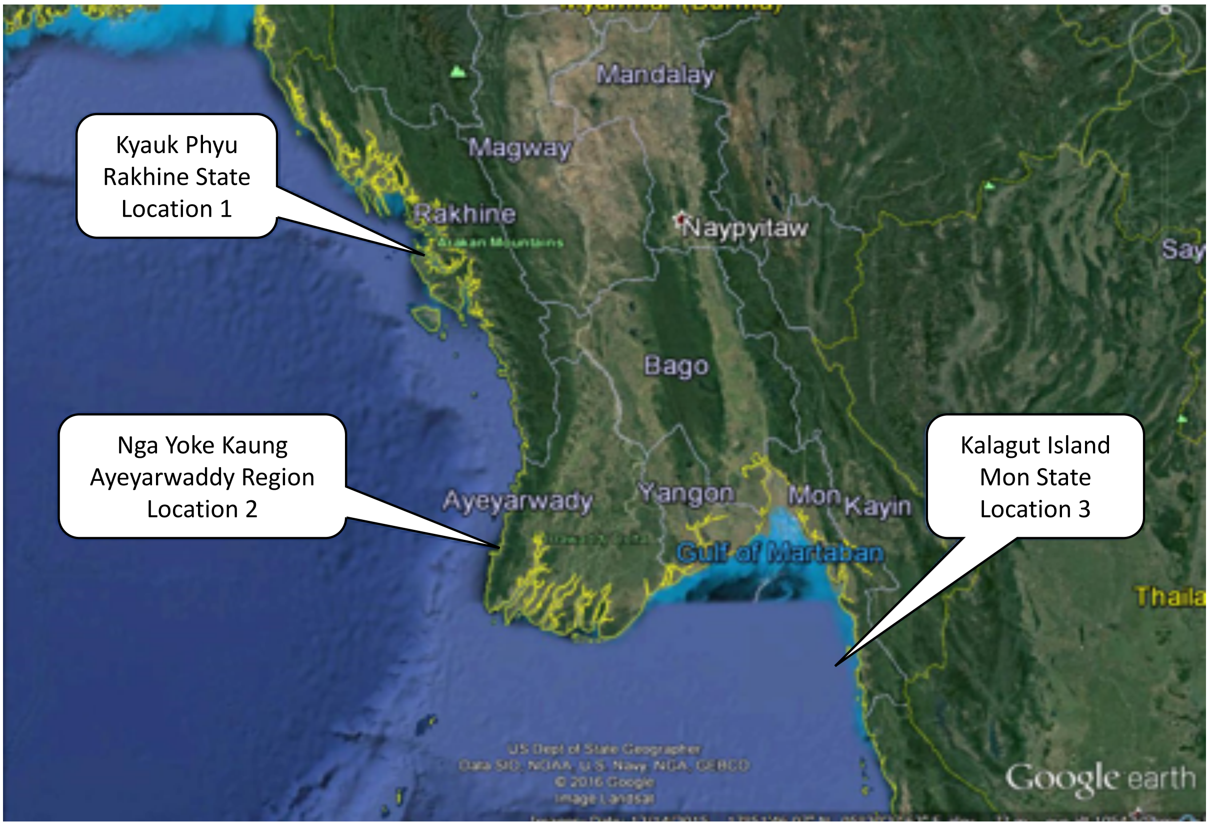
# Section A Metocean Report

## A.1 Introduction

CA Metocean has been requested to produce preliminary metocean data to support the review process of three potential locations along the coast of Myanmar to install LNG import facilities. These potential locations are:

- Kyauk Phyu, Rakhine state, referred to as area 1 in the hereby report.
- Nga Yoke Kaung, Ayeyarwaddy region, referred to as area 2 in the hereby report.
- Kalagut Island, Mon state, referred to as area 3 in the hereby report.

**Figure 83 – Interest locations along Myanmar's coast (Google Inc., 2013) [1]** [34]




## A.2 Study approach

Since the locations of interest are very close to the coast, it was considered necessary to use a numerical model in order to take into account the effects of the bathymetry on the wave climate at each location.

In outline, the approach to the study involved:

- Defining the model domain such that:

[34] *This work has been carried out in accordance with CA Metocean's proposal CAMQ_16002, dated 5th August 2016.*

  - The locations of interest are sufficiently far from the boundaries to allow the modelled conditions to fully stabilise.
  - Nearby offshore hindcast model information (calibrated against measurements as available) can be used as boundary conditions.
- Identification of the wave model boundary conditions: all available time series from the freely available hindcast were extracted and used as input for the wave model.
- Setting up a 2-dimensional numerical spectral wave transformation underpinned by a grid across the domain.
- Propagation of 20 years of waves from the model's open boundaries to the interest locations over a constant sea level: Mean Sea Level.
- Extraction of 20 years long time series of wave heights, period and direction at each of the interest locations.
- Derivation of the percentage exceedance and waiting on weather statistics.

## A.3 Deliverables

### A.3.1.1 Non cyclonic conditions

### A.3.1.2 Waves

- Monthly and all year directional tables of significant wave height occurrence and % exceedance.
- Monthly and all year omni-directional tables of significant wave height versus peak period.
- Monthly and all year significant wave height rosettes.

### A.3.1.3 Winds (10m asl)[35]

- Monthly and all year directional tables of hourly wind speed occurrence and % exceedance.
- Monthly and all year hourly wind speed rosettes.

### A.3.1.4 Waiting on weather

- Monthly waiting on weather statistics for window durations of 3, 6, 12, 24, 48, 72 and 96 hours, and Hs thresholds of 1.00, 1.25, 1.50, 1.75 and 2.00m.[36]
- Monthly probability of waiting times being longer than 24, 48 and 72 hours for the same window durations and wave thresholds above[37].
- Maximum waiting time for each operation during the 20 years simulated.[4]

### A.3.1.5 Cyclone statistics

Cyclonic activity in each location was analysed and statistics presented as follows:

- Map of cyclone tracks for period 1990-2014.

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[35] *Only results for the all-year are presented in the hereby report. Monthly tables and roses can be found in the embedded Excel spreadsheet "ScatterTables_LOI_Area_i.xslx*

[36] *Only results for Hs threshold of 1.75m are presented in the hereby report. Remaining results can be found in the embedded Excel spreadsheet "WOW_LOIs.xslx".*

[37] *Results can be found in the embedded Excel spreadsheet "WOW_LOIs_Waves_2.xslx".*

- Tables of monthly frequency of occurrence and maximum wind speed for period 1990-2014.

# A.4 Data sources

## A.4.1 Wave and wind data

### A.4.1.1 NOAA Wave Watch 3 Model data

The NOAA (National Oceanic and Atmospheric Administration) has released a new 31 years long hindcast based on the Wave Watch 3 third generation model with a global resolution of 30 minutes in the area of interest [2], [3] and [4].

For each output point, the model provides 3-hourly time series including: significant wave height, peak period, wave direction, wind speed and wind direction, for a period of 31 years (from 01 January 1979 to 31 December 2009).

### A.4.1.2 Satellite data

Satellite measurements from GlobWave Project have been used in order to verify the model wave and wind data before using it for further analysis, as necessary (Logica, 2010), (Satellite Oceanographic Consultants, 2010).

Subsidised by the Centre National d'Études Spatiales (CNES), the GlobWave Project is an initiative funded by the European Space Agency (ESA) through the Date User Element (DUE) program. This is a programmatic element of the 3rd period of the Earth Observation Envelope Programme (EOEP-3), an optional programme of ESA.  The main goals are: (1) to develop and maintain a GlobWave web portal providing a single point of reference for satellite wave data and its associated calibration and validation information and (2) to provide a uniform, harmonised, quality controlled, multi-sensor set of satellite wave data and ancillary information in a common format, with a consistent characterisation of errors and bias. GlobWave Database consists of eight satellite post-processed missions: ERS-1, ERS-2, ENVISAT, Topex/Poseidon, Jason-1, Jason-2, GEOSAT and GEOSAT Follow-On (GFO), covering a 29-year period (from 1985 to 2014). The raw-data satellite measurements were calibrated and quality-controlled before being made available.

### A.4.1.3 Cyclone Tracks

Tropical cyclone track data, including wind speeds and locations every 6 hours are in the public domain and made available by various agencies.

The best track data can be obtained from the International Best Tracks for Climate Stewardship (IBTrACS) database [7]. The IBTrACS project contains the most complete global set of historical tropical cyclones available. It combines information from numerous tropical cyclone datasets, simplifying interagency comparisons by providing storm data from multiple sources in one place. As part of the project the quality of storm inventories, positions, pressures, and wind speeds are checked and information about the quality of the data is passed on to the user.

The World Meteorological Organization (WMO) Tropical Cyclone Programme has endorsed IBTrACS as an official archiving and distribution resource for tropical cyclone best track data. In addition, the WMO endorses one set of best track data for each cyclone; the data originating from various agencies depending on the region.

The latest update of that database is IBTrACS v03r08, which contains cyclone data from 1848 up to 2014 (included) and was released in January 2016.

#### A.4.1.4 Bathymetric Data

The General Bathymetric Chart of the Oceans (GEBCO (Organization, 2016)) consists of an international group of experts who work on the development of a range of bathymetric data sets and data products, with the aim of providing the most authoritative, publicly-available bathymetric grids for the world's oceans.

GEBCO operates under the joint auspices of the International Hydrographic Organisation (IHO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The GEBCO_08 Grid is a continuous terrain model for ocean and land with a spatial resolution of 30 arc-seconds. The bathymetric portion of the grid has largely been generated from a database of ship-track soundings with interpolation between soundings guided by satellite-derived gravity data. However, in areas where they improve on the existing GEBCO_08 grid, data sets generated by other methods have been included.

The latest release of the GEBCO 30 arc-second global grid of elevations, GEBCO_2014 Grid, was published in 2014. Is provides an update to the GEBCO_08 Grid.

It was generated by combining quality-controlled ship depth soundings with interpolation between sounding points guided by satellite-derived gravity data. Where they improve on the existing grid, data sets developed by other methods are included to create a continuous terrain model for ocean and land.

The GEBCO_2014 Grid is accompanied by a Source Identifier (SID) Grid. This identifies which cells are based on actual depth values and which contain predicted depth values. In future releases, the SID grid will also contain a code to identify the individual surveys used to generate the data set.

## A.5 Bay of Bengal climate overview

### A.5.1 Monsoons

The climate in Myanmar can be described as a tropical monsoon climate, with three seasons:

- The cool, relatively dry northeast monsoon (late October to mid-February)
- The hot, dry inter-monsoonal season (mid-February to mid-May),
- The rainy southwest monsoon (mid-May to late October).

### A.5.2 Cyclones

Cyclones in the South Asian region originate primarily from the Bay of Bengal. There are some pre-existing favorable weather conditions, higher sea temperature and lower level cyclonic circulation. The life time of the cyclones in the Bay of Bengal is about four to five days according to the geography of the Bay of Bengal, and they move initially North or Northwest in low latitude and recurve North or Northeast around 18.00° N.

Myanmar has two cyclone season; the first one during the pre-Monsoon months from March to June and the second one after the Monsoon season is over, from October to December. However, weak cyclones also occur outside of the season months.

The following chart shows the tracks of all cyclones affecting the Bay of Bengal between 1990 and 2014 (25- year long period).

**Figure 84 - Cyclones in the Bay of Bengal for the period 1990-2014**

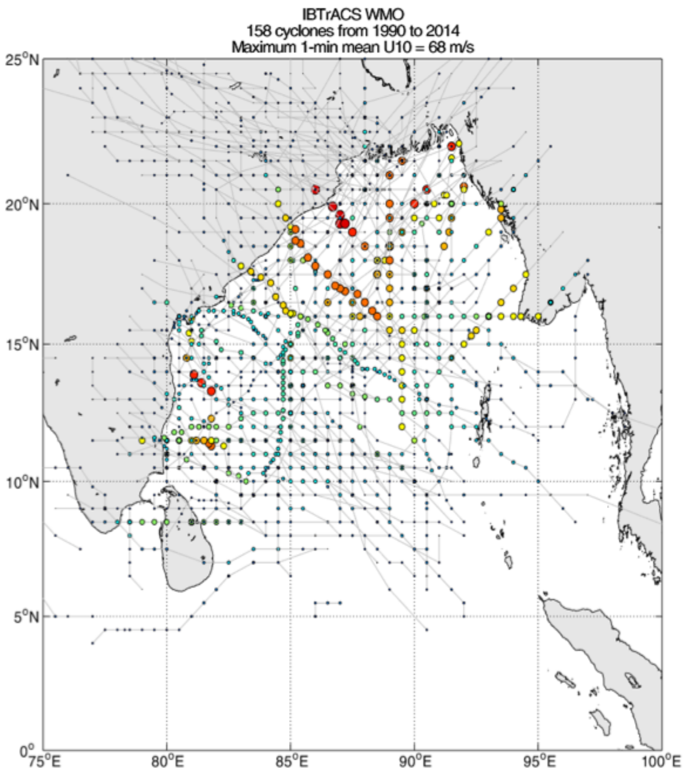
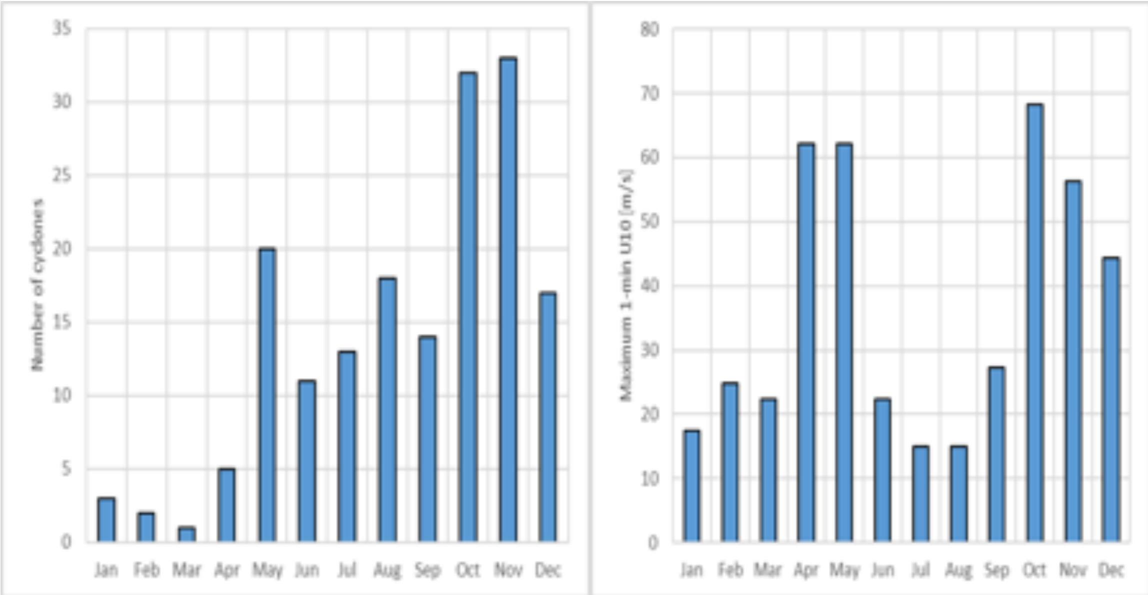



**Table 37 - Cyclones monthly statistics for the period 1990-2014**

| IBTrACS WMO data - Area: 0 to 25°N, 75 to 100°E - Period: 1990-2014 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | All-year |
| Number of events [] | 3 | 2 | 1 | 5 | 20 | 11 | 13 | 18 | 14 | 32 | 33 | 17 | 158 |
| Maximum 1-min U10 [m/s] | 17 | 25 | 22 | 62 | 62 | 22 | 15 | 15 | 27 | 68 | 56 | 44 | 68 |
| Mean 1-min U10 [m/s] | 14 | 15 | 16 | 25 | 20 | 12 | 11 | 10 | 12 | 19 | 19 | 19 | 17 |

**: Cyclones might occur over more than one month and hence can be included twice*

**Figure 85 - Cyclones monthly statistics for the period 1990-2014**

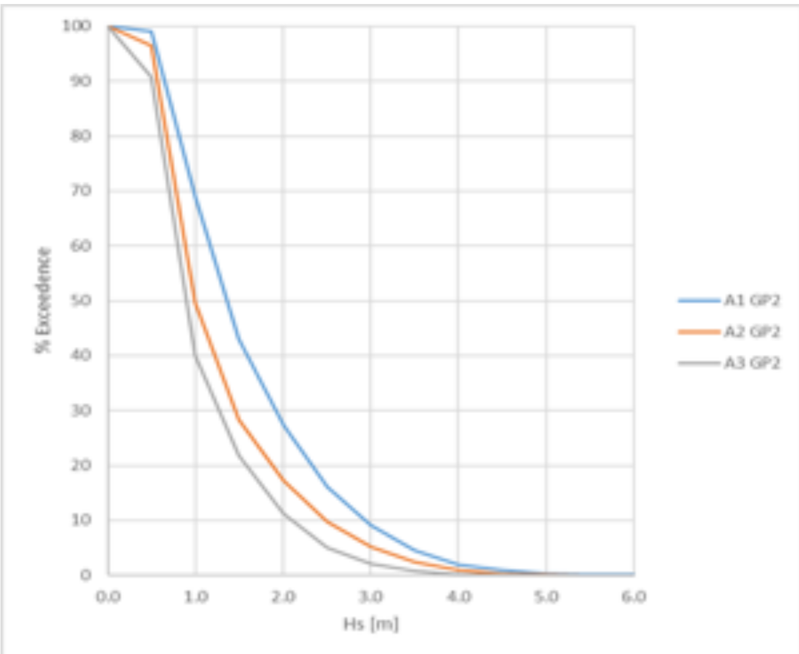



## A.5.3 Offshore Waves in the Interest Areas

### A.5.3.1 Comparison of the offshore waves

The plot and table below show the cumulative frequency analysis for the significant wave height offshore of the three interest locations, highlighting the fact that offshore waves decrease as we move South.

**Figure 86 - Cumulative frequency distribution for Hs. Plot (left) and values (right)**

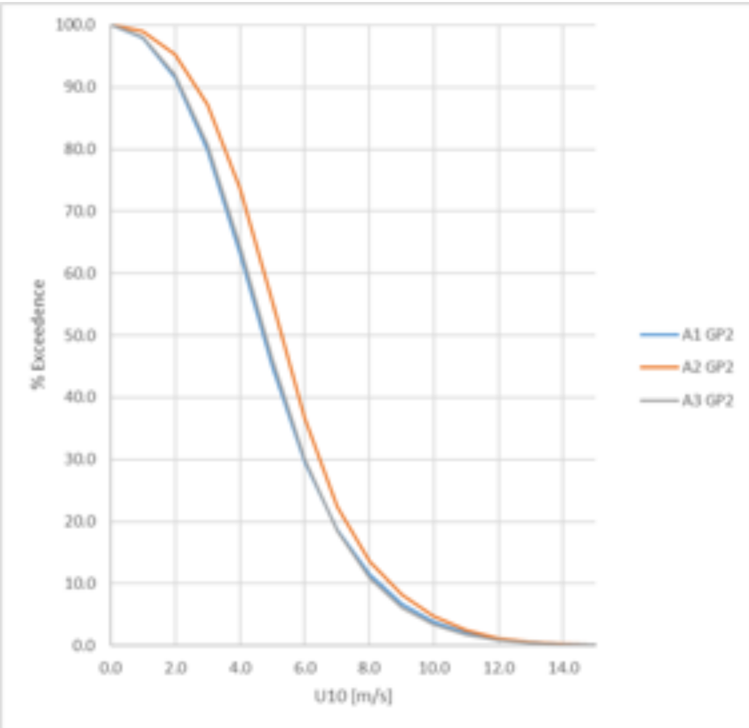



| NOAA WW3 - All dir. - All-year | | | |
|---|---|---|---|
| Hs [m] | A1 GP2 | A2 GP2 | A3 GP2 |
| 9.5 | 0 | 0 | 0 |
| 9.0 | 0.0 | 0.0 | 0.0 |
| 8.5 | 0.0 | 0.0 | 0.0 |
| 8.0 | 0.0 | 0.0 | 0.0 |
| 7.5 | 0.0 | 0.0 | 0.0 |
| 7.0 | 0.0 | 0.0 | 0.0 |
| 6.5 | 0.0 | 0.0 | 0.0 |
| 6.0 | 0.1 | 0.0 | 0.0 |
| 5.5 | 0.1 | 0.0 | 0.0 |
| 5.0 | 0.3 | 0.1 | 0.0 |
| 4.5 | 0.9 | 0.3 | 0.1 |
| 4.0 | 2.0 | 0.9 | 0.2 |
| 3.5 | 4.5 | 2.4 | 0.8 |
| 3.0 | 9.1 | 5.2 | 2.1 |
| 2.5 | 16.2 | 9.7 | 5.1 |
| 2.0 | 27.4 | 17.3 | 11.2 |
| 1.5 | 43.1 | 28.4 | 21.8 |
| 1.0 | 69.0 | 49.8 | 40.0 |
| 0.5 | 99.1 | 96.5 | 90.9 |
| 0.0 | 100.0 | 100.0 | 100.0 |

### A.5.3.2 Comparison of the offshore winds

The plot and table below show the cumulative frequency analysis for the wind speed at the three interest locations, showing that the winds are almost identical in location 1 and 3 and slightly higher in the central location: Nga Yoke Kaung.

**Figure 87 - Cumulative frequency distribution for wind speed. Plot (left) and values (right)**




| NOAA WW3 - All dir. - All-year | | | |
|---|---|---|---|
| U10 [m/s] | A1 GP2 | A2 GP2 | A3 GP2 |
| 23.0 | 0.0 | 0.0 | 0.0 |
| 22.0 | 0.0 | 0.0 | 0.0 |
| 21.0 | 0.0 | 0.0 | 0.0 |
| 20.0 | 0.0 | 0.0 | 0.0 |
| 19.0 | 0.0 | 0.0 | 0.0 |
| 18.0 | 0.0 | 0.0 | 0.0 |
| 17.0 | 0.0 | 0.0 | 0.0 |
| 16.0 | 0.1 | 0.1 | 0.0 |
| 15.0 | 0.2 | 0.2 | 0.1 |
| 14.0 | 0.3 | 0.3 | 0.2 |
| 13.0 | 0.6 | 0.6 | 0.3 |
| 12.0 | 1.1 | 1.2 | 0.8 |
| 11.0 | 2.1 | 2.6 | 1.7 |
| 10.0 | 3.8 | 4.7 | 3.3 |
| 9.0 | 6.7 | 8.2 | 6.1 |
| 8.0 | 11.5 | 13.6 | 10.8 |
| 7.0 | 18.7 | 22.4 | 18.5 |
| 6.0 | 29.6 | 36.7 | 30.1 |
| 5.0 | 45.0 | 55.5 | 46.1 |
| 4.0 | 63.2 | 73.7 | 64.4 |
| 3.0 | 79.9 | 87.2 | 80.7 |
| 2.0 | 91.5 | 95.3 | 92.0 |
| 1.0 | 98.0 | 99.0 | 98.2 |
| 0.0 | 100.0 | 100.0 | 100.0 |

## A.6 Methods

### A.6.1 Numerical Modelling

Metocean studies are often based on hindcast data from one or two grid points, validated against a single set of nearby measurements. Such hindcasts are usually of relatively coarse resolution and therefore very important processes, which occur during the wave propagation, are not properly resolved in the data. This is of particular relevance in coastal areas such as the areas of interest analysed in this study.

Numerical modelling presents an ideal solution, in which complex dynamic equations are solved by computer at every point on a pre-determined, high resolution grid. Data can be extracted from model output databases at any number of locations and, provided the model has been carefully calibrated, will be of a higher level of precision. In addition, modelling allows finer resolution of criteria in areas of highly complex dynamics such as in the coastal zone.

Two models are usually run in the numerical modelling studies:

- A flow model to reproduce the oceanic flows and water level changes induced by tide, surge, wind and density gradients.

- A wave model to reproduce the growth, decay and transformation of wind generated waves and swell, including wave growth by action of wind, non-linear wave-wave interaction, dissipation due to white-capping, dissipation due to bottom friction, dissipation due to depth-induced wave breaking, wave-current interaction, refraction and shoaling due to depth variations, diffraction and reflection.

Simulating the tides was out of the scope of work and therefore no flow model was used in the present study. Regarding the wave simulations, both TOMAWAC [9] and SWAN [10] third-generation wave models were used to reproduce the coastal waves in the three locations of interest for a one-year long period. After comparing the results obtained with each software, it was decided to use SWAN for the 20 years long simulations at each area.

### A.6.2 Swan model overview

SWAN (Simulating Wave Nearshore) is a third-generation phase-averaged wave model, developed at Delft University of Technology, that computes random, short-crested wind-generated waves in coastal regions and inland waters. The model is based on the wave action balance equation with sources and sinks. The following physical phenomena are reproduced by SWAN:

- Wind generation of waves.
- Dissipation due to whitecapping.
- Non- linear deep water quadruplet interactions.
- Non-linear shallow water triad interactions.
- Bottom friction.
- Depth induced wave breaking.
- Dissipation due to vegetation, mud and turbulence.
- Wave set-up (shoaling).
- Transmission through obstacles.
- Diffraction and depth- induced refraction.

### A.6.3 Model domain

The first step for the modelling exercise was to define a modelling area making a compromise between model run times, the proximity of the boundaries to the interest location, and the location of the available boundary condition data.

The domain of the wave model for each interest site is shown in the figures below.

**Figure 88 - Location 1 - Kyauk Phyu: model data used as inputs**


The grid points used to force the model for Location 1, Kyauk Phyu, are as follows:

- NOAA WW3 GP1 (Waves): 19.00°N, 093.50°E.
- NOAA WW3 GP2 (Waves): 19.00°N, 093.00°E.
- NOAA WW3 GP3 (Waves): 19.50°N, 093.00°E.
- NOAA WW3 GP4 (Wind): 19.50°N, 093.50°E.

**Figure 89 - Location 2 - Nga Yoke Kaung: model data used as inputs**

The grid points used to force the model for Location 2, Nga Yoke Kaung, are as follows:

- NOAA WW3 GP1 (Waves): 16.00°N, 094.00°E.
- NOAA WW3 GP2 (Waves): 16.50°N, 094.00°E.
- NOAA WW3 GP3 (Waves and wind): 17.00°N, 094.00°E.

**Figure 90 - Location 3 - Kalagut Island: model data used as inputs**


The grid points used to force the model for Location 3, Kalagut Island, are as follows:

- NOAA WW3 GP1 (Waves): 15.00°N, 097.50°E.
- NOAA WW3 GP2 (Waves): 15.00°N, 097.00°E.
- NOAA WW3 GP3 (Waves): 15.50°N, 097.00°E.
- NOAA WW3 GP4 (Waves): 16.00°N, 097.00°E.
- NOAA WW3 GP5 (Waves): 16.00°N, 097.50°E.
- NOAA WW3 GP6 (Wind): 15.50°N, 097.50°E.

### A.6.4 Computational grid and bathymetry

Due to the lack of detailed bathymetric information in any of the interest areas, the General Bathymetric Chart of the Oceans (GEBCO [8]) was used to retrieve the bathymetric information necessary to set up the SWAN numerical model.

A key aspect of any numerical exercise is the definition of the grid used to perform the spatial discretisation. SWAN allows the use structured grids that may be rectilinear and uniform or curvilinear, and they always consist of quadrilaterals in which the number of grid cells that meet each other in an internal grid point is 4.

For this study a rectilinear and uniform grid has been used for each area, with a resolution of 0.00833x0.00833°.
Defining the model's grid required consideration of the following:

- Adequate resolution of the bathymetry and wave fields. This is very important in the coastal areas, where the more complex bathymetry undoubtedly affects the physical conditions.
- The need for computational efficiency to achieve timely delivery of the study results.

The resultant computational grid, obtained by interpolating the bathymetric information from GEBCO into the model's grid, are shown below.

**Figure 91 - Location 1 - Kyauk Phyu: Wave model's computational grid**

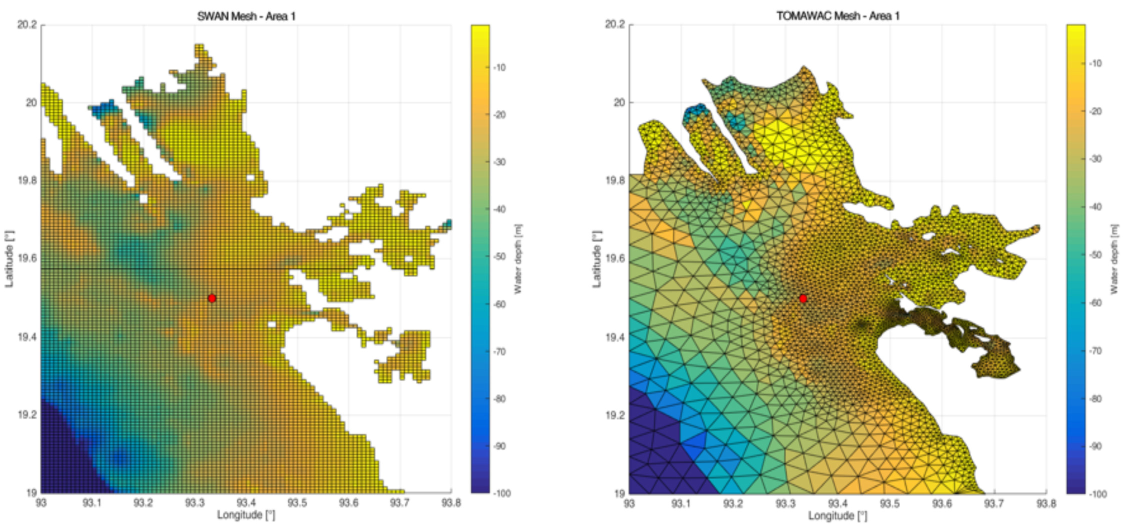



**Figure 92 - Location 2 - Nga Yoke Kaung: Wave model's computational grids**

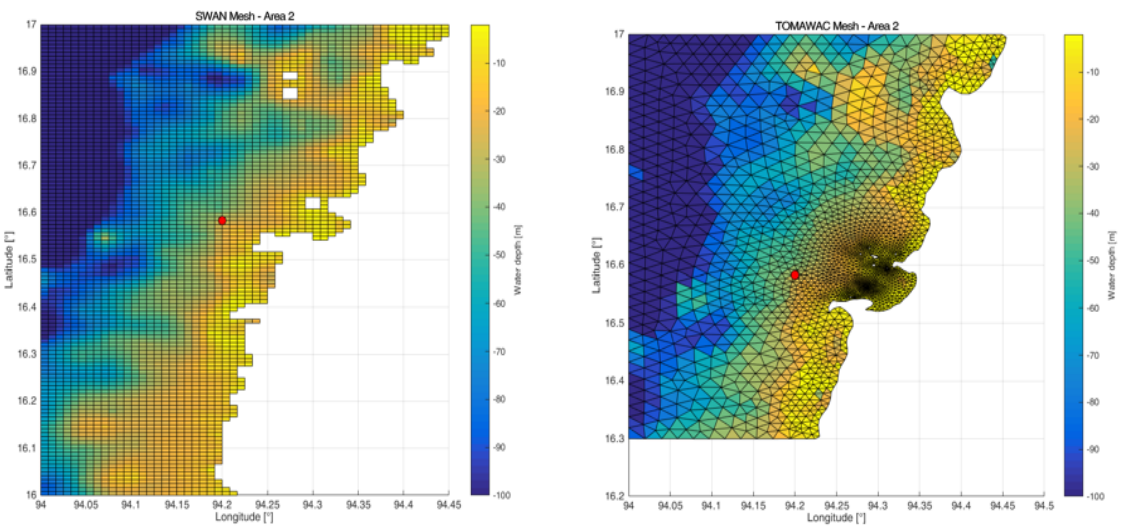
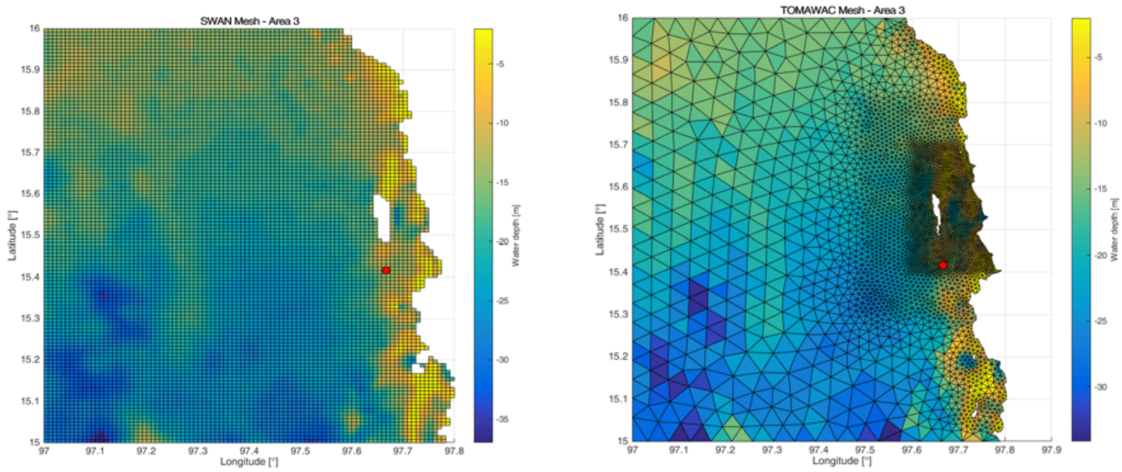


**Figure 93 - Location 3 - Kalagut Island: Wave model's computational grids**



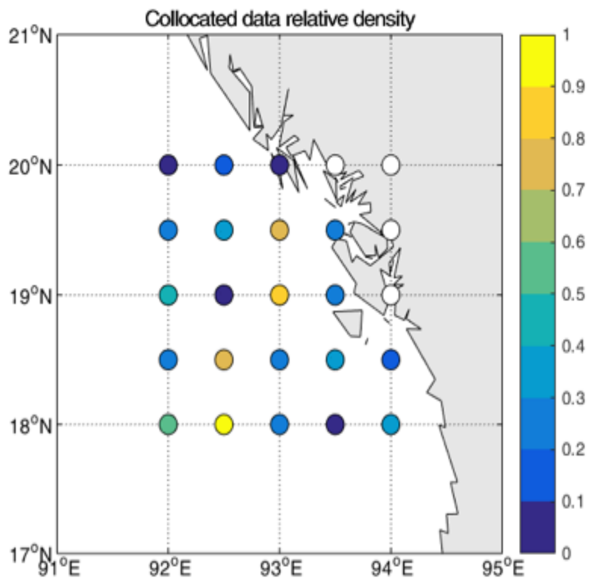

## A.6.4.1 Boundary conditions calibration

The wave model was run in each interest Location for a 20 years long period using the wave and wind time series retrieved from NOAA (described in A.4.1.1) as input along the open boundaries, as shown.

Before using NOAA's waves and winds as input to the wave model, they were verified against satellite measurements (described in A.4.1.2 ) showing, in general, a very good agreement for both waves and winds.

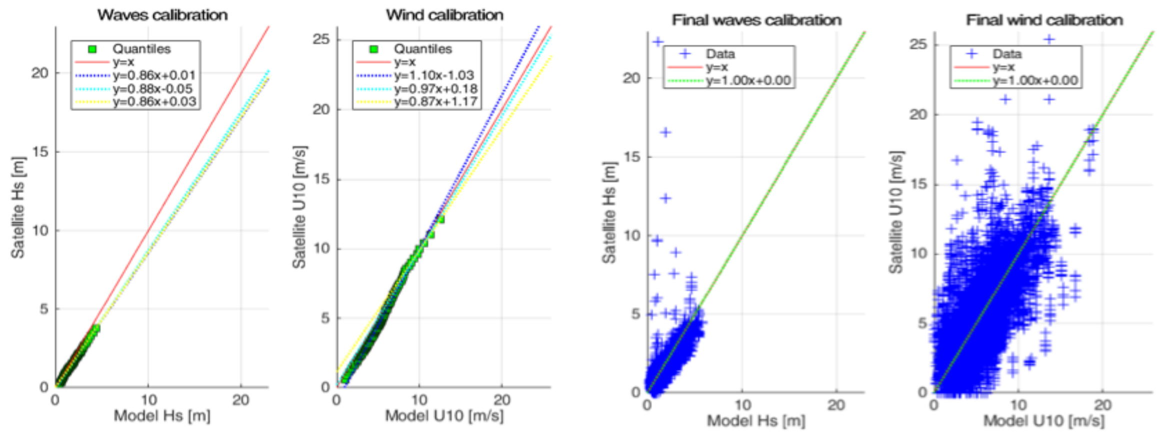
The relative co-located data density per grid point, as well as the co-located wave and wind data from the NOAA WWIII 30-min global model and merged satellite data, and the Q-Q plots for each one of the interest Locations are shown in the figures below.

**Figure 94 - Location 1 – Kyauk Phyu: Co-located satellite-model data relative density**



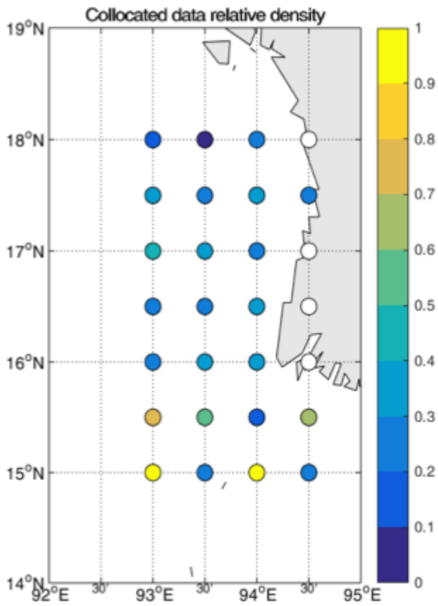
The quantile-quantile plots used to analyse the correlation between the two datasets are shown below, as well as the scatter plots of co-located data.

**Figure 95 - Location 1 – Kyauk Phyu: Satellite-model data – QQ and scatter plots**



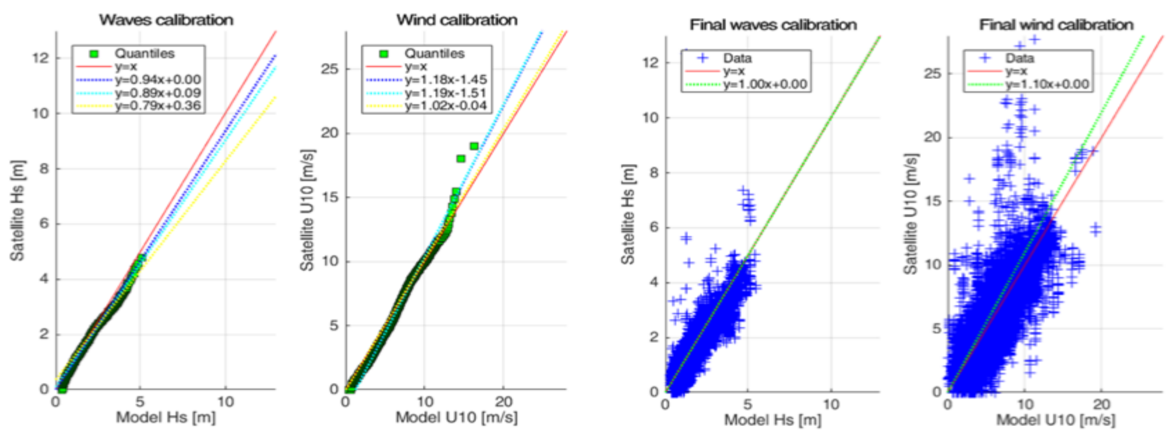

As can be seen in the figure above, with the exception of some disputable satellite data, the wave from the model seems to be slightly over-estimated, and the modelled wind speed is overall in line with the remote measurements. Therefore, it was chosen not to alter neither the model waves nor wind.

**Figure 96 - Location 2 - Nga Yoke Kaung: Co-located satellite-model data relative density**



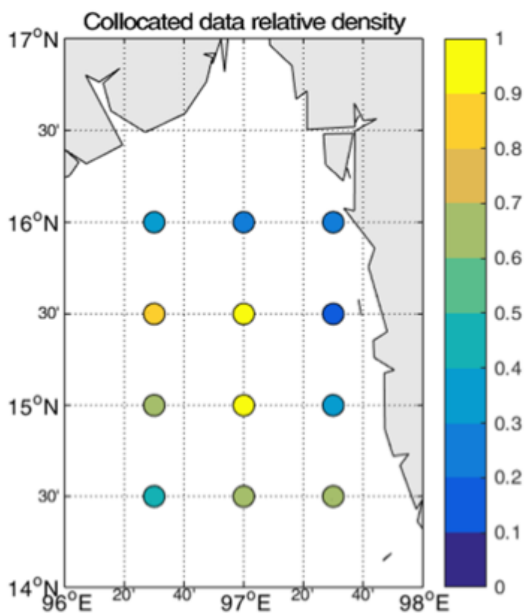

The quantile-quantile plots used to analyse the correlation between the two datasets are shown below, as well as the scatter plots of co-located data.

**Figure 97 - Location 2 - Nga Yoke Kaung: Satellite-model data – QQ and scatter plots**



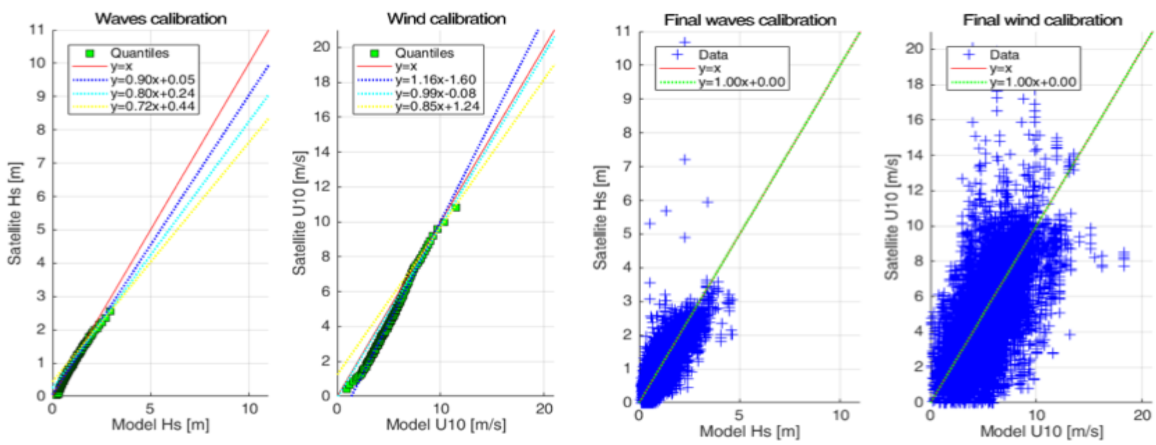

As can be seen in the figure above, with the exception of some disputable satellite data, the wave from the model seems to be slightly over-estimated whilst the highest winds seem to be a bit on the low side. Therefore, it was chosen to uplift 10% the winds above 14 m/s in this area.

**Figure 98 - Location 3 - Kalagut Island: Co-located satellite-model data relative density**




The quantile-quantile plots used to analyse the correlation between the two datasets are shown below, as well as the scatter plots.

**Figure 99 - Location 3 - Kalagut Island: Satellite-model data – QQ and scatter plots**




As can be seen in the figure above, the correlation between model and satellite data is very good in Location 3 too, with model waves slightly over-estimated and the modelled wind speed is overall in line with the remote measurements. Therefore, it was chosen not to alter neither the model waves nor wind.

The calibrated NOAA's wave time series were used as input along the open boundaries of the model. The winds were input as time varying maps of spatially constant wind speeds and directions across the model's domain.

### A.6.4.2 Model setup summary

A regular computational grid with the same spatial resolution as the bathymetric data, i.e. 0.00833x0.00833° (about 800-900m), was used. The model was forced by NOAA WW3 data as follows:

- Open boundaries: time series of Hs, Tp, direction and directional spreading for period 01-01-1990 00:00:00 to 31-12-2009 21:00:00, varying in time and along boundaries.
- Over whole area: time series of Eastward and Northward wind speed components for period 01-01-1990 00:00:00 to 31-12-2009 21:00:00, varying in time and constant over the area.

The wave spectrum was setup as follows:

- JONSWAP spectrum.
- 16 sectors directional discretization.
- Minimum spectral frequency equal to 0.04 (25 seconds).
- Frequential ratio of 1.1, and 25 frequencies.

The model physics applied were:

- Exponential wind-wave growth following Komen formulation (1984).
- Whitecapping following Komen et al. formulation (1984).
- Inclusion of non-linear quadruplet wave interactions (fully explicit DIA per sweep).
- Inclusion of triad wave-wave interactions following Eldeberky formulation (1996).
- Inclusion of depth-induced wave breaking.
- Bottom friction using Hasselman et al. formulation (1973).

The BSBT numerical scheme was used for computation, non-stationary mode with a 3-hour time step.

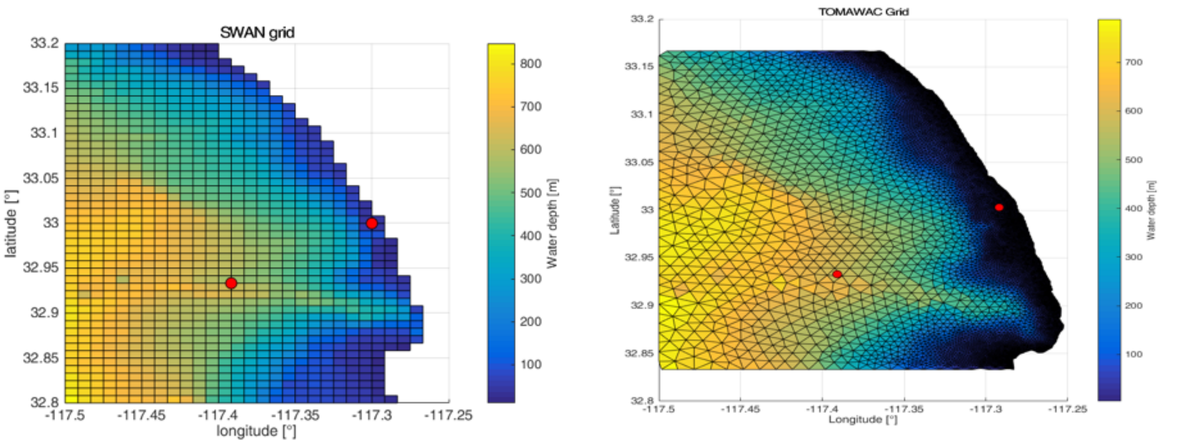
### A.6.4.3 Model verification

No measured data within the area of interests was available to calibrate the results from the model. However, a quick check using the same setup was run for a small area offshore San Diego, California, USA. Two buoys have been used to cross check results from the models:

- NDBC station 46225: 32.933°N 117.391°W, in water depth of 550m.
- NDBC station 46241: 33.003°N 117.292°W, in water depth of 20m.

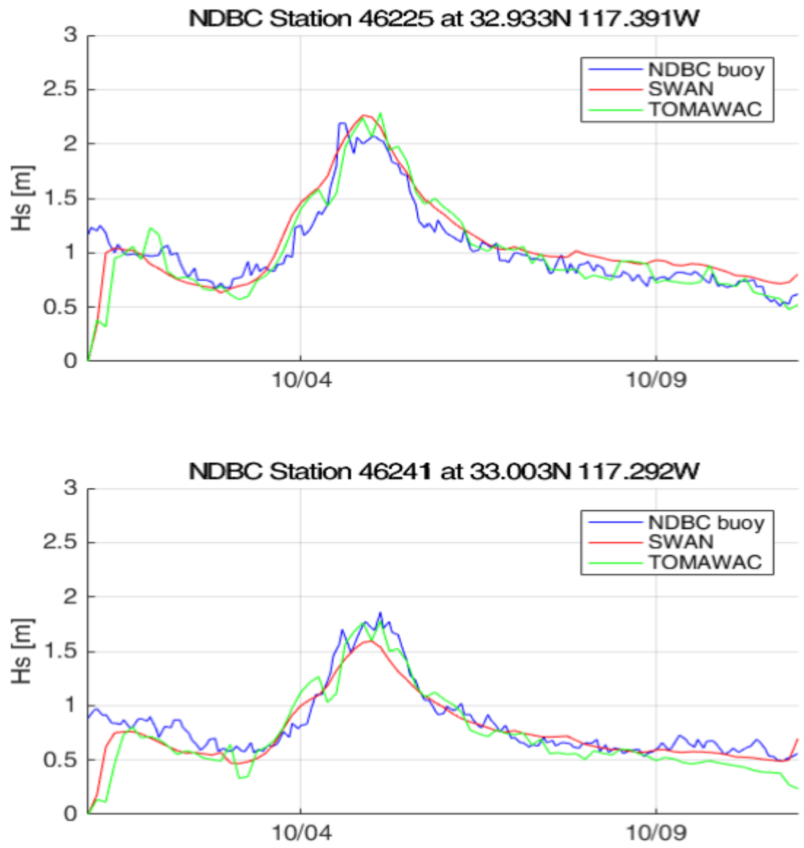
The grid used are shown in, the location of the buoys is indicated by the red dots within the figures below.

**Figure 100 - Offshore San Diego – SWAN and TOMAWAC grids**




Both models were run for 10 days, from the 1st to the 10th of October 2009. Results are shown in the figure above.

**Figure 101 - Offshore San Diego – Comparison Model-Buoy - Hs**




The purpose of that quick exercise is to demonstrate the ability of the models to represent coastal waves. It should be noted that this was done using the same bathymetric data, which is too coarse to accurately represent the near coast areas.

Then, two main conclusions can be drawn:

- Using a more refined resolution in an attempt to represent the coast doesn't improve the results due to the lack of detailed bathymetric data.
- Although both models seem to give fairly similar results, SWAN appears to be more stable to run long-term wave climate.
- Overall, models are performing well-enough for preliminary results purposes.

If the need of more accurate results arises, it is strongly recommended to use detailed bathymetric information of the area of interest.

## A.6.5 Derivation of Results

### A.6.5.1 Locations of interest

Time series from the SWAN model's runs were extracted at three grid points, one per area. The coordinates of these locations of interest (LOI) are as follows:

- Location 1, Kyauk Phyu, LOI: 19.50°N 093.33°E, WD=23m.

- Location 2, Nga Yoke Kaung, LOI: 16.58°N 094.20°E, WD=30m.
- Location 3, Kalagut Island, LOI: 15.42°N 097.66°E, WD=14m.

### A.6.5.2 Removal of cyclonic data

Global hindcast models generally provide a poor representation of cyclones and therefore, cyclonic data within the hindcast data have been removed prior to using it to derive waiting on weather and fatigue data.

Tracks of the cyclones that occurred within the simulation's period (1st January 1990 to 31st December 2009) have been downloaded from IBTrACS. Subsequently, cyclones within a radius of 5 degrees have been identified and corresponding records in the model output removed. The radius has been adjusted to remove the entire peak due to a tropical cyclone by visual inspection of the data.

**Figure 102 - Location 1 – Hs time series at LOI**

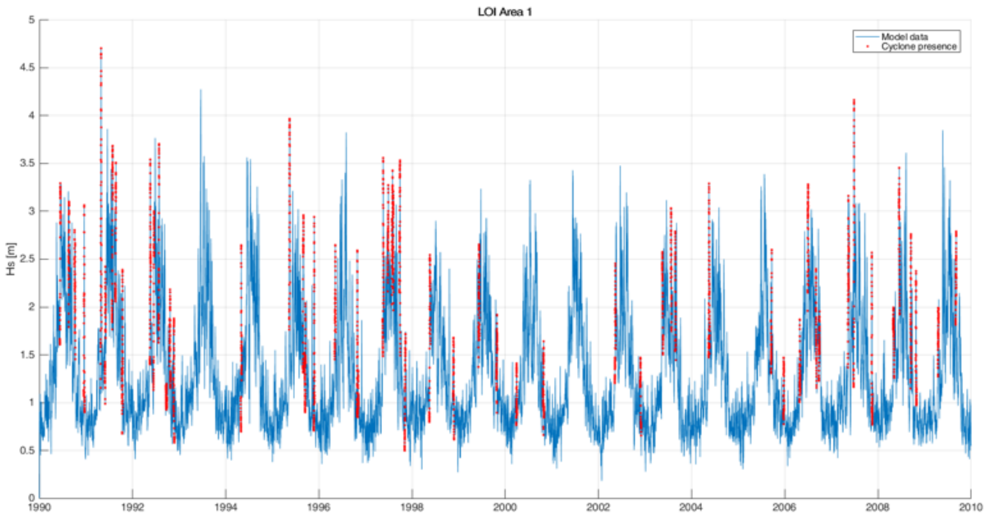


**Figure 103 - Locations 1 – U10 time series at LOI**

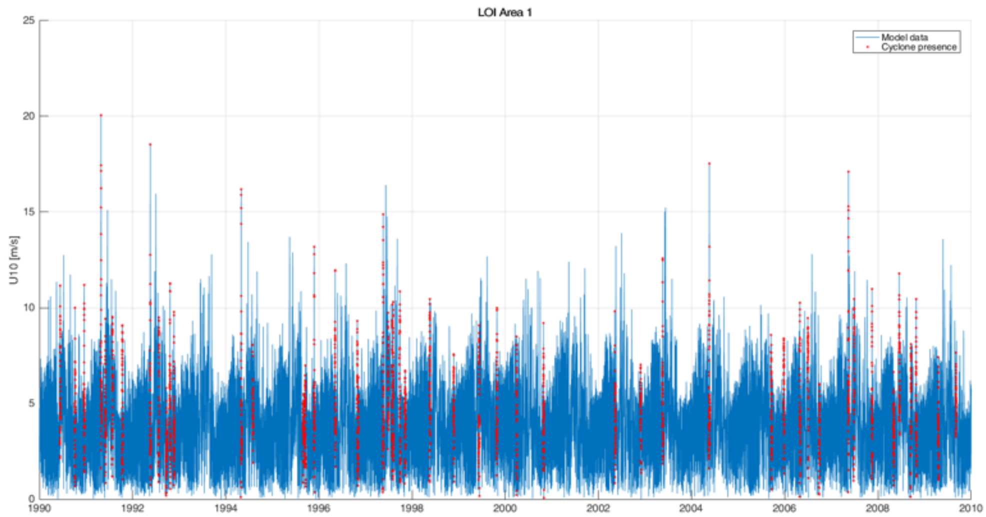



**Figure 104 - Location 2 – Hs time series at LOI**

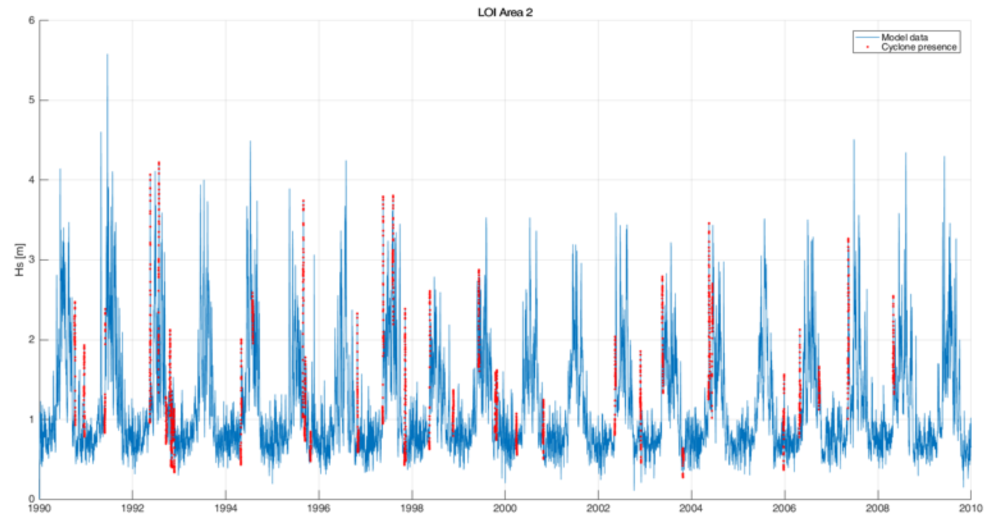


**Figure 105 - Location 2 – U10 time series at LOI**

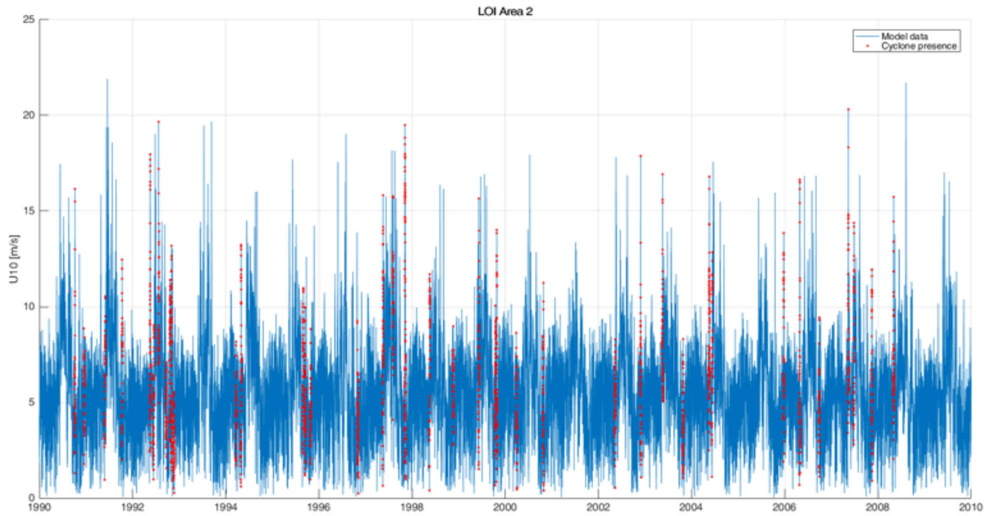



**Figure 106 - Location 3 – Hs time series at LOI**

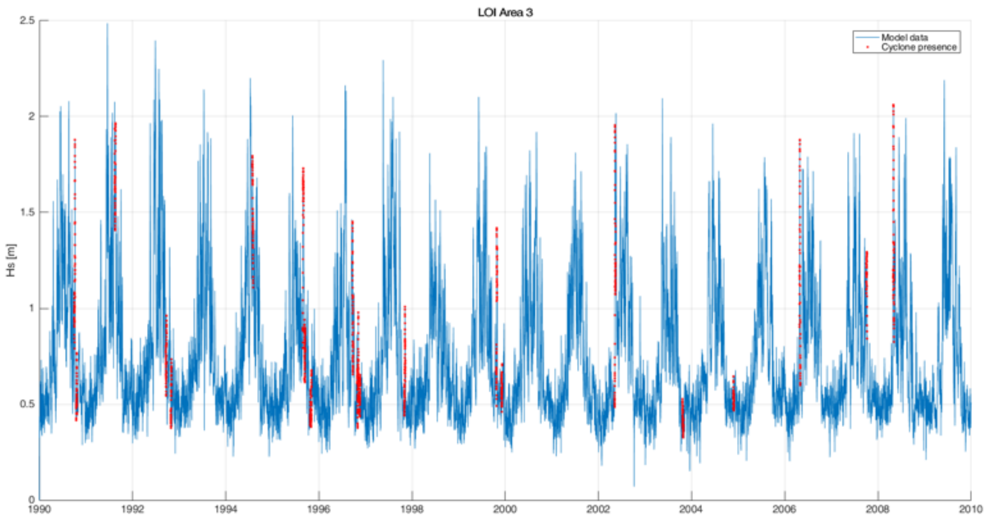
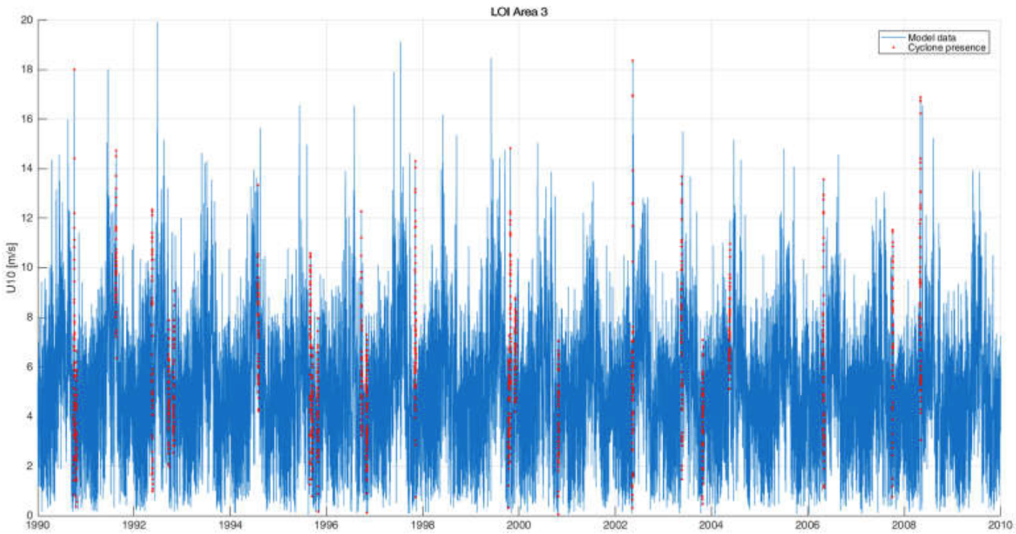


**Figure 107 - Location 3 – U10 time series at LOI**




## A.6.5.3 Waiting on weather

Once the cyclone data is removed from the modelled waves at each of the extracted time series the waiting on weather statistics were carried out.
Three different analysis were carried out to obtain the following statistics:

- The monthly waiting times associated with different levels of probability.
- The monthly probabilities of waiting times being longer than specific durations (24, 48 and 72 hours).
- The monthly maximum waiting time for the 20 years long period analysed.

The waiting on weather investigates the total waiting time necessary in order to be able to complete an operation. With an operation defined by the limiting threshold of significant wave height and the required time to complete it.

For each month and time step of the hindcast time series, the time series is checked looking for windows that fulfil the metocean criteria and duration required to complete the operation. The time elapsed between the starting time step and the end of the operation is then calculated.

This process is repeated for each time step of the time series, i.e. the operation can start at any time, and once the waiting times are obtained the results are analysed to produce the monthly waiting times associated with each of the standard probabilities (50%,75%, etc) , the monthly probability of waiting times being longer than specific durations and the maximum waiting times respectively.

Results for the waiting times associated with standard probabilities for Hs<1.75m are shown in the tables below. The rest of the results obtained from the waiting on weather analysis are presented in the embedded Excel spreadsheets "WOW_LOIs.xslx" and "WOW_LOIs_Waves_2.xslx".

## A.7 Results

### A.7.1 Monthly waiting times associated with standard probability levels

#### A.7.1.1 Location 1 – Kyauk Phyu

**Figure 108 - Location 1 – Waiting on weather – Hs <= 1.75**

Area 1 - 19.4998°N 093.3332°E - Water depth = 23m
Waiting time [hrs] - Hs <= 1.75 m

3-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 163 | 226 | 990 | 739 | 410 | 180 | 195 | 155 | 91 |
| | 95% | 0 | 0 | 0 | 4 | 164 | 579 | 491 | 308 | 125 | 102 | 70 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 117 | 424 | 379 | 237 | 86 | 22 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 33 | 217 | 223 | 132 | 21 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 57 | 74 | 34 | 0 | 0 | 0 | 0 |

6-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 166 | 231 | 1023 | 742 | 413 | 183 | 198 | 158 | 94 |
| | 95% | 0 | 0 | 0 | 8 | 170 | 583 | 500 | 310 | 128 | 105 | 72 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 122 | 431 | 386 | 239 | 89 | 27 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 38 | 223 | 230 | 137 | 24 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 67 | 81 | 39 | 0 | 0 | 0 | 0 |

12-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 172 | 301 | 1176 | 982 | 497 | 190 | 202 | 164 | 100 |
| | 95% | 0 | 0 | 0 | 18 | 199 | 889 | 611 | 360 | 135 | 111 | 78 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 144 | 643 | 469 | 282 | 96 | 32 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 49 | 300 | 292 | 162 | 33 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 97 | 126 | 53 | 0 | 0 | 0 | 0 |

24-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 188 | 445 | 1451 | 1045 | 565 | 222 | 211 | 176 | 112 |
| | 95% | 0 | 0 | 0 | 42 | 283 | 1250 | 782 | 432 | 158 | 121 | 88 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 206 | 968 | 605 | 350 | 123 | 42 | 7 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 86 | 523 | 374 | 221 | 55 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 189 | 177 | 87 | 0 | 0 | 0 | 0 |

48-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 43 | 212 | 2029 | 2010 | 1297 | 730 | 312 | 232 | 208 | 136 |
| | 95% | 0 | 0 | 0 | 86 | 492 | 1688 | 1060 | 573 | 208 | 141 | 115 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 362 | 1415 | 885 | 486 | 161 | 64 | 31 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 153 | 623 | 544 | 319 | 85 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 274 | 277 | 144 | 0 | 0 | 0 | 0 |

72-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 67 | 264 | 2077 | 2208 | 1711 | 1084 | 513 | 302 | 228 | 160 |
| | 95% | 0 | 0 | 0 | 118 | 1326 | 1893 | 1478 | 773 | 353 | 184 | 132 | 0 |
| | 90% | 0 | 0 | 0 | 11 | 720 | 1559 | 1281 | 631 | 238 | 109 | 52 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 229 | 860 | 758 | 413 | 123 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 14 | 422 | 402 | 196 | 12 | 0 | 0 | 0 |

96-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 91 | 456 | 2782 | 2271 | 1825 | 1084 | 537 | 315 | 250 | 184 |
| | 95% | 0 | 0 | 0 | 152 | 2046 | 1960 | 1516 | 814 | 390 | 204 | 152 | 0 |
| | 90% | 0 | 0 | 0 | 52 | 1260 | 1736 | 1321 | 674 | 286 | 128 | 70 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 321 | 1125 | 960 | 454 | 161 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 49 | 563 | 599 | 242 | 34 | 0 | 0 | 0 |

## A.7.1.2 Location 2 – Nga Yoke Kaung

**Figure 109 - Location 2 – Waiting on weather – Hs <= 1.75m**

**Area 2 - 16.5831°N 094.1999°E - Water depth = 30m**
**Waiting time [hrs] - Hs <= 1.75 m**

3-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 147 | 211 | 642 | 569 | 376 | 138 | 176 | 165 | 82 |
| | 95% | 0 | 0 | 0 | 0 | 133 | 336 | 398 | 259 | 79 | 90 | 58 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 83 | 246 | 285 | 194 | 44 | 8 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 0 | 123 | 133 | 85 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 12 | 19 | 6 | 0 | 0 | 0 | 0 |

6-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 150 | 215 | 645 | 582 | 385 | 140 | 179 | 168 | 85 |
| | 95% | 0 | 0 | 0 | 0 | 136 | 378 | 420 | 288 | 82 | 94 | 60 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 86 | 275 | 288 | 218 | 48 | 11 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 0 | 141 | 141 | 98 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 19 | 24 | 10 | 0 | 0 | 0 | 0 |

12-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 156 | 251 | 1167 | 728 | 413 | 145 | 186 | 173 | 91 |
| | 95% | 0 | 0 | 0 | 0 | 153 | 827 | 544 | 306 | 94 | 102 | 63 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 100 | 403 | 385 | 243 | 59 | 19 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 5 | 181 | 173 | 119 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 33 | 37 | 18 | 0 | 0 | 0 | 0 |

24-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 168 | 289 | 1179 | 734 | 477 | 170 | 200 | 181 | 103 |
| | 95% | 0 | 0 | 0 | 0 | 186 | 839 | 551 | 384 | 111 | 120 | 69 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 124 | 522 | 419 | 311 | 74 | 34 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 21 | 244 | 207 | 170 | 6 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 64 | 59 | 40 | 0 | 0 | 0 | 0 |

48-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 61 | 192 | 721 | 1203 | 836 | 557 | 243 | 229 | 197 | 127 |
| | 95% | 0 | 0 | 0 | 0 | 250 | 930 | 667 | 442 | 157 | 149 | 82 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 175 | 695 | 564 | 371 | 110 | 60 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 50 | 398 | 294 | 227 | 30 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 136 | 110 | 83 | 0 | 0 | 0 | 0 |

72-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 85 | 216 | 985 | 1227 | 897 | 662 | 267 | 261 | 215 | 151 |
| | 95% | 0 | 0 | 0 | 0 | 642 | 955 | 753 | 520 | 183 | 173 | 96 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 294 | 731 | 654 | 443 | 129 | 87 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 94 | 461 | 429 | 289 | 50 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 213 | 178 | 120 | 0 | 0 | 0 | 0 |

96-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 109 | 240 | 1870 | 1509 | 1393 | 749 | 371 | 478 | 233 | 175 |
| | 95% | 0 | 0 | 0 | 50 | 1080 | 1209 | 917 | 589 | 243 | 265 | 110 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 495 | 1015 | 752 | 505 | 185 | 147 | 5 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 137 | 643 | 524 | 338 | 81 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 332 | 249 | 148 | 0 | 0 | 0 | 0 |

### A.7.1.3 Location 3 – Kalagut Island

**Figure 110 - LOCATION 3 – WAITING ON WEATHER – HS <= 1.75M**

**Area 3 - 15.4165°N 097.66642°E - Water depth = 14m**
**Waiting time [hrs] - Hs <= 1.75 m**

3-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 69 | 94 | 74 | 104 | 103 | 117 | 202 | 125 | 4 |
| | 95% | 0 | 0 | 0 | 0 | 0 | 7 | 14 | 12 | 0 | 94 | 8 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

6-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 75 | 95 | 77 | 107 | 106 | 120 | 205 | 126 | 7 |
| | 95% | 0 | 0 | 0 | 0 | 0 | 10 | 18 | 15 | 0 | 99 | 9 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

12-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 87 | 98 | 83 | 113 | 112 | 126 | 211 | 129 | 13 |
| | 95% | 0 | 0 | 0 | 0 | 0 | 16 | 25 | 24 | 0 | 107 | 11 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

24-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 111 | 104 | 95 | 125 | 131 | 144 | 223 | 135 | 25 |
| | 95% | 0 | 0 | 0 | 0 | 3 | 29 | 41 | 40 | 10 | 120 | 15 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

48-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 150 | 190 | 122 | 186 | 155 | 179 | 247 | 152 | 29 |
| | 95% | 0 | 0 | 0 | 0 | 25 | 55 | 80 | 64 | 34 | 144 | 28 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 0 | 8 | 35 | 13 | 0 | 27 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

72-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 174 | 214 | 160 | 243 | 199 | 204 | 271 | 176 | 29 |
| | 95% | 0 | 0 | 0 | 0 | 47 | 83 | 116 | 90 | 60 | 166 | 42 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 0 | 34 | 64 | 37 | 0 | 54 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

96-hour window

| | % Non-exc. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.75 m | 99% | 0 | 0 | 0 | 198 | 238 | 184 | 267 | 253 | 228 | 295 | 194 | 29 |
| | 95% | 0 | 0 | 0 | 0 | 71 | 105 | 152 | 122 | 91 | 192 | 56 | 0 |
| | 90% | 0 | 0 | 0 | 0 | 0 | 57 | 94 | 64 | 0 | 83 | 0 | 0 |
| | 75% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 50% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## A.7.2 Fatigue tables and rosettes

### A.7.2.1 Location 1 – Kyauk Phyu

***Waves***

**Figure 111 - LOCATION 1 - OCCURRENCES HS VS. DIRECTION - ALL-YEAR**

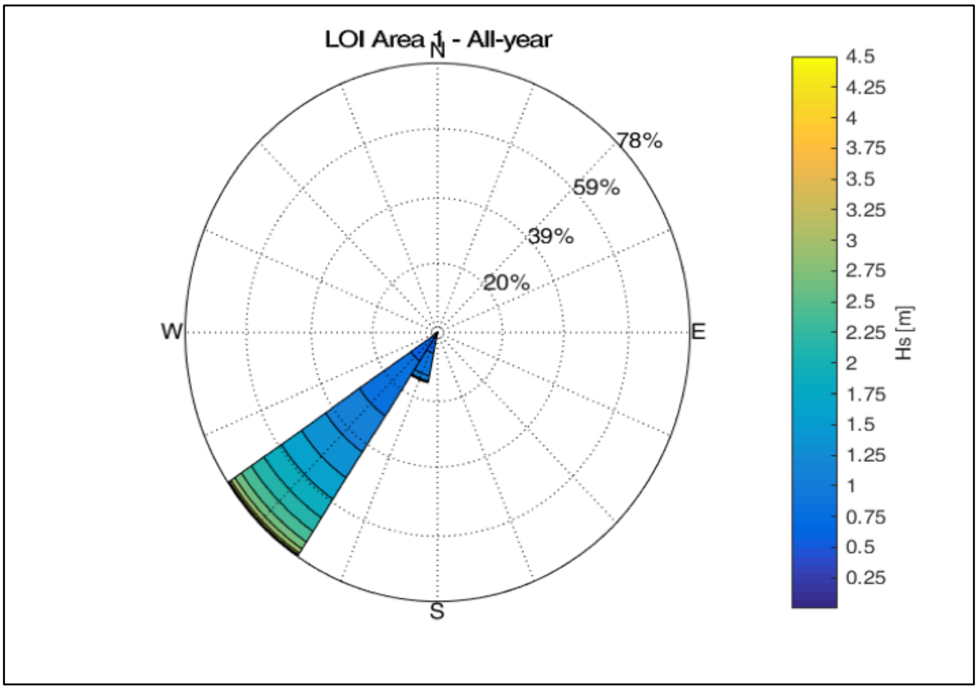
Area 1 - 19.4998°N 093.3332°E - Water depth = 23m
All-year

| Occurences Hs [m] | Direction From N | NE | E | SE | S | SW | W | NW | Total |
|---|---|---|---|---|---|---|---|---|---|
| 4.75 - 5.00 | | | | | | | | | |
| 4.50 - 4.75 | | | | | | | | | |
| 4.25 - 4.50 | | | | | | 1 | | | 1 |
| 4.00 - 4.25 | | | | | | 17 | | | 17 |
| 3.75 - 4.00 | | | | | | 16 | | | 16 |
| 3.50 - 3.75 | | | | | | 58 | | | 58 |
| 3.25 - 3.50 | | | | | | 151 | | | 151 |
| 3.00 - 3.25 | | | | | | 372 | | | 372 |
| 2.75 - 3.00 | | | | | | 863 | 4 | | 867 |
| 2.50 - 2.75 | | | | | | 1456 | 2 | | 1458 |
| 2.25 - 2.50 | | | | | | 2205 | 1 | | 2206 |
| 2.00 - 2.25 | | | | | | 2798 | 5 | | 2803 |
| 1.75 - 2.00 | | | | | | 3810 | 15 | | 3825 |
| 1.50 - 1.75 | | | | | | 4474 | 22 | | 4496 |
| 1.25 - 1.50 | | | | | | 5521 | 25 | 3 | 5549 |
| 1.00 - 1.25 | | | | | 47 | 8228 | 37 | 1 | 8313 |
| 0.75 - 1.00 | | | | | 442 | 14773 | 31 | 3 | 15249 |
| 0.50 - 0.75 | | | | 5 | 590 | 8600 | 54 | 20 | 9269 |
| 0.25 - 0.50 | | | | 4 | 90 | 400 | 81 | 21 | 596 |
| 0.00 - 0.25 | | | | | | 1 | 1 | 5 | 7 |
| Total | | | | 9 | 1169 | 53744 | 278 | 53 | 55253 |

**Figure 112 - Location 1 - % Exceedance Hs vs. direction - All-year**

| Area 1 - 19.4998°N 093.3332°E - Water depth = 23m All-year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| % Exceedence | Direction From | | | | | | | | Total |
| Hs [m] | N | NE | E | SE | S | SW | W | NW | |
| 4.75 | . | . | . | . | . | . | . | . | . |
| 4.50 | . | . | . | . | . | . | . | . | . |
| 4.25 | . | . | . | . | . | . | . | . | . |
| 4.00 | . | . | . | . | . | . | . | . | . |
| 3.75 | . | . | . | . | . | .1 | . | . | .1 |
| 3.50 | . | . | . | . | . | .2 | . | . | .2 |
| 3.25 | . | . | . | . | . | .4 | . | . | .4 |
| 3.00 | . | . | . | . | . | 1.1 | . | . | 1.1 |
| 2.75 | . | . | . | . | . | 2.7 | . | . | 2.7 |
| 2.50 | . | . | . | . | . | 5.3 | . | . | 5.3 |
| 2.25 | . | . | . | . | . | 9.3 | . | . | 9.3 |
| 2.00 | . | . | . | . | . | 14.4 | . | . | 14.4 |
| 1.75 | . | . | . | . | . | 21.3 | . | . | 21.3 |
| 1.50 | . | . | . | . | . | 29.4 | .1 | . | 29.4 |
| 1.25 | . | . | . | . | . | 39.3 | .1 | . | 39.5 |
| 1.00 | . | . | . | . | .1 | 54.2 | .2 | . | 54.5 |
| 0.75 | . | . | . | . | .9 | 81. | .3 | . | 82.1 |
| 0.50 | . | . | . | . | 2. | 96.5 | .4 | . | 98.9 |
| 0.25 | . | . | . | . | 2.1 | 97.3 | .5 | .1 | 100. |
| 0.00 | . | . | . | . | 2.1 | 97.3 | .5 | .1 | 100. |

**Figure 113 - – Location 1 – Wave rose – All-year**



## Figure 114 - – Location 1 - Occurrences Hs vs. Tp - All-year

Area 1 - 19.4998°N 093.3332°E - Water depth = 23m
All-year

| Occurences Hs [m] | Peak period Tp [s] 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 | 20-21 | 21-22 | 22-23 | 23-24 | 24-25 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.75 - 5.00 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.50 - 4.75 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.25 - 4.50 | | | | | | | | | | | 1 | | | | | | | | | | | | | | | 1 |
| 4.00 - 4.25 | | | | | | | | | | | 7 | 10 | | | | | | | | | | | | | | 17 |
| 3.75 - 4.00 | | | | | | | | | | | 4 | 6 | 4 | | | | 2 | | | | | | | | | 16 |
| 3.50 - 3.75 | | | | | | | | | | 2 | 10 | 32 | 1 | | | 1 | 8 | 1 | 3 | | | | | | | 58 |
| 3.25 - 3.50 | | | | | | | | | | 15 | 56 | 44 | 1 | | 6 | 8 | 13 | 2 | 4 | 2 | | | | | | 151 |
| 3.00 - 3.25 | | | | | | | | | 2 | 81 | 120 | 55 | 3 | | 40 | 13 | 35 | 6 | 12 | 3 | 2 | | | | | 372 |
| 2.75 - 3.00 | | | | | | | | | 5 | 275 | 178 | 53 | 6 | 4 | 124 | 38 | 118 | 22 | 27 | 15 | 1 | 1 | | | | 867 |
| 2.50 - 2.75 | | | | | | | | | 100 | 546 | 128 | 27 | 14 | 25 | 229 | 75 | 202 | 44 | 50 | 13 | 5 | | | | | 1458 |
| 2.25 - 2.50 | | | | | | | | | 417 | 521 | 109 | 20 | 44 | 74 | 416 | 116 | 303 | 66 | 99 | 16 | 3 | 2 | | | | 2206 |
| 2.00 - 2.25 | | | | | | | | 40 | 600 | 344 | 39 | 18 | 165 | 171 | 619 | 149 | 412 | 100 | 93 | 34 | 10 | 7 | 2 | | | 2803 |
| 1.75 - 2.00 | | | | | | | | 129 | 570 | 268 | 39 | 45 | 343 | 237 | 1069 | 235 | 580 | 122 | 125 | 44 | 7 | 12 | | | | 3825 |
| 1.50 - 1.75 | | | | | | | 1 | 285 | 357 | 146 | 19 | 76 | 603 | 431 | 1339 | 287 | 626 | 118 | 130 | 53 | 8 | 16 | 1 | | | 4496 |
| 1.25 - 1.50 | | | | | | | 15 | 180 | 115 | 99 | 48 | 194 | 1016 | 569 | 1748 | 335 | 832 | 155 | 165 | 51 | 8 | 15 | 3 | 1 | | 5549 |
| 1.00 - 1.25 | | | | | | 1 | 35 | 47 | 52 | 58 | 50 | 393 | 2083 | 976 | 2630 | 462 | 1099 | 191 | 172 | 52 | 7 | 5 | | | | 8313 |
| 0.75 - 1.00 | | | | 1 | 1 | 9 | 17 | 8 | 26 | 45 | 89 | 1532 | 4842 | 1836 | 4306 | 617 | 1317 | 265 | 226 | 68 | 16 | 27 | 1 | | | 15249 |
| 0.50 - 0.75 | | | 6 | 14 | 32 | 55 | 16 | 25 | 35 | 75 | 235 | 2249 | 3130 | 846 | 1632 | 228 | 460 | 113 | 85 | 22 | 5 | 4 | 2 | | | 9269 |
| 0.25 - 0.50 | | | 21 | 17 | 87 | 11 | 3 | 5 | 7 | 26 | 31 | 156 | 126 | 18 | 65 | 9 | 8 | 1 | 5 | | | | | | | 596 |
| 0.00 - 0.25 | | | | 6 | | | | | | | | | 1 | | | | | | | | | | | | | 7 |
| Total | | | 27 | 38 | 120 | 76 | 87 | 719 | 2286 | 2501 | 1163 | 4910 | 12382 | 5187 | 14223 | 2573 | 6015 | 1206 | 1196 | 373 | 72 | 89 | 9 | 1 | | 55253 |

### *Wind*

## Figure 115 - LOCATION 1 - OCCURRENCES U10 VS. DIRECTION - ALL-YEAR

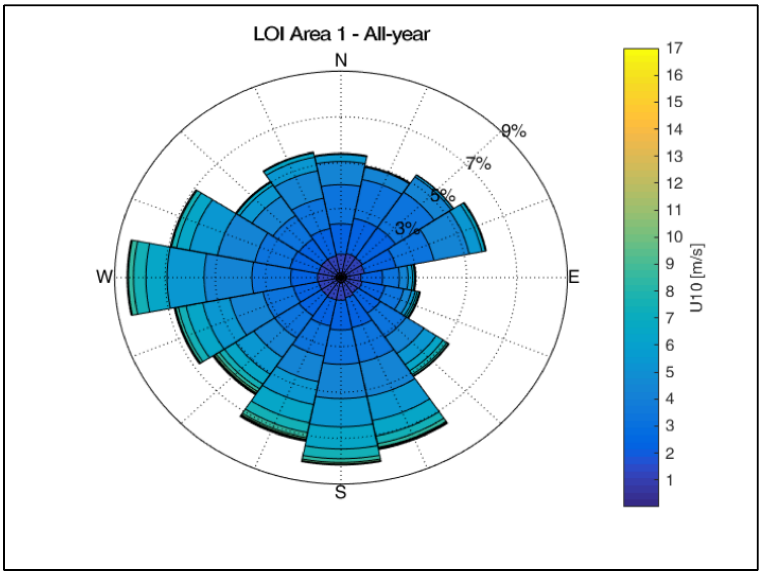
Area 1 - 19.4998°N 093.3332°E - Water depth = 23m
All-year

| Occurences Hourly U10 [m/s] | Direction From N | NE | E | SE | S | SW | W | NW | Total |
|---|---|---|---|---|---|---|---|---|---|
| 21.0 - 22.0 | | | | | | | | | |
| 20.0 - 21.0 | | | | | | | | | |
| 19.0 - 20.0 | | | | | | | | | |
| 18.0 - 19.0 | | | | | | | | | |
| 17.0 - 18.0 | | | | | | | | | |
| 16.0 - 17.0 | | | | | | 1 | | | 1 |
| 15.0 - 16.0 | | | | | | 3 | | 1 | 4 |
| 14.0 - 15.0 | | | | | 2 | | | 1 | 3 |
| 13.0 - 14.0 | | | | | 2 | 4 | | | 6 |
| 12.0 - 13.0 | | | | 4 | 12 | 11 | 1 | | 28 |
| 11.0 - 12.0 | | | | 9 | 15 | 27 | | | 51 |
| 10.0 - 11.0 | 1 | | 3 | 13 | 25 | 45 | 8 | 2 | 97 |
| 9.0 - 10.0 | | | 8 | 25 | 68 | 86 | 35 | 4 | 226 |
| 8.0 - 9.0 | | 4 | 19 | 84 | 206 | 178 | 162 | 25 | 678 |
| 7.0 - 8.0 | 9 | 7 | 44 | 213 | 475 | 326 | 473 | 86 | 1633 |
| 6.0 - 7.0 | 62 | 44 | 114 | 378 | 1005 | 662 | 942 | 279 | 3486 |
| 5.0 - 6.0 | 378 | 198 | 312 | 669 | 1315 | 1071 | 1622 | 803 | 6368 |
| 4.0 - 5.0 | 1167 | 1073 | 648 | 1013 | 1714 | 1230 | 2032 | 1312 | 10189 |
| 3.0 - 4.0 | 1922 | 2104 | 967 | 1403 | 1708 | 1410 | 1688 | 1497 | 12699 |
| 2.0 - 3.0 | 1571 | 1807 | 1067 | 1282 | 1487 | 1257 | 1230 | 1288 | 10989 |
| 1.0 - 2.0 | 907 | 929 | 733 | 744 | 862 | 857 | 818 | 826 | 6676 |
| 0.0 - 1.0 | 295 | 280 | 273 | 225 | 272 | 233 | 297 | 245 | 2120 |
| Total | 6312 | 6446 | 4188 | 6062 | 9168 | 7401 | 9308 | 6369 | 55254 |

**Figure 116 - Location 1 - % Exceedance U10 vs. direction - All-year**

| Area 1 - 19.4998°N 093.3332°E - Water depth = 23m All-year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| % Exceedence | Direction From | | | | | | | | Total |
| Hourly U10 [m/s] | N | NE | E | SE | S | SW | W | NW | |
| 21.0 | . | . | . | . | . | . | . | . | . |
| 20.0 | . | . | . | . | . | . | . | . | . |
| 19.0 | . | . | . | . | . | . | . | . | . |
| 18.0 | . | . | . | . | . | . | . | . | . |
| 17.0 | . | . | . | . | . | . | . | . | . |
| 16.0 | . | . | . | . | . | . | . | . | . |
| 15.0 | . | . | . | . | . | . | . | . | . |
| 14.0 | . | . | . | . | . | . | . | . | . |
| 13.0 | . | . | . | . | . | . | . | . | . |
| 12.0 | . | . | . | . | . | . | . | . | .1 |
| 11.0 | . | . | . | . | .1 | .1 | . | . | .2 |
| 10.0 | . | . | . | . | .1 | .2 | . | . | .3 |
| 9.0 | . | . | . | .1 | .2 | .3 | .1 | . | .8 |
| 8.0 | . | . | .1 | .2 | .6 | .6 | .4 | .1 | 2. |
| 7.0 | . | . | .1 | .6 | 1.5 | 1.2 | 1.2 | .2 | 4.9 |
| 6.0 | .1 | .1 | .3 | 1.3 | 3.3 | 2.4 | 2.9 | .7 | 11.2 |
| 5.0 | .8 | .5 | .9 | 2.5 | 5.7 | 4.4 | 5.9 | 2.2 | 22.8 |
| 4.0 | 2.9 | 2.4 | 2.1 | 4.4 | 8.8 | 6.6 | 9.5 | 4.5 | 41.2 |
| 3.0 | 6.4 | 6.2 | 3.8 | 6.9 | 11.8 | 9.1 | 12.6 | 7.3 | 64.2 |
| 2.0 | 9.2 | 9.5 | 5.8 | 9.2 | 14.5 | 11.4 | 14.8 | 9.6 | 84.1 |
| 1.0 | 10.9 | 11.2 | 7.1 | 10.6 | 16.1 | 13. | 16.3 | 11.1 | 96.2 |
| 0.0 | 11.4 | 11.7 | 7.6 | 11. | 16.6 | 13.4 | 16.8 | 11.5 | 100. |

**Figure 117 - Location 1 – Wind rose – All-year**



## A.7.2.2 Location 2 – Nga Yoke Kaung

***Waves***

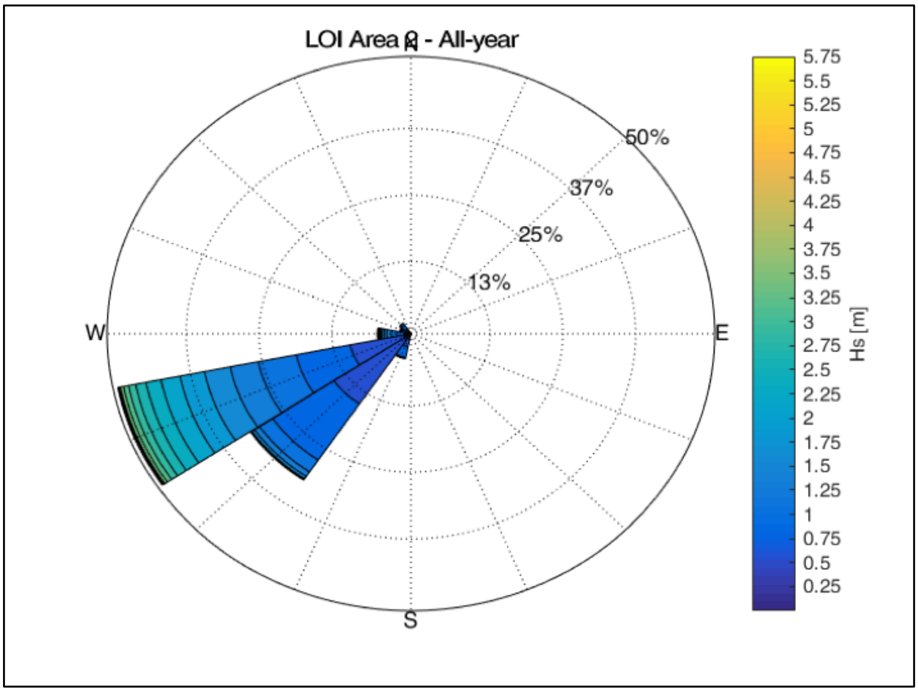
**Figure 118 - Location 2 - Occurrences Hs vs. direction - All-year**

| Area 2 - 16.5831°N 094.1999°E - Water depth = 30m<br>All-year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Occurences | Direction From | | | | | | | | Total |
| Hs [m] | N | NE | E | SE | S | SW | W | NW | |
| 5.75 - 6.00 | | | | | | | | | |
| 5.50 - 5.75 | | | | | | | 2 | | 2 |
| 5.25 - 5.50 | | | | | | | 3 | | 3 |
| 5.00 - 5.25 | | | | | | | 3 | | 3 |
| 4.75 - 5.00 | | | | | | | 2 | | 2 |
| 4.50 - 4.75 | | | | | | | 5 | | 5 |
| 4.25 - 4.50 | | | | | | 2 | 28 | | 30 |
| 4.00 - 4.25 | | | | | | 7 | 33 | | 40 |
| 3.75 - 4.00 | | | | | | 10 | 62 | | 72 |
| 3.50 - 3.75 | | | | | | 21 | 136 | | 157 |
| 3.25 - 3.50 | | | | | | 114 | 221 | | 335 |
| 3.00 - 3.25 | | | | | | 243 | 315 | | 558 |
| 2.75 - 3.00 | | | | | | 402 | 355 | | 757 |
| 2.50 - 2.75 | | | | | | 593 | 491 | | 1084 |
| 2.25 - 2.50 | | | | | | 991 | 531 | | 1522 |
| 2.00 - 2.25 | 1 | | | | | 1295 | 747 | 7 | 2050 |
| 1.75 - 2.00 | 13 | | | | | 1858 | 894 | 16 | 2781 |
| 1.50 - 1.75 | 21 | | | | | 2023 | 1106 | 36 | 3186 |
| 1.25 - 1.50 | 23 | | | | | 2158 | 1665 | 98 | 3944 |
| 1.00 - 1.25 | 17 | 14 | | | 21 | 3825 | 2132 | 260 | 6269 |
| 0.75 - 1.00 | 19 | | | | 287 | 11730 | 2519 | 866 | 15421 |
| 0.50 - 0.75 | 7 | | | 1 | 528 | 12994 | 1883 | 631 | 16044 |
| 0.25 - 0.50 | 5 | | | 1 | 107 | 1467 | 306 | 128 | 2014 |
| 0.00 - 0.25 | | | | | 3 | 11 | 3 | 1 | 18 |
| Total | 106 | 14 | | 2 | 946 | 39744 | 13442 | 2043 | 56297 |

**Figure 119 - Location 2 - % Exceedance Hs vs. direction - All-year**

| Area 2 - 16.5831°N 094.1999°E - Water depth = 30m All-year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| % Exceedance | Direction From | | | | | | | | Total |
| Hs [m] | N | NE | E | SE | S | SW | W | NW | |
| 5.75 | . | . | . | . | . | . | . | . | . |
| 5.50 | . | . | . | . | . | . | . | . | . |
| 5.25 | . | . | . | . | . | . | . | . | . |
| 5.00 | . | . | . | . | . | . | . | . | . |
| 4.75 | . | . | . | . | . | . | . | . | . |
| 4.50 | . | . | . | . | . | . | . | . | . |
| 4.25 | . | . | . | . | . | . | .1 | . | .1 |
| 4.00 | . | . | . | . | . | . | .1 | . | .2 |
| 3.75 | . | . | . | . | . | . | .2 | . | .3 |
| 3.50 | . | . | . | . | . | .1 | .5 | . | .6 |
| 3.25 | . | . | . | . | . | .3 | .9 | . | 1.2 |
| 3.00 | . | . | . | . | . | .7 | 1.4 | . | 2.1 |
| 2.75 | . | . | . | . | . | 1.4 | 2.1 | . | 3.5 |
| 2.50 | . | . | . | . | . | 2.5 | 2.9 | . | 5.4 |
| 2.25 | . | . | . | . | . | 4.2 | 3.9 | . | 8.1 |
| 2.00 | . | . | . | . | . | 6.5 | 5.2 | . | 11.8 |
| 1.75 | . | . | . | . | . | 9.8 | 6.8 | . | 16.7 |
| 1.50 | .1 | . | . | . | . | 13.4 | 8.8 | .1 | 22.4 |
| 1.25 | .1 | . | . | . | . | 17.3 | 11.7 | .3 | 29.4 |
| 1.00 | .1 | . | . | . | . | 24.1 | 15.5 | .7 | 40.5 |
| 0.75 | .2 | . | . | . | .5 | 44.9 | 20. | 2.3 | 67.9 |
| 0.50 | .2 | . | . | . | 1.5 | 68. | 23.3 | 3.4 | 96.4 |
| 0.25 | .2 | . | . | . | 1.7 | 70.6 | 23.9 | 3.6 | 100. |
| 0.00 | .2 | . | . | . | 1.7 | 70.6 | 23.9 | 3.6 | 100. |

## Figure 120 - Location 2 – Wave rose – All-year




## Figure 121 - Location 2 - Occurrences Hs vs. Tp - All-year

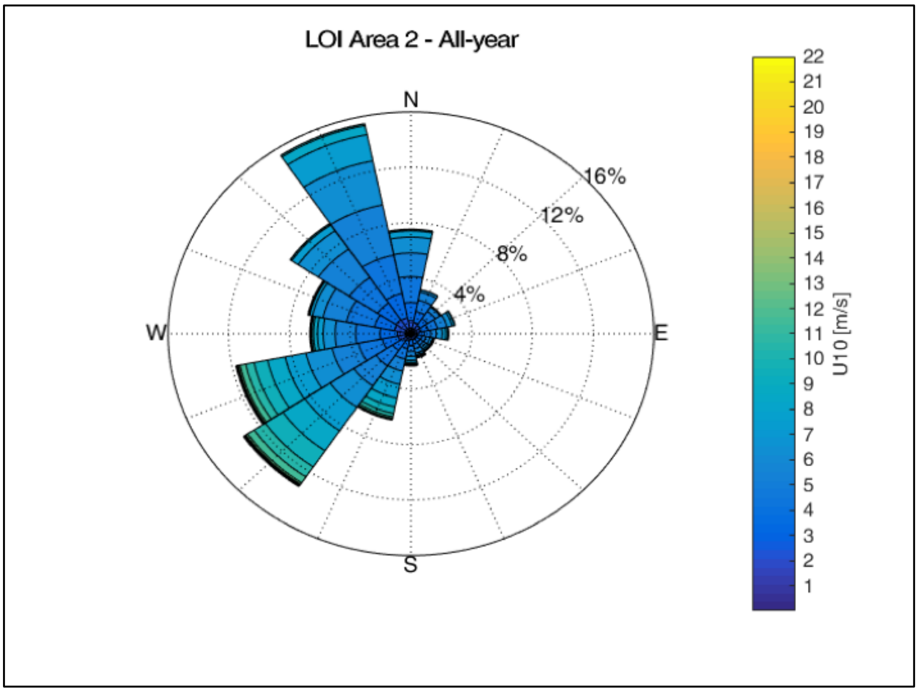
| All-year | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Occurences | Peak period Tp [s] | | | | | | | | | | | | | | | | | | | | | | | | | Total |
| Hs [m] | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 | 20-21 | 21-22 | 22-23 | 23-24 | 24-25 | |
| 5.75 - 6.00 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5.50 - 5.75 | | | | | | | | | | | | | 2 | | | | | | | | | | | | | 2 |
| 5.25 - 5.50 | | | | | | | | | | | | | 3 | | | | | | | | | | | | | 3 |
| 5.00 - 5.25 | | | | | | | | | | | | 2 | 1 | | | | | | | | | | | | | 3 |
| 4.75 - 5.00 | | | | | | | | | | | | 1 | 1 | | | | | | | | | | | | | 2 |
| 4.50 - 4.75 | | | | | | | | | | | | 3 | 2 | | | | | | | | | | | | | 5 |
| 4.25 - 4.50 | | | | | | | | | | | 2 | 26 | 2 | | | | | | | | | | | | | 30 |
| 4.00 - 4.25 | | | | | | | | | | 4 | 13 | 22 | 1 | | | | | | | | | | | | | 40 |
| 3.75 - 4.00 | | | | | | | | | | 18 | 47 | 5 | 2 | | | | | | | | | | | | | 72 |
| 3.50 - 3.75 | | | | | | | | | 2 | 106 | 36 | 12 | 1 | | | | | | | | | | | | | 157 |
| 3.25 - 3.50 | | | | | | | | | 33 | 251 | 47 | 1 | 1 | | | | | | | 1 | 1 | | | | | 335 |
| 3.00 - 3.25 | | | | | | | | | 98 | 387 | 59 | 2 | 1 | | | | 2 | | 3 | 6 | | | | | | 558 |
| 2.75 - 3.00 | | | | | | | | | 337 | 345 | 43 | 12 | 1 | | | | 6 | 5 | 5 | 3 | | | | | | 757 |
| 2.50 - 2.75 | | | | | | | | 31 | 690 | 291 | 4 | 7 | 2 | | 4 | 7 | 21 | 11 | 8 | 7 | 1 | | | | | 1084 |
| 2.25 - 2.50 | | | | | | | | 267 | 912 | 194 | 10 | 5 | 2 | 1 | 22 | 16 | 49 | 17 | 16 | 9 | 2 | | | | | 1522 |
| 2.00 - 2.25 | | | | | | | 2 | 722 | 831 | 159 | 22 | 3 | 3 | 4 | 84 | 25 | 109 | 34 | 30 | 14 | 2 | 6 | | | | 2050 |
| 1.75 - 2.00 | | | | | 7 | 2 | 92 | 1221 | 686 | 111 | 19 | 7 | 10 | 21 | 225 | 86 | 167 | 54 | 45 | 21 | 6 | 1 | | | | 2781 |
| 1.50 - 1.75 | | | | | 1 | | 288 | 995 | 499 | 165 | 13 | 9 | 45 | 86 | 500 | 102 | 318 | 74 | 56 | 30 | 5 | | | | | 3186 |
| 1.25 - 1.50 | | | | | 19 | 27 | 394 | 610 | 329 | 107 | 17 | 25 | 165 | 241 | 892 | 235 | 554 | 178 | 105 | 37 | 6 | 3 | | | | 3944 |
| 1.00 - 1.25 | | | | 16 | 20 | 203 | 279 | 300 | 279 | 146 | 41 | 83 | 673 | 540 | 1812 | 502 | 875 | 253 | 150 | 64 | 14 | 19 | | | | 6269 |
| 0.75 - 1.00 | | | | 92 | 199 | 906 | 198 | 139 | 174 | 137 | 88 | 631 | 3347 | 1878 | 4400 | 968 | 1495 | 397 | 245 | 88 | 19 | 18 | 2 | | | 15421 |
| 0.50 - 0.75 | | | 38 | 408 | 708 | 379 | 96 | 97 | 93 | 121 | 124 | 1910 | 4611 | 1906 | 3388 | 759 | 967 | 262 | 104 | 58 | 11 | 4 | | | | 16044 |
| 0.25 - 0.50 | | | 86 | 164 | 208 | 47 | 14 | 11 | 7 | 35 | 57 | 363 | 436 | 169 | 256 | 61 | 62 | 29 | 7 | 2 | | | | | | 2014 |
| 0.00 - 0.25 | | 10 | 1 | | | 1 | 1 | 2 | | 1 | | | 1 | | 1 | | | | | | | | | | | 18 |
| Total | | 10 | 125 | 680 | 1162 | 1565 | 1364 | 4395 | 4970 | 2578 | 642 | 3129 | 9313 | 4846 | 11584 | 2761 | 4625 | 1314 | 774 | 340 | 67 | 51 | 2 | | | 56297 |

*Wind*

**Figure 122 - Location 2 - Occurrences U10 vs. direction - All-year**

| Area 2 - 16.5831°N 094.1999°E - Water depth = 30m All-year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Occurences | Direction From | | | | | | | | Total |
| Hourly U10 [m/s] | N | NE | E | SE | S | SW | W | NW | |
| 21.0 - 22.0 | | | | | 1 | 2 | | | 3 |
| 20.0 - 21.0 | | | | | | | | | |
| 19.0 - 20.0 | | | | | | 8 | 1 | | 9 |
| 18.0 - 19.0 | | | | | | 6 | 1 | | 7 |
| 17.0 - 18.0 | | | | | 1 | 10 | 2 | 1 | 14 |
| 16.0 - 17.0 | | | | | 2 | 27 | 8 | 1 | 38 |
| 15.0 - 16.0 | | | | | 3 | 24 | 6 | | 33 |
| 14.0 - 15.0 | | | | | 9 | 68 | 8 | | 85 |
| 13.0 - 14.0 | 1 | | 1 | 1 | 5 | 65 | 15 | | 88 |
| 12.0 - 13.0 | | | 2 | 4 | 15 | 147 | 25 | 1 | 194 |
| 11.0 - 12.0 | | | 2 | 15 | 42 | 515 | 88 | | 662 |
| 10.0 - 11.0 | 8 | | 10 | 29 | 83 | 836 | 144 | 11 | 1121 |
| 9.0 - 10.0 | 60 | | 40 | 33 | 120 | 1375 | 256 | 42 | 1926 |
| 8.0 - 9.0 | 293 | 5 | 106 | 52 | 201 | 1701 | 458 | 240 | 3056 |
| 7.0 - 8.0 | 865 | 34 | 240 | 117 | 325 | 2066 | 613 | 869 | 5129 |
| 6.0 - 7.0 | 1634 | 149 | 424 | 179 | 432 | 2047 | 1095 | 2143 | 8103 |
| 5.0 - 6.0 | 2281 | 522 | 509 | 304 | 537 | 1856 | 1735 | 2991 | 10735 |
| 4.0 - 5.0 | 2173 | 766 | 528 | 314 | 533 | 1517 | 1927 | 2675 | 10433 |
| 3.0 - 4.0 | 1591 | 719 | 442 | 340 | 468 | 992 | 1366 | 1744 | 7662 |
| 2.0 - 3.0 | 803 | 502 | 374 | 304 | 296 | 500 | 740 | 976 | 4495 |
| 1.0 - 2.0 | 283 | 246 | 193 | 175 | 191 | 239 | 315 | 340 | 1982 |
| 0.0 - 1.0 | 80 | 78 | 59 | 62 | 54 | 57 | 65 | 68 | 523 |
| Total | 10072 | 3021 | 2930 | 1929 | 3318 | 14058 | 8868 | 12102 | 56298 |

**Figure 123 - Location 2 – Wind rose – All-year**




## A.7.2.3 Location 3 – Kalagut Island

***Waves***

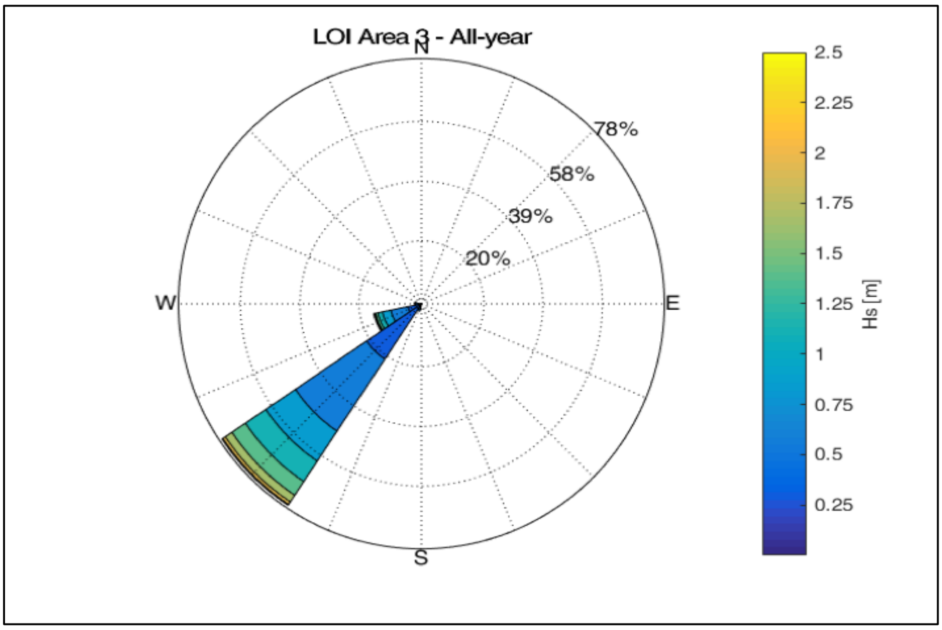
**Figure 124 - Location 3 - Occurrences Hs vs. direction - All-year**

| Area 3 - 15.4165°N 097.66642°E - Water depth = 14m All-year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Occurences Hs [m] | | | Direction From N | NE | E | SE | S | SW | W | NW | Total |
| 4.75 | - | 5.00 | | | | | | | | | |
| 4.50 | - | 4.75 | | | | | | | | | |
| 4.25 | - | 4.50 | | | | | | | | | |
| 4.00 | - | 4.25 | | | | | | | | | |
| 3.75 | - | 4.00 | | | | | | | | | |
| 3.50 | - | 3.75 | | | | | | | | | |
| 3.25 | - | 3.50 | | | | | | | | | |
| 3.00 | - | 3.25 | | | | | | | | | |
| 2.75 | - | 3.00 | | | | | | | | | |
| 2.50 | - | 2.75 | | | | | | | | | |
| 2.25 | - | 2.50 | | | | | | 28 | | | 28 |
| 2.00 | - | 2.25 | | | | | | 189 | | | 189 |
| 1.75 | - | 2.00 | | | | | | 718 | | | 718 |
| 1.50 | - | 1.75 | | | | | | 1640 | 10 | | 1650 |
| 1.25 | - | 1.50 | 4 | | | | | 3468 | 43 | 8 | 3523 |
| 1.00 | - | 1.25 | 4 | | | | | 5327 | 221 | 14 | 5566 |
| 0.75 | - | 1.00 | 3 | 7 | 1 | 1 | 13 | 7987 | 485 | 25 | 8522 |
| 0.50 | - | 0.75 | 2 | 3 | | 1 | 33 | 19139 | 1298 | 12 | 20488 |
| 0.25 | - | 0.50 | 1 | | | | 115 | 15115 | 1185 | 8 | 16424 |
| 0.00 | - | 0.25 | 1 | 1 | | | 20 | 47 | 13 | 10 | 92 |
| Total | | | 15 | 11 | 1 | 2 | 181 | 53658 | 3255 | 77 | 57200 |

**Figure 125 - Location 3 - % Exceedance Hs vs. direction - All-year**

| Area 3 - 15.4165°N 097.66642°E - Water depth = 14m All-year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| % Exceedence | Direction From | | | | | | | | Total |
| Hs [m] | N | NE | E | SE | S | SW | W | NW | |
| 4.75 | . | . | . | . | . | . | . | . | . |
| 4.50 | . | . | . | . | . | . | . | . | . |
| 4.25 | . | . | . | . | . | . | . | . | . |
| 4.00 | . | . | . | . | . | . | . | . | . |
| 3.75 | . | . | . | . | . | . | . | . | . |
| 3.50 | . | . | . | . | . | . | . | . | . |
| 3.25 | . | . | . | . | . | . | . | . | . |
| 3.00 | . | . | . | . | . | . | . | . | . |
| 2.75 | . | . | . | . | . | . | . | . | . |
| 2.50 | . | . | . | . | . | . | . | . | . |
| 2.25 | . | . | . | . | . | . | . | . | . |
| 2.00 | . | . | . | . | . | .4 | . | . | .4 |
| 1.75 | . | . | . | . | . | 1.6 | . | . | 1.6 |
| 1.50 | . | . | . | . | . | 4.5 | . | . | 4.5 |
| 1.25 | . | . | . | . | . | 10.6 | .1 | . | 10.7 |
| 1.00 | . | . | . | . | . | 19.9 | .5 | . | 20.4 |
| 0.75 | . | . | . | . | . | 33.8 | 1.3 | .1 | 35.3 |
| 0.50 | . | . | . | . | .1 | 67.3 | 3.6 | .1 | 71.1 |
| 0.25 | . | . | . | . | .3 | 93.7 | 5.7 | .1 | 99.8 |
| 0.00 | . | . | . | . | .3 | 93.8 | 5.7 | .1 | 100. |

**Figure 126 - Location 3 – Wave rose – All-year**



## Figure 127 - Location 3 - Occurrences Hs vs. Tp - All-year

Area 3 - 15.4165°N 097.66642°E - Water depth = 14m
All-year

| Occurences | Peak period Tp [s] | | | | | | | | | | | | | | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs [m] | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 | 20-21 | 21-22 | 22-23 | 23-24 | 24-25 | |
| 4.75 - 5.00 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.50 - 4.75 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.25 - 4.50 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4.00 - 4.25 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.75 - 4.00 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.50 - 3.75 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.25 - 3.50 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.00 - 3.25 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.75 - 3.00 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.50 - 2.75 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.25 - 2.50 | | | | | | | | | 2 | 26 | | | | | | | | | | | | | | | | 28 |
| 2.00 - 2.25 | | | | | | | | | 106 | 82 | | | | | | | | | 1 | | | | | | | 189 |
| 1.75 - 2.00 | | | | | | | | 4 | 614 | 94 | | | | | | | | 2 | 4 | | | | | | | 718 |
| 1.50 - 1.75 | | | | | | | | 524 | 1035 | 44 | 2 | | | | 7 | 4 | 19 | 5 | 7 | 3 | | | | | | 1650 |
| 1.25 - 1.50 | | | | | | | 232 | 2171 | 656 | 59 | | 1 | 8 | 14 | 134 | 28 | 126 | 32 | 50 | 11 | 1 | | | | | 3523 |
| 1.00 - 1.25 | | | | | | 43 | 1710 | 1608 | 263 | 82 | 14 | 10 | 118 | 117 | 808 | 154 | 451 | 62 | 71 | 42 | 6 | 7 | | | | 5566 |
| 0.75 - 1.00 | | | | | | 428 | 996 | 535 | 167 | 63 | 40 | 151 | 1158 | 732 | 2414 | 360 | 1094 | 158 | 177 | 46 | 2 | 1 | | | | 8522 |
| 0.50 - 0.75 | | | 6 | 27 | 434 | 340 | 162 | 127 | 124 | 130 | 139 | 1715 | 6016 | 2145 | 5767 | 789 | 1870 | 301 | 301 | 81 | 4 | 10 | | | | 20488 |
| 0.25 - 0.50 | | 1 | 148 | 216 | 381 | 25 | 33 | 78 | 72 | 185 | 400 | 3046 | 5369 | 1666 | 3246 | 368 | 845 | 170 | 128 | 36 | 3 | 6 | 2 | | | 16424 |
| 0.00 - 0.25 | | 10 | 27 | 21 | | 1 | | 2 | 1 | 2 | 5 | 11 | 4 | | 1 | 2 | 5 | | | | | | | | | 92 |
| Total | | 11 | 181 | 264 | 815 | 837 | 3133 | 5049 | 3040 | 767 | 600 | 4934 | 12673 | 4674 | 12377 | 1705 | 4410 | 730 | 739 | 219 | 16 | 24 | 2 | | | 57200 |

### *Wind*

## Figure 128 - Location 3 - Occurrences U10 vs. direction - All-year

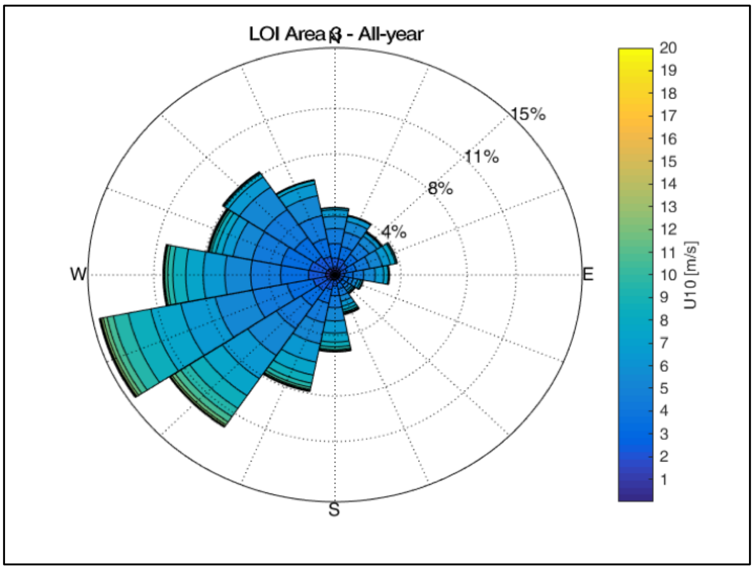
Area 3 - 15.4165°N 097.66642°E - Water depth = 14m
All-year

| Occurences | Direction From | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Hourly U10 [m/s] | N | NE | E | SE | S | SW | W | NW | |
| 21.0 - 22.0 | | | | | | | | | |
| 20.0 - 21.0 | | | | | | | | | |
| 19.0 - 20.0 | | | | | 1 | 1 | | | 2 |
| 18.0 - 19.0 | | | | | | 2 | 1 | | 3 |
| 17.0 - 18.0 | | | | | | | 2 | | 2 |
| 16.0 - 17.0 | | | | | | 6 | 2 | | 8 |
| 15.0 - 16.0 | | | | | 2 | 10 | 7 | 2 | 21 |
| 14.0 - 15.0 | | | | | 3 | 28 | 13 | | 44 |
| 13.0 - 14.0 | | | | | 19 | 61 | 15 | 4 | 99 |
| 12.0 - 13.0 | | 1 | | 2 | 15 | 130 | 61 | 7 | 216 |
| 11.0 - 12.0 | | | 3 | 8 | 71 | 243 | 99 | 12 | 436 |
| 10.0 - 11.0 | 1 | 6 | 6 | 26 | 107 | 426 | 218 | 30 | 820 |
| 9.0 - 10.0 | 8 | 18 | 20 | 40 | 209 | 754 | 503 | 47 | 1599 |
| 8.0 - 9.0 | 31 | 35 | 88 | 57 | 387 | 1215 | 930 | 128 | 2871 |
| 7.0 - 8.0 | 150 | 105 | 314 | 122 | 675 | 1658 | 1297 | 319 | 4640 |
| 6.0 - 7.0 | 552 | 327 | 540 | 194 | 941 | 2085 | 1600 | 941 | 7180 |
| 5.0 - 6.0 | 1003 | 718 | 748 | 287 | 1023 | 2395 | 1915 | 1883 | 9972 |
| 4.0 - 5.0 | 1249 | 1018 | 700 | 307 | 943 | 2154 | 2187 | 2314 | 10872 |
| 3.0 - 4.0 | 1130 | 845 | 574 | 372 | 770 | 1432 | 1989 | 1757 | 8869 |
| 2.0 - 3.0 | 779 | 596 | 359 | 290 | 490 | 899 | 1183 | 1105 | 5701 |
| 1.0 - 2.0 | 423 | 349 | 262 | 210 | 286 | 407 | 520 | 456 | 2913 |
| 0.0 - 1.0 | 134 | 117 | 95 | 85 | 102 | 129 | 140 | 131 | 933 |
| Total | 5460 | 4135 | 3709 | 2000 | 6044 | 14035 | 12682 | 9136 | 57201 |

**Figure 129 - Location 3 - % Exceedance U10 vs. direction - All-year**

| Area 3 - 15.4165°N 097.66642°E - Water depth = 14m All-year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| % Exceedence | Direction From | | | | | | | | Total |
| Hourly U10 [m/s] | N | NE | E | SE | S | SW | W | NW | |
| 21.0 | . | . | . | . | . | . | . | . | . |
| 20.0 | . | . | . | . | . | . | . | . | . |
| 19.0 | . | . | . | . | . | . | . | . | . |
| 18.0 | . | . | . | . | . | . | . | . | . |
| 17.0 | . | . | . | . | . | . | . | . | . |
| 16.0 | . | . | . | . | . | . | . | . | . |
| 15.0 | . | . | . | . | . | . | . | . | .1 |
| 14.0 | . | . | . | . | . | .1 | . | . | .1 |
| 13.0 | . | . | . | . | . | .2 | .1 | . | .3 |
| 12.0 | . | . | . | . | .1 | .4 | .2 | . | .7 |
| 11.0 | . | . | . | . | .2 | .8 | .3 | . | 1.5 |
| 10.0 | . | . | . | .1 | .4 | 1.6 | .7 | .1 | 2.9 |
| 9.0 | . | . | .1 | .1 | .7 | 2.9 | 1.6 | .2 | 5.7 |
| 8.0 | .1 | .1 | .2 | .2 | 1.4 | 5. | 3.2 | .4 | 10.7 |
| 7.0 | .3 | .3 | .8 | .4 | 2.6 | 7.9 | 5.5 | 1. | 18.8 |
| 6.0 | 1.3 | .9 | 1.7 | .8 | 4.2 | 11.6 | 8.3 | 2.6 | 31.4 |
| 5.0 | 3.1 | 2.1 | 3. | 1.3 | 6. | 15.8 | 11.6 | 5.9 | 48.8 |
| 4.0 | 5.2 | 3.9 | 4.2 | 1.8 | 7.7 | 19.5 | 15.5 | 9.9 | 67.8 |
| 3.0 | 7.2 | 5.4 | 5.2 | 2.5 | 9. | 22. | 18.9 | 13. | 83.3 |
| 2.0 | 8.6 | 6.4 | 5.9 | 3. | 9.9 | 23.6 | 21. | 14.9 | 93.3 |
| 1.0 | 9.3 | 7. | 6.3 | 3.3 | 10.4 | 24.3 | 21.9 | 15.7 | 98.4 |
| 0.0 | 9.5 | 7.2 | 6.5 | 3.5 | 10.6 | 24.5 | 22.2 | 16. | 100. |

**Figure 130 - Location 3 – Wind rose – All-year**



## A.7.3 CYCLONE TACK MAPS AND STATISTICS

### A.7.3.1 Location 1 – Kyauk Phyu

**Figure 131 - Location 1 - Kyauk Phyu: Cyclones that affected the Location for the period 1990-2014**

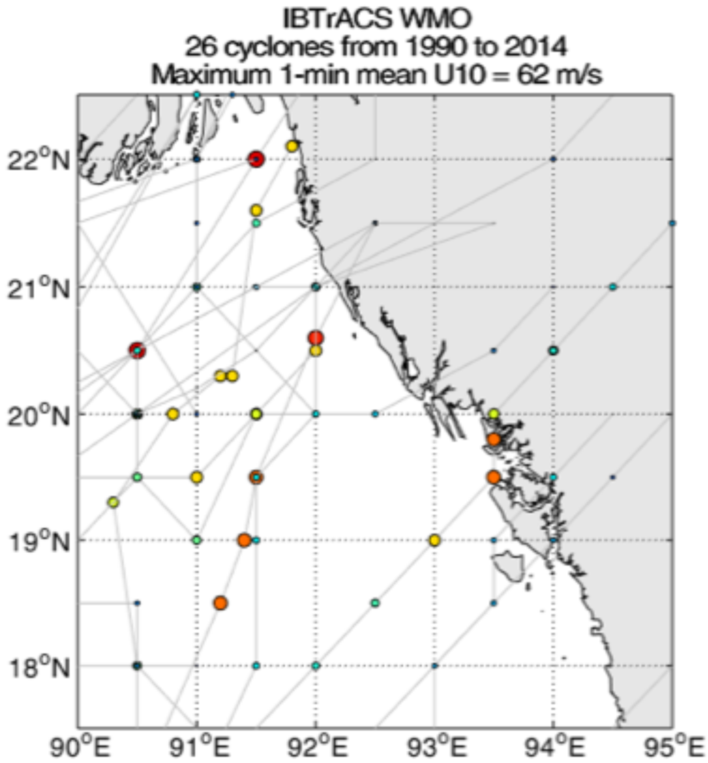



**Table 38 - Cyclones monthly statistics for the period 1990-2014. Location 1 - Kyauk Phyu**

| IBTrACS WMO data - Area 1 - Period: 1990-2014 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | All-year |
| Number of events [] | 0 | 0 | 0 | 3 | 9 | 1 | 0 | 1 | 2 | 5 | 4 | 1 | 26 |
| Maximum 1-min U10 [m/s] | 0 | 0 | 0 | 62 | 56 | 22 | 0 | 12 | 27 | 52 | 44 | 22 | 62 |
| Mean 1-min U10 [m/s] | 0 | 0 | 0 | 34 | 27 | 22 | 0 | 12 | 20 | 20 | 22 | 18 | 24 |

## A.7.3.2 Location 2 – Nga Yoke Kaung

**Figure 132 - Location 2 - Nga Yoke Kaung: Cyclones that affected the Location for the period 1990-2014**

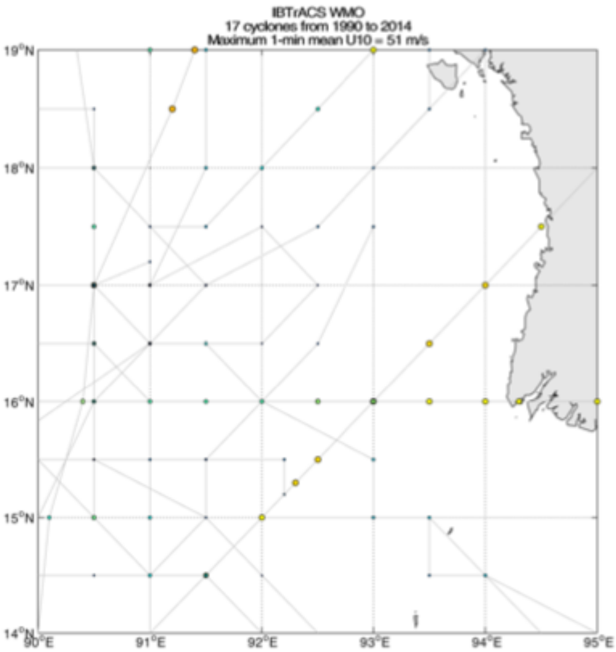



**Table 39 - Cyclones monthly statistics for the period 1990-2014. Location 2 - Nga Yoke Kaung**

| IBTrACS WMO data - Area 2 - Period: 1990-2014 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | All-year |
| Number of events [] | 0 | 0 | 1 | 1 | 8 | 0 | 0 | 0 | 0 | 5 | 2 | 0 | 17 |
| Maximum 1-min U10 [m/s] | 0 | 0 | 12 | 49 | 50 | 0 | 0 | 0 | 0 | 44 | 17 | 0 | 50 |
| Mean 1-min U10 [m/s] | 0 | 0 | 12 | 43 | 22 | 0 | 0 | 0 | 0 | 23 | 16 | 0 | 23 |

### A.7.3.3 Location 3 – Kalagut Island

**Figure 133 - Location 3 - Kalagut Island: Cyclones that affected the area for the period 1990-2014**

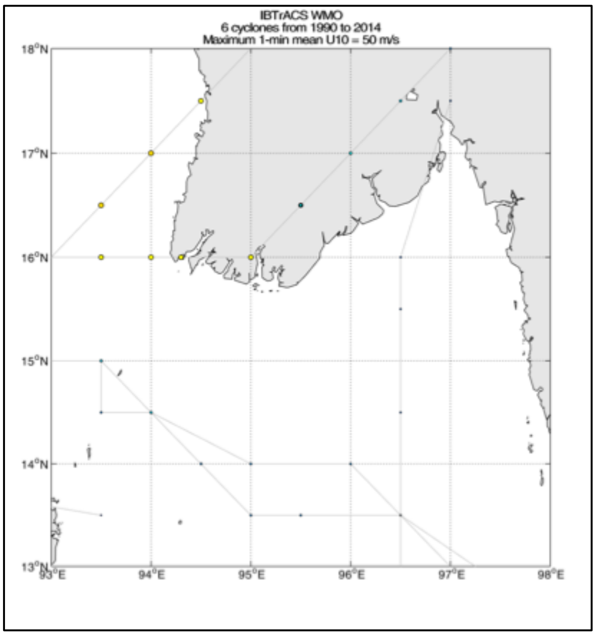



**Table 40 - Cyclones monthly statistics for the period 1990-2014. Location 3 - Kalagut Island**

| IBTrACS WMO data - Area 3 - Period: 1990-2014 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | All-year |
| Number of events [] | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 6 |
| Maximum 1-min U10 [m/s] | 0 | 0 | 0 | 49 | 44 | 0 | 0 | 0 | 0 | 22 | 17 | 0 | 49 |
| Mean 1-min U10 [m/s] | 0 | 0 | 0 | 38 | 28 | 0 | 0 | 0 | 0 | 18 | 17 | 0 | 25 |

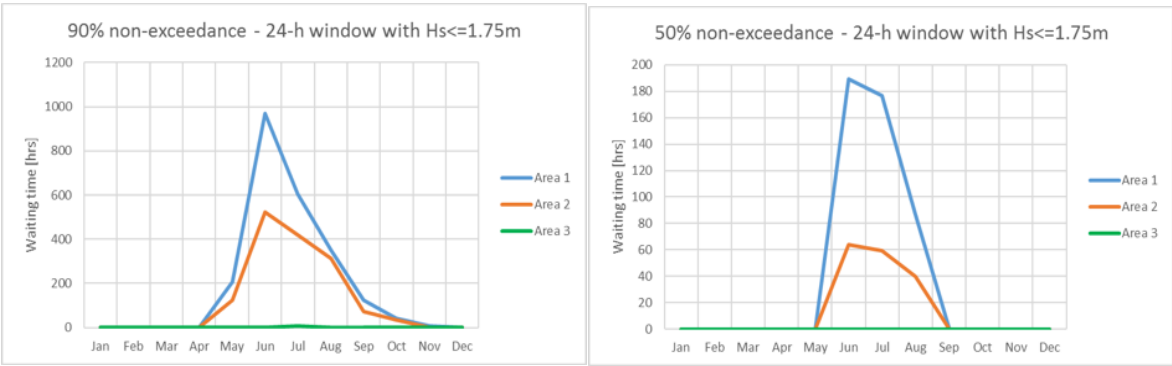
## A.8 Conclusions

Comparing the fatigue data results obtained at the three selected locations produced the following conclusions:

- Maximum significant wave heights are highest in the area of interest in Location 2, with a maximum significant wave height of about 5.75m, whilst all waves in Location 1 are lower than 4.5m and lower than 2.5 m in the location in Location 3.
- Low waves, are more frequent as we move South, with about 54% of the waves above 1m in the area of interest in Location 1, about 40% in Location 2 and about 20% in Location 3.
- Wave directionalities are quite similar between the three Locations, with most of the waves arriving from SW-W sectors as expected.
- The winds are very similar between Locations 1 and 3, with slightly higher winds in Location 3 of 20 m/s and same directionality pattern. Location 2 presents the highest winds with maximum wind speeds of 22 m/s and very low frequency of Easterly winds.

Looking at the results obtained with the waiting on weather analysis, it is clear that the area of interest in Location 3 is much more sheltered and shows much lower waiting on weather times than the other 2 locations. This is illustrated below.

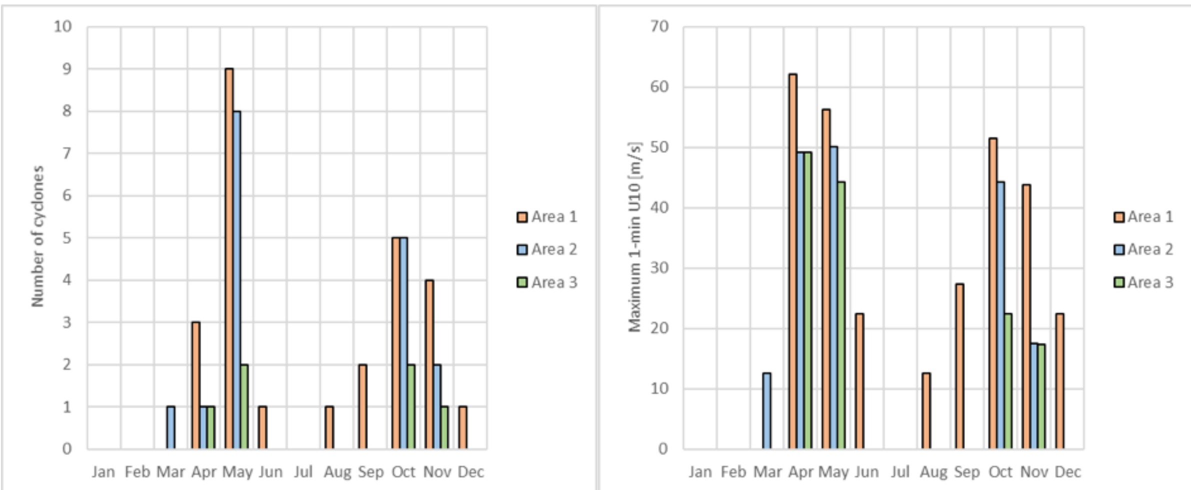
**Figure 134 - Comparison waiting on weather for 24-h window and Hs<=1.75m**




The figure above shows the waiting on weather times for a 24-hour window with the Hs threshold of 1.75m, the waiting time during the SW monsoon decreases from the northern to the southern area.

Finally, the analysis of cyclone activity in the vicinity of each Location showed that the northern area was the most likely to be affected by cyclones, with an approximate rate of 1 cyclone per year, and with the strongest winds. Whereas the southern area was unlikely to be affected by fully developed cyclones, with an approximate rate of 1 cyclone every four years, and lower cyclonic wind speeds. This is shown below

**Figure 135 - Comparison of cyclonic statistics in each area. Number of cyclones (left) and Wind intensity (right)**




Therefore, based on the results obtained, which clearly show that the selected area in Location 3, Kalagut Island, has the least severe wave climate of the three locations and is less prone to cyclones, it can be concluded that it is, from the metocean point of view, the best option for the LNG terminal. It is important to note that the conclusions above regarding fatigue and waiting on weather of waves are quite sensitive to the coordinates of the interest area selected for each Location. The results obtained will most probably be different if different interest locations, with different levels of exposure to offshore waves, were selected within each Location.

## A.9 References

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# A.10 Addendum 1

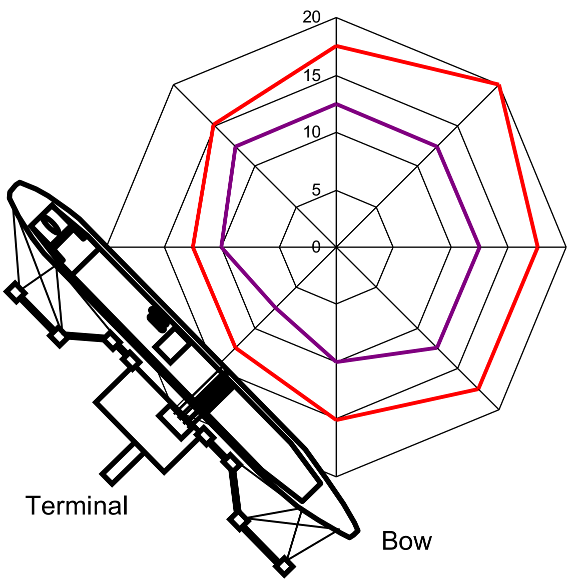
## A.10.1 Waiting on Weather

The original waiting on weather analysis was performed at the pilot station positions where the LNG carrier would take on board a pilot for final navigation to the site. These sites are by definition in deeper water and therefore more exposed, in most cases, than the berthing locations. To investigate the impact of weather on lay time this subsequent analysis was performed at the proposed berth locations.

The waiting on weather analysis investigates the total waiting time necessary in order to be able to complete an operation, in this case the transit, turning, berthing unloading and unberthing of an LNG carrier. A set of actions that will take up to 24 hours depending on the size of ship and the amount of LNG to be transferred. The limiting thresholds for these operations are:

- ***Wave height*** 1.5 m Hs for a conventional jetty and 2.0 m Hs for a floating vessel offshore.
- ***Wind speed*** Guidance from SIGTTO and depends on direction as shown.

**Figure 136 - Weather Analysis 1**




For each month and time step of the hindcast time series, the time series is checked, looking for windows that fulfil the metocean criteria and duration required to complete the different operations. The time elapsed between the starting time step and the end of the operation is then calculated.
Results are presented in tabulated forms presenting the probability of waiting time (in hours) to complete certain operations to exceed 24, 48 and 72 hours.

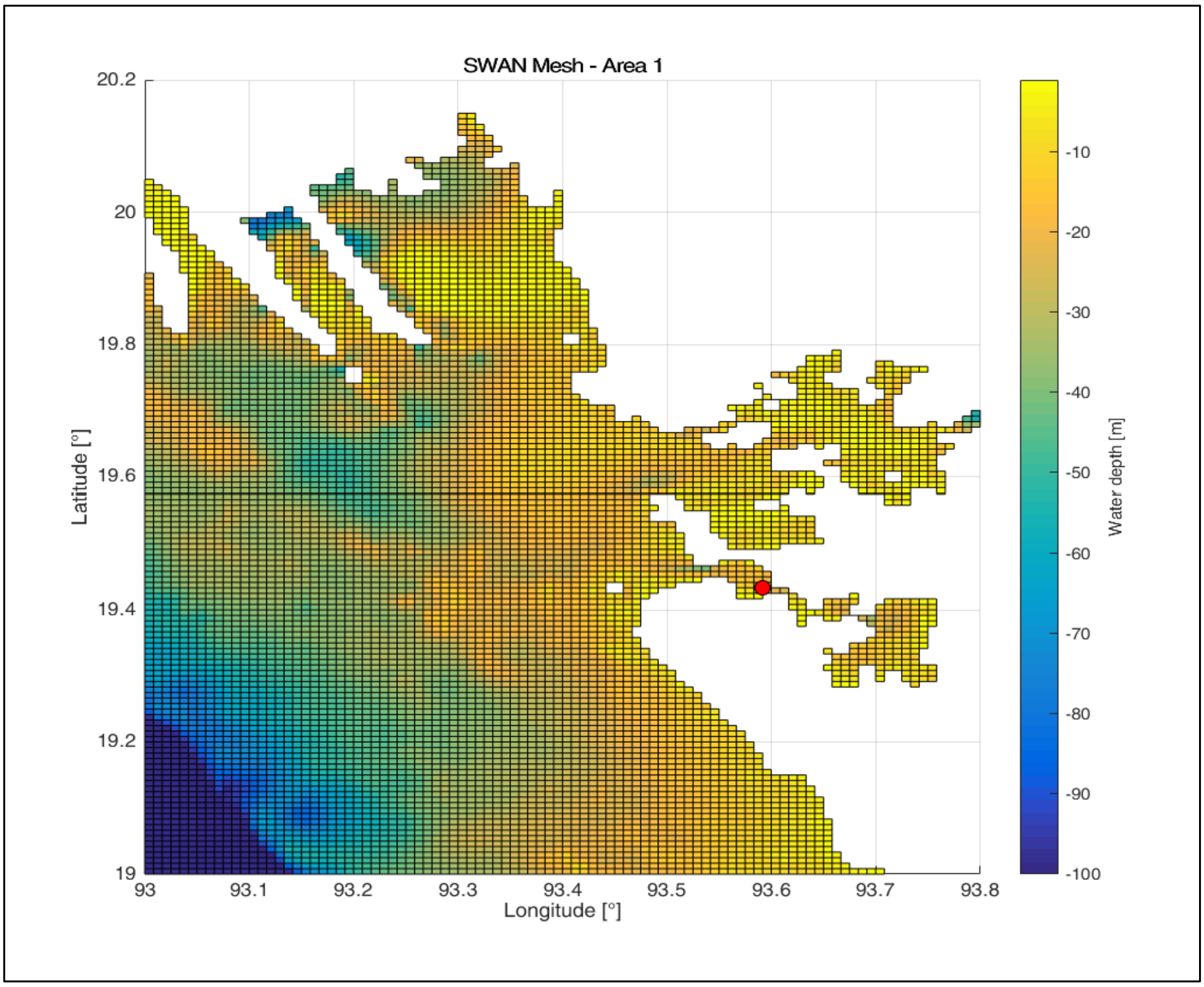
## A.10.2 Results

### A.10.2.1 Waiting on Weather Statistics

### Location 1 – Kyauk Phyu

The location used for the berth analysis is 19.4332° N 093.5914° E and is shown in the figure below:

**Figure 137 - Berth Analysis for Site 1: Kayauk Phyu**




The analysis was unable to model the exact Site location but at this distance up the Madegyan River all wave effects have been reduced to minimal levels. The data is therefore slightly conservative for the actual berth location.

## Table 41 - Site 1 (Kyauk Phyu): Waiting on Weather analysis (Hs ≤ 1.5m)

**Area 1 - 19.4332°N 093.5914°E - Water depth = 16m**
**Probability of exceedance of waiting time - Hs <= 1.50 m**

| | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **3-hour window** | | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 1% | 4% | 11% | 6% | 4% | 2% | 7% | 7% | 7% | 2% |
| Hs <= 1.50 m | >= 48 hrs | 0% | 0% | 1% | 3% | 9% | 5% | 3% | 2% | 6% | 6% | 6% | 2% |
| Hs <= 1.50 m | >= 72 hrs | 0% | 0% | 1% | 3% | 8% | 4% | 3% | 1% | 5% | 5% | 5% | 1% |
| **6-hour window** | | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 1% | 4% | 11% | 6% | 4% | 2% | 7% | 7% | 7% | 2% |
| Hs <= 1.50 m | >= 48 hrs | 0% | 0% | 1% | 4% | 10% | 5% | 3% | 2% | 6% | 6% | 6% | 2% |
| Hs <= 1.50 m | >= 72 hrs | 0% | 0% | 1% | 3% | 8% | 4% | 3% | 1% | 5% | 5% | 5% | 1% |
| **12-hour window** | | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 1% | 4% | 12% | 6% | 4% | 2% | 8% | 7% | 7% | 2% |
| Hs <= 1.50 m | >= 48 hrs | 0% | 0% | 1% | 4% | 10% | 5% | 3% | 2% | 6% | 6% | 6% | 2% |
| Hs <= 1.50 m | >= 72 hrs | 0% | 0% | 1% | 3% | 8% | 4% | 3% | 1% | 5% | 5% | 5% | 1% |
| **24-hour window** | | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 1% | 4% | 13% | 7% | 4% | 2% | 8% | 8% | 8% | 2% |
| Hs <= 1.50 m | >= 48 hrs | 0% | 0% | 1% | 4% | 11% | 6% | 4% | 2% | 7% | 7% | 7% | 2% |
| Hs <= 1.50 m | >= 72 hrs | 0% | 0% | 1% | 4% | 9% | 5% | 3% | 2% | 6% | 6% | 6% | 1% |
| **48-hour window** | | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 1% | 5% | 14% | 8% | 5% | 3% | 9% | 9% | 9% | 2% |
| Hs <= 1.50 m | >= 48 hrs | 0% | 0% | 1% | 5% | 12% | 7% | 4% | 2% | 8% | 8% | 8% | 2% |
| Hs <= 1.50 m | >= 72 hrs | 0% | 0% | 1% | 5% | 10% | 6% | 4% | 2% | 7% | 7% | 7% | 2% |
| **72-hour window** | | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 1% | 6% | 15% | 9% | 6% | 3% | 10% | 10% | 10% | 3% |
| Hs <= 1.50 m | >= 48 hrs | 0% | 0% | 1% | 6% | 14% | 8% | 5% | 3% | 9% | 9% | 9% | 2% |
| Hs <= 1.50 m | >= 72 hrs | 0% | 0% | 1% | 5% | 12% | 7% | 5% | 2% | 8% | 8% | 8% | 2% |
| **96-hour window** | | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 1% | 7% | 17% | 10% | 6% | 3% | 11% | 11% | 11% | 3% |
| Hs <= 1.50 m | >= 48 hrs | 0% | 0% | 1% | 7% | 15% | 9% | 6% | 3% | 10% | 10% | 10% | 3% |
| Hs <= 1.50 m | >= 72 hrs | 0% | 0% | 1% | 6% | 13% | 8% | 5% | 2% | 9% | 9% | 8% | 2% |

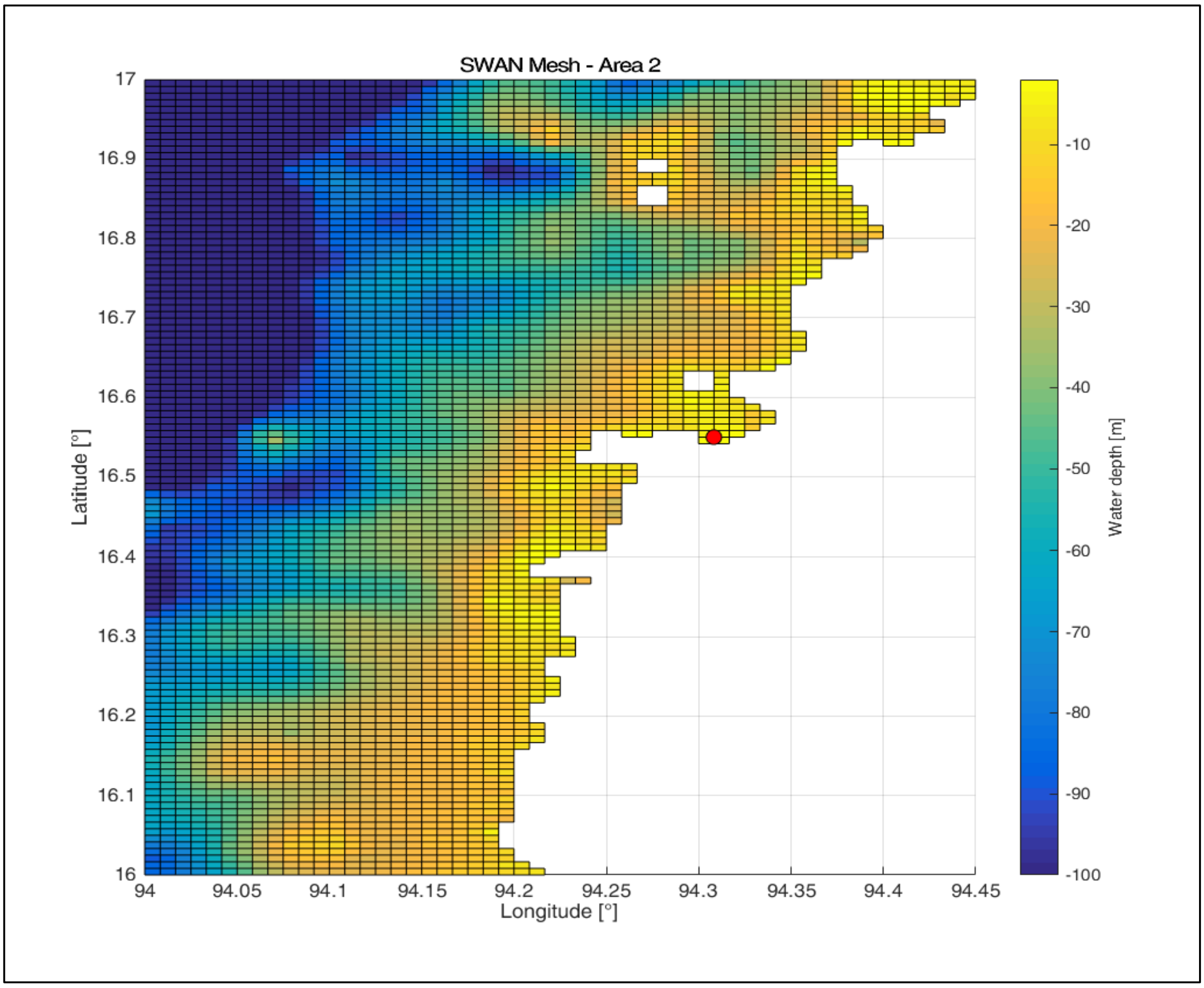
**Maximum waiting time in 20Y [hrs] - Hs <= 1.50m**

| | Weather window | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.50 m | 3-hour | 0 | 0 | 147 | 201 | 249 | 195 | 303 | 165 | 219 | 225 | 195 | 177 |
| Hs <= 1.50 m | 6-hour | 0 | 0 | 150 | 204 | 252 | 198 | 306 | 165 | 222 | 228 | 198 | 180 |
| Hs <= 1.50 m | 12-hour | 0 | 0 | 156 | 210 | 258 | 204 | 312 | 165 | 228 | 234 | 204 | 186 |
| Hs <= 1.50 m | 24-hour | 0 | 0 | 168 | 222 | 270 | 216 | 324 | 168 | 240 | 246 | 216 | 198 |
| Hs <= 1.50 m | 48-hour | 0 | 0 | 192 | 246 | 294 | 240 | 348 | 192 | 264 | 270 | 240 | 222 |
| Hs <= 1.50 m | 72-hour | 0 | 0 | 216 | 270 | 318 | 264 | 372 | 216 | 288 | 294 | 264 | 246 |
| Hs <= 1.50 m | 96-hour | 0 | 0 | 240 | 294 | 342 | 288 | 396 | 240 | 312 | 318 | 288 | 270 |

## Location 2 – Nga Yoke Kaung

Two points need to be considered at Nga Yoke Kaung. The first point (Site 2A) is at the berth location close to the southern headland within the bay. This is at 16.5418° N 094.3082° E and is shown in the figure below:

**Figure 138 - Berth Analysis for Site 2A: Nga Yoke Kaung**




The second site is in deep water and exposed. The current pilot station data suitably represents the conditions at this point, therefore the model has not been re-run.

**Table 42 - Site 2A (Nga Yoke Kaung): Waiting on Weather analysis (Hs ≤ 1.5m)**

| Area 2 - 16.5498°N 094.3082°E - Water depth = 2m<br>Probability of exceedance of waiting time - Hs <= 1.50 m | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3-hour window | | | | | | | | | | | | | |
| Hs <= 1.50 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 2% | 10% | 2% | 1% | 2% | 3% | 7% | 6% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 2% | 9% | 2% | 1% | 2% | 2% | 6% | 5% | 1% |
| | >= 72 hrs | 0% | 0% | 1% | 2% | 7% | 1% | 1% | 1% | 2% | 5% | 4% | 1% |
| 6-hour window | | | | | | | | | | | | | |
| Hs <= 1.50 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 2% | 10% | 2% | 1% | 2% | 3% | 7% | 7% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 2% | 9% | 2% | 1% | 2% | 2% | 6% | 6% | 1% |
| | >= 72 hrs | 0% | 0% | 1% | 2% | 7% | 1% | 1% | 1% | 2% | 5% | 5% | 1% |
| 12-hour window | | | | | | | | | | | | | |
| Hs <= 1.50 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 2% | 11% | 2% | 1% | 2% | 3% | 7% | 7% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 2% | 9% | 2% | 1% | 2% | 2% | 7% | 6% | 2% |
| | >= 72 hrs | 0% | 0% | 1% | 2% | 7% | 1% | 1% | 1% | 2% | 6% | 5% | 1% |
| 24-hour window | | | | | | | | | | | | | |
| Hs <= 1.50 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 3% | 11% | 2% | 2% | 2% | 3% | 8% | 7% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 2% | 10% | 2% | 1% | 2% | 2% | 7% | 6% | 2% |
| | >= 72 hrs | 0% | 0% | 1% | 2% | 8% | 2% | 1% | 1% | 2% | 6% | 5% | 1% |
| 48-hour window | | | | | | | | | | | | | |
| Hs <= 1.50 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 3% | 13% | 3% | 2% | 2% | 3% | 10% | 7% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 3% | 11% | 2% | 2% | 2% | 3% | 9% | 6% | 2% |
| | >= 72 hrs | 0% | 0% | 1% | 3% | 9% | 2% | 2% | 1% | 2% | 8% | 5% | 2% |
| 72-hour window | | | | | | | | | | | | | |
| Hs <= 1.50 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 4% | 14% | 3% | 3% | 2% | 4% | 11% | 8% | 3% |
| | >= 48 hrs | 0% | 0% | 1% | 3% | 12% | 3% | 2% | 2% | 3% | 10% | 7% | 2% |
| | >= 72 hrs | 0% | 0% | 1% | 3% | 11% | 2% | 2% | 2% | 3% | 9% | 6% | 2% |
| 96-hour window | | | | | | | | | | | | | |
| Hs <= 1.50 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 4% | 15% | 3% | 3% | 3% | 4% | 12% | 8% | 3% |
| | >= 48 hrs | 0% | 0% | 1% | 4% | 14% | 3% | 3% | 2% | 4% | 11% | 7% | 3% |
| | >= 72 hrs | 0% | 0% | 1% | 4% | 12% | 3% | 3% | 2% | 3% | 10% | 6% | 2% |

| Maximum waiting time in 20Y [hrs] - Hs <= 1.50m | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weather window | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Hs <= 1.50 m | 3-hour | 0 | 0 | 153 | 207 | 261 | 177 | 147 | 153 | 207 | 231 | 273 | 159 |
| | 6-hour | 0 | 0 | 156 | 210 | 264 | 180 | 150 | 156 | 210 | 234 | 276 | 162 |
| | 12-hour | 0 | 0 | 162 | 216 | 270 | 186 | 156 | 162 | 216 | 282 | 279 | 168 |
| | 24-hour | 0 | 0 | 174 | 228 | 282 | 198 | 168 | 174 | 228 | 294 | 279 | 180 |
| | 48-hour | 0 | 0 | 198 | 252 | 306 | 222 | 192 | 198 | 252 | 318 | 279 | 204 |
| | 72-hour | 0 | 0 | 222 | 276 | 330 | 246 | 216 | 222 | 276 | 342 | 279 | 228 |
| | 96-hour | 0 | 0 | 246 | 300 | 354 | 270 | 240 | 246 | 300 | 366 | 282 | 252 |

**Table 43 - Site 2B (Nga Yoke Kaung): Waiting on Weather analysis (Hs ≤ 2.0m)**

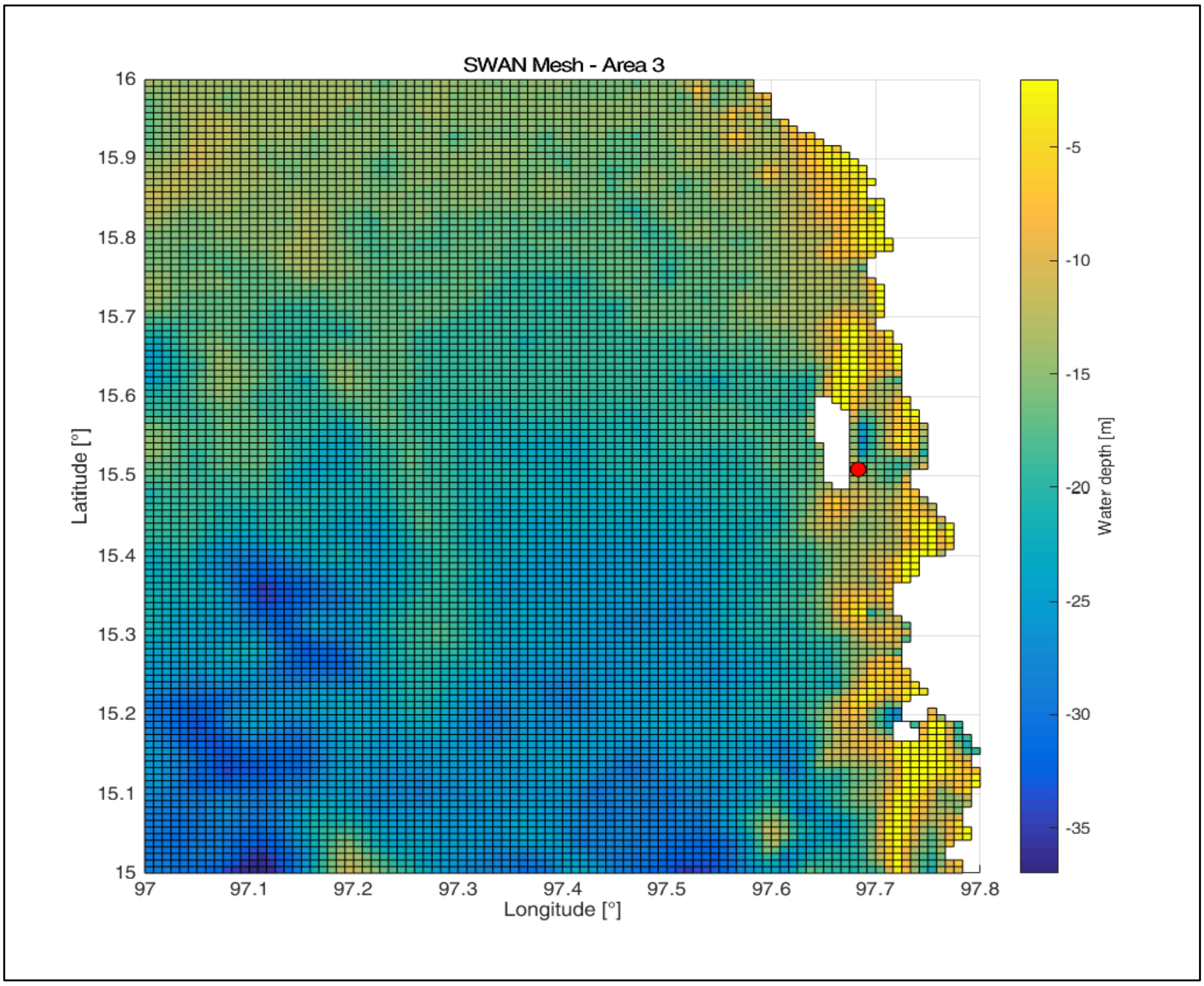
| Area 2 - 16.6331°N 094.2582°E - Water depth = 19m<br>Probability of exceedance of waiting time - Hs <= 2.00 m | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **3-hour window** | | | | | | | | | | | | | |
| Hs <= 2.00 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 3% | 13% | 26% | 27% | 20% | 6% | 8% | 6% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 2% | 10% | 21% | 22% | 15% | 4% | 7% | 5% | 1% |
| | >= 72 hrs | 0% | 0% | 1% | 2% | 8% | 17% | 17% | 12% | 3% | 6% | 4% | 1% |
| **6-hour window** | | | | | | | | | | | | | |
| Hs <= 2.00 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 3% | 13% | 27% | 28% | 21% | 7% | 8% | 6% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 2% | 11% | 22% | 23% | 16% | 4% | 7% | 5% | 1% |
| | >= 72 hrs | 0% | 0% | 1% | 2% | 8% | 18% | 18% | 12% | 3% | 6% | 4% | 1% |
| **12-hour window** | | | | | | | | | | | | | |
| Hs <= 2.00 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 3% | 14% | 29% | 31% | 23% | 8% | 9% | 6% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 3% | 11% | 24% | 24% | 17% | 5% | 7% | 5% | 2% |
| | >= 72 hrs | 0% | 0% | 1% | 2% | 9% | 19% | 19% | 13% | 3% | 6% | 4% | 1% |
| **24-hour window** | | | | | | | | | | | | | |
| Hs <= 2.00 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 3% | 16% | 35% | 36% | 27% | 9% | 10% | 6% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 3% | 13% | 30% | 31% | 21% | 6% | 8% | 5% | 2% |
| | >= 72 hrs | 0% | 0% | 1% | 3% | 11% | 25% | 26% | 16% | 4% | 7% | 4% | 1% |
| **48-hour window** | | | | | | | | | | | | | |
| Hs <= 2.00 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 4% | 19% | 42% | 44% | 34% | 13% | 11% | 7% | 2% |
| | >= 48 hrs | 0% | 0% | 1% | 4% | 16% | 36% | 39% | 28% | 9% | 10% | 6% | 2% |
| | >= 72 hrs | 0% | 0% | 1% | 3% | 13% | 31% | 34% | 23% | 6% | 9% | 5% | 2% |
| **72-hour window** | | | | | | | | | | | | | |
| Hs <= 2.00 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 5% | 22% | 50% | 51% | 40% | 17% | 13% | 7% | 3% |
| | >= 48 hrs | 0% | 0% | 1% | 4% | 19% | 46% | 46% | 34% | 13% | 12% | 6% | 2% |
| | >= 72 hrs | 0% | 0% | 1% | 4% | 16% | 41% | 41% | 29% | 10% | 10% | 5% | 2% |
| **96-hour window** | | | | | | | | | | | | | |
| Hs <= 2.00 m | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | >= 24 hrs | 0% | 0% | 1% | 5% | 25% | 56% | 56% | 44% | 20% | 15% | 8% | 3% |
| | >= 48 hrs | 0% | 0% | 1% | 5% | 22% | 53% | 52% | 40% | 16% | 14% | 7% | 3% |
| | >= 72 hrs | 0% | 0% | 1% | 5% | 19% | 49% | 48% | 35% | 13% | 13% | 6% | 2% |

| Maximum waiting time in 20Y [hrs] - Hs <= 2.00m | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 2.00 m | Weather window | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| | 3-hour | 0 | 0 | 153 | 207 | 261 | 504 | 441 | 273 | 207 | 237 | 273 | 159 |
| | 6-hour | 0 | 0 | 156 | 210 | 264 | 507 | 444 | 276 | 210 | 240 | 276 | 162 |
| | 12-hour | 0 | 0 | 162 | 216 | 270 | 552 | 450 | 282 | 216 | 282 | 279 | 168 |
| | 24-hour | 0 | 0 | 174 | 228 | 348 | 564 | 462 | 294 | 228 | 294 | 279 | 180 |
| | 48-hour | 0 | 0 | 198 | 252 | 372 | 798 | 588 | 471 | 252 | 318 | 279 | 204 |
| | 72-hour | 0 | 0 | 222 | 276 | 396 | 1098 | 723 | 495 | 276 | 342 | 279 | 228 |
| | 96-hour | 0 | 0 | 246 | 300 | 420 | 1350 | 912 | 594 | 300 | 552 | 282 | 252 |

## Location 3 – Kalagauk Island

Two points need to be considered at Kalegauk Island. The first point (Site 3A) is at the berth location on the eastern side of the island. This is at 15.5081° N 097.6837° E and is shown in the figure below:

Figure 139 - **Berth Analysis for Site 3A: Kalegauk Island**




The second site is in deep water and exposed. The current pilot station data suitably represents the conditions at this point, therefore the model has not been re-run.

## Table 44 - Site 3 (Kalegauk Island): Waiting on Weather analysis (Hs ≤ 1.5m)

**Area 3 - 15.5081°N 097.6831°E - Water depth = 18m**
**Probability of exceedance of waiting time - Hs <= 1.50 m**

| | Waiting time [hrs] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **3-hour window** | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 0% | 1% | 3% | 0% | 1% | 2% | 4% | 8% | 4% | 1% |
| | >= 48 hrs | 0% | 0% | 0% | 1% | 2% | 0% | 1% | 2% | 3% | 7% | 3% | 1% |
| | >= 72 hrs | 0% | 0% | 0% | 1% | 2% | 0% | 1% | 1% | 2% | 6% | 2% | 1% |
| | **6-hour window** | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 0% | 1% | 3% | 0% | 1% | 2% | 4% | 8% | 4% | 1% |
| | >= 48 hrs | 0% | 0% | 0% | 1% | 2% | 0% | 1% | 2% | 3% | 7% | 3% | 1% |
| | >= 72 hrs | 0% | 0% | 0% | 1% | 2% | 0% | 1% | 1% | 3% | 6% | 2% | 1% |
| | **12-hour window** | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 0% | 1% | 3% | 0% | 1% | 2% | 4% | 8% | 4% | 1% |
| | >= 48 hrs | 0% | 0% | 0% | 1% | 2% | 0% | 1% | 2% | 3% | 7% | 3% | 1% |
| | >= 72 hrs | 0% | 0% | 0% | 1% | 2% | 0% | 1% | 1% | 3% | 6% | 2% | 1% |
| | **24-hour window** | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 0% | 1% | 3% | 0% | 1% | 2% | 5% | 9% | 4% | 1% |
| | >= 48 hrs | 0% | 0% | 0% | 1% | 3% | 0% | 1% | 2% | 4% | 8% | 3% | 1% |
| | >= 72 hrs | 0% | 0% | 0% | 1% | 2% | 0% | 1% | 1% | 3% | 7% | 2% | 1% |
| | **48-hour window** | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 0% | 2% | 3% | 0% | 1% | 3% | 6% | 10% | 4% | 1% |
| | >= 48 hrs | 0% | 0% | 0% | 2% | 3% | 0% | 1% | 2% | 5% | 9% | 3% | 1% |
| | >= 72 hrs | 0% | 0% | 0% | 2% | 2% | 0% | 1% | 2% | 4% | 8% | 3% | 1% |
| | **72-hour window** | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 0% | 2% | 4% | 0% | 1% | 3% | 7% | 11% | 4% | 1% |
| | >= 48 hrs | 0% | 0% | 0% | 2% | 3% | 0% | 1% | 3% | 6% | 10% | 4% | 1% |
| | >= 72 hrs | 0% | 0% | 0% | 2% | 3% | 0% | 1% | 2% | 5% | 9% | 3% | 1% |
| | **96-hour window** | | | | | | | | | | | | |
| Hs <= 1.50 m | >= 24 hrs | 0% | 0% | 0% | 2% | 4% | 0% | 1% | 3% | 8% | 12% | 5% | 1% |
| | >= 48 hrs | 0% | 0% | 0% | 2% | 3% | 0% | 1% | 3% | 7% | 11% | 4% | 1% |
| | >= 72 hrs | 0% | 0% | 0% | 2% | 3% | 0% | 1% | 2% | 6% | 10% | 3% | 1% |

**Maximum waiting time in 20Y [hrs] - Hs <= 1.50m**

| | Weather window | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hs <= 1.50 m | 3-hour | 0 | 0 | 0 | 183 | 189 | 0 | 159 | 153 | 183 | 291 | 195 | 153 |
| | 6-hour | 0 | 0 | 0 | 186 | 192 | 0 | 162 | 156 | 186 | 294 | 195 | 156 |
| | 12-hour | 0 | 0 | 0 | 192 | 198 | 0 | 168 | 162 | 192 | 300 | 195 | 162 |
| | 24-hour | 0 | 0 | 0 | 204 | 210 | 0 | 180 | 174 | 204 | 312 | 195 | 174 |
| | 48-hour | 0 | 0 | 0 | 228 | 234 | 0 | 204 | 198 | 228 | 336 | 198 | 177 |
| | 72-hour | 0 | 0 | 0 | 252 | 258 | 0 | 228 | 222 | 252 | 360 | 222 | 177 |
| | 96-hour | 0 | 0 | 0 | 276 | 282 | 0 | 252 | 246 | 276 | 384 | 246 | 177 |

# Section B Marine Access Report

## B.1 Introduction

Wherever an LNG marine terminal is located, the berths must have safe navigational access for LNGCs under a range of environmental conditions. Therefore, the purpose of this report is to examine the following areas:

- LNGC navigation needs – Port Locations.
- LNGC Berth and Terminal Options.
- Marine Access Review for Location 1 – Kyauk Phyu.
- Marine Access Review for Location 2 – Nga Yoke Kaung.
- Marine Access Review for Location 3 – Kalegauk Island.

## B.2 LNGC Navigation Needs – Port Locations

### B.2.1 Use of the "Design Ship"

This study has adopted the following "Design Ship" because it is representative of the size and type of vessel that might reasonably be expected for both the FSRU and delivery ship elements of this project. There are larger LNGCs currently trading, as a consequence of the massive expansion in exports from Qatar – the QFlex LNGCs (215,000m3) and the QMax LNGCs (255,000m3). However, these are few in number, tend to be committed to long-term contracts, and it is understood that none have been used as an FSRU.

**Figure 140 -** "Maersk Methane"

**Table 45 - "Maersk Methane" has the following principal dimensions:**

| Characteristic | Value |
|---|---|
| Length Over All (LOA) | 285.0m |
| Beam Width | 43.4m |
| Maximum Draft | 12.1m |
| Displacement | 113,609 tonnes |
| Deadweight | 82,115 dwt |
| Capacity | 163,195 m3 |

Industry best practice (much of which is described in SIGTTO Working Paper 14) points towards the following water space requirements for the above vessel:

**Table 46 - Water space requirements for "Maersk Methane"**

| | |
|---|---|
| Minimum water depth required | LNGC draft x 1.1 |
| Channel width required | LNGC width x 4 or 5 |
| Turning circle required | LNGC length x 1.5 to 2.0 |

**Figure 141 - Typical Minimum Water Depth Requirements For LNGC**

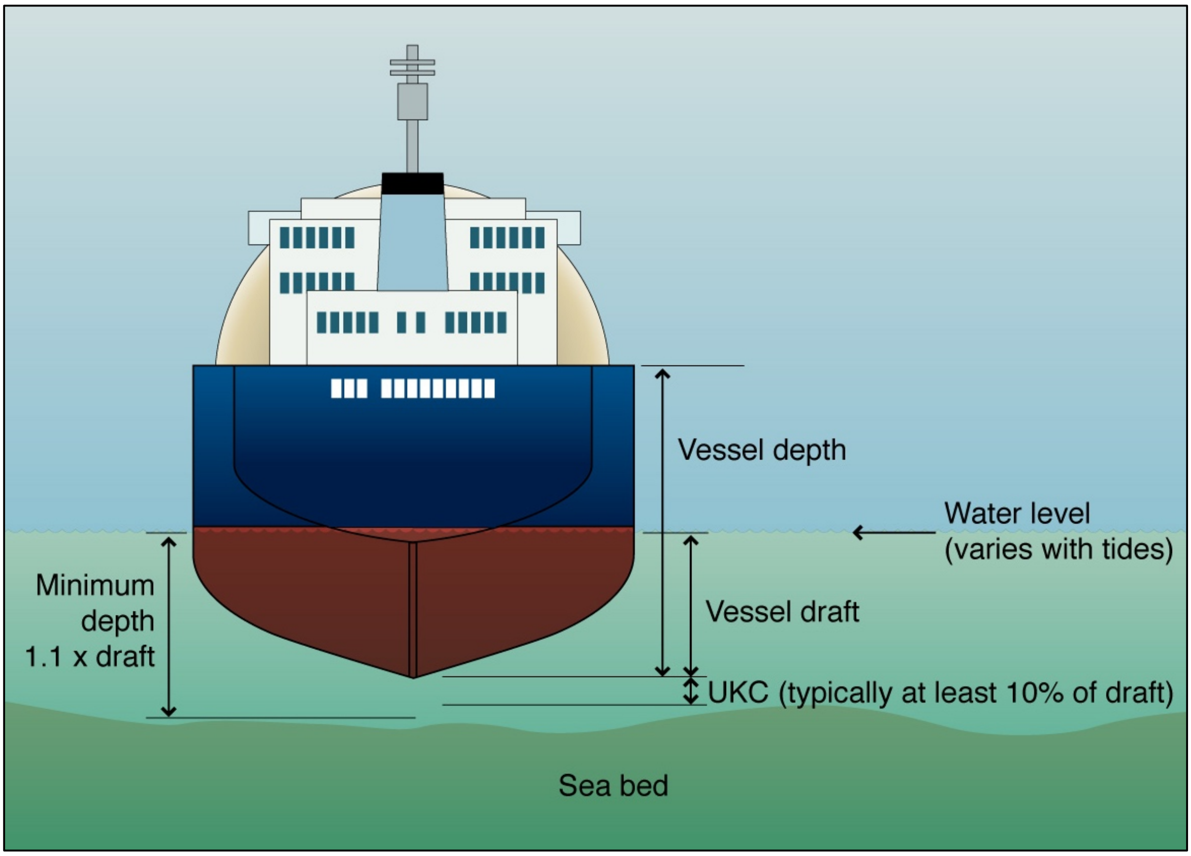


**Figure 142 - Typical Channel Width Requirements For LNGC**

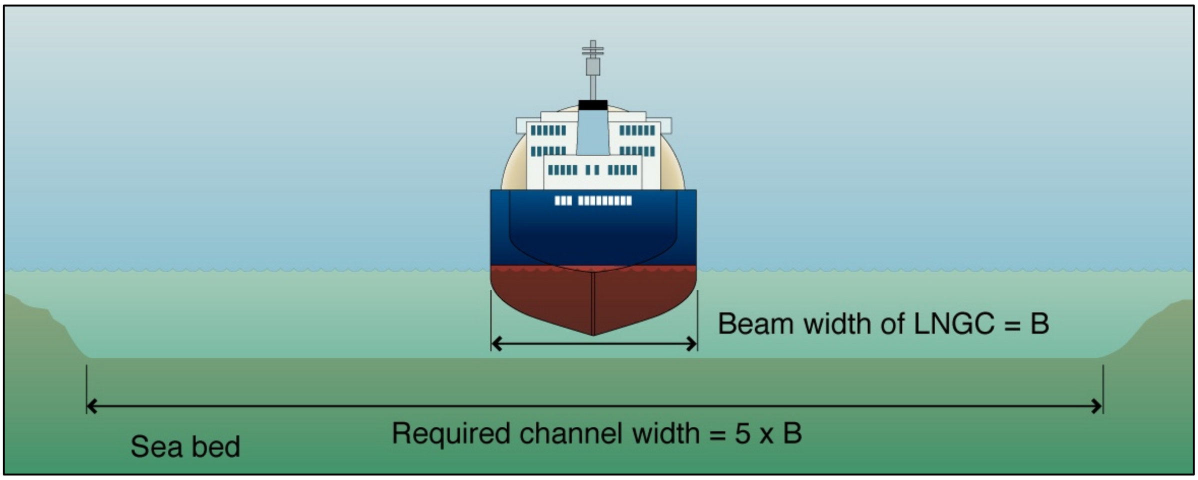
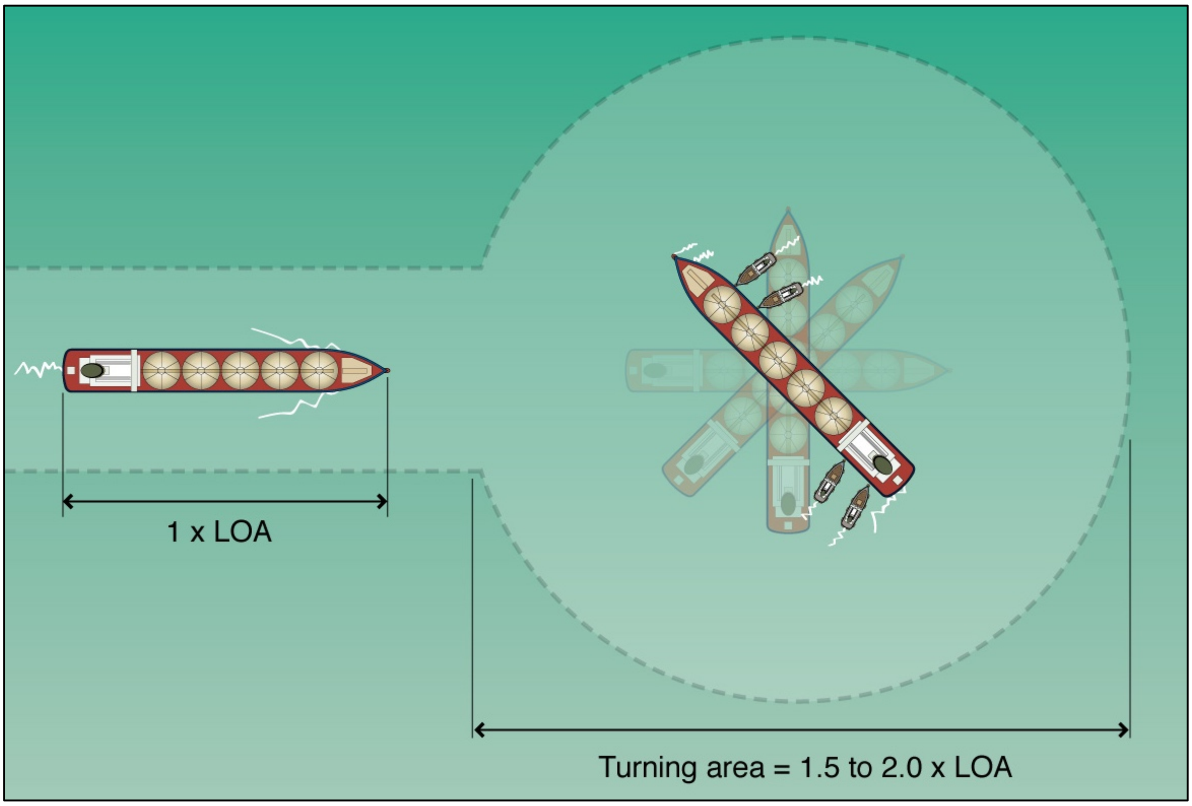



**Figure 143 - Typical Turning Area Requirements For LNGC**




Therefore, for our “Design Ship”, any of the study port sites would have to have natural or man-made water space as follows:

**Table 47 - Water space requirements for "Design Ship"**

| | |
|---|---|
| Minimum water depth required (LNGC draft x 1.1 | 13.3m (say 14.0m) |
| Channel width required (LNGC width x 4 or 5) | 174m to 217m |
| Turning circle required (LNGC LOA x 1.5 to 2.0) | 428m to 570m |

# B.3 LNGC Berth and Terminal Options

## B.3.1 Conventional Berth Concepts

SIGTTO and best practice also gives guidance on siting an LNG terminal, much of which relates to safety and the need to ensure that any escape of gas does not impact nearby communities.

As this study has not identified any potential land for an LNG terminal, only very general consideration can be given to the type of berth solutions, which might be appropriate. As can be seen, there are many options for berths. The final design will depend on a wide range of factors such as soil condition, land availability, current flows, exposure to waves etc.

**Figure 144 - Concept 1: Long Trestle and Nil Dredging**

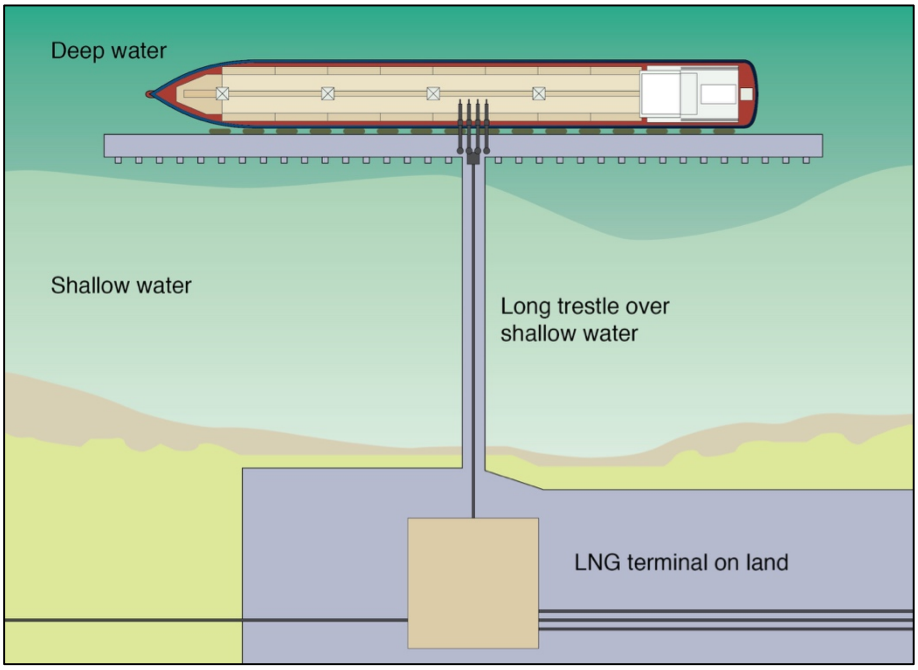


**Figure 145 - Concept 2: Short Trestle and Most Dredging**

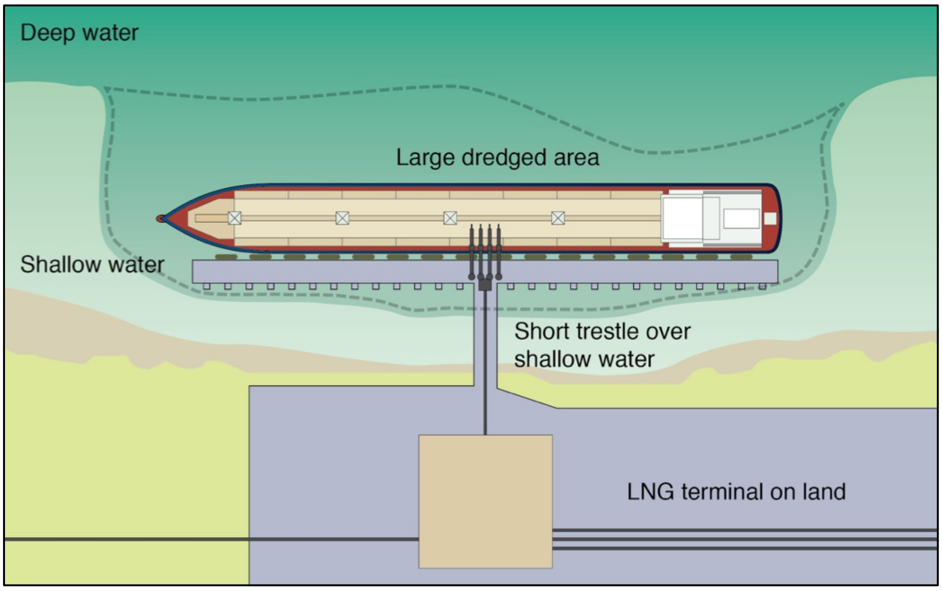



**Figure 146 - Concept 3: Optimised Trestle and Dredging**

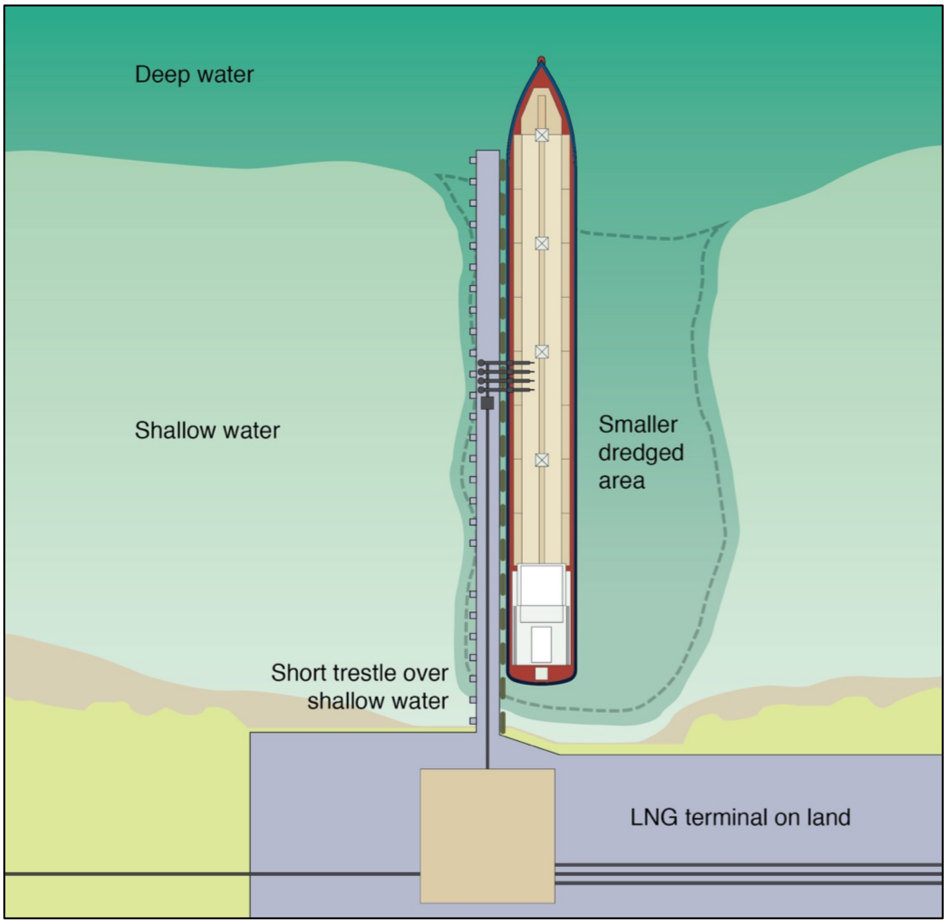


**Figure 147 - Concept 4: In-Line Berthing**

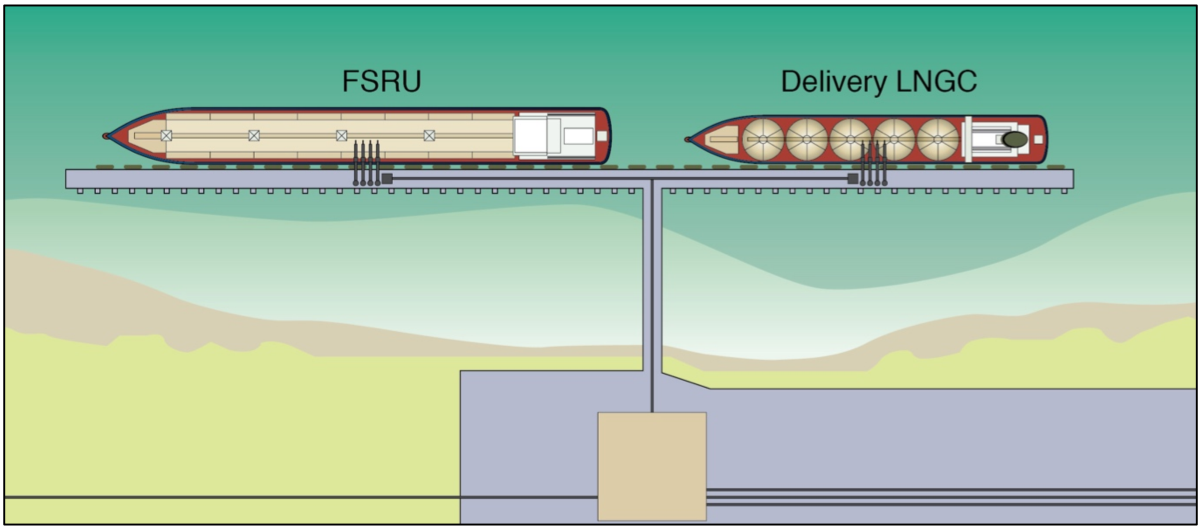
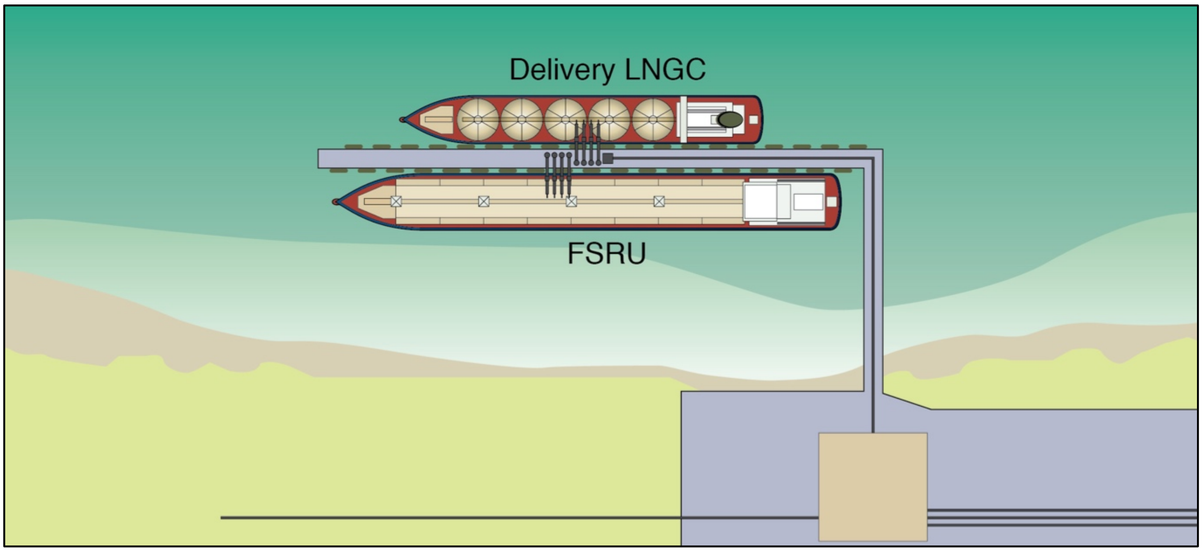



**Figure 148 - Concept 5: Tandem Berthing**




## B.3.2 FLNG Moored Concepts

Here, consideration is given to the concept of an FLNG moored in a port area, but without the construction of a traditional trestle and berth.

Much of the preceding aspects around water depth, channel width, turning area, and shelter from waves holds true. The FLNG still has to navigate safely in to its chosen location and, eventually, away again at the end of the project. The delivery LNGCs have to safely navigate from open sea to the FLNG site, and return when cargo is transferred.

The key aspects for an FLNG site, which is inside a port area, but does not include a berth, are as follows:

- The "navigability" of the waterways for the FLNG and offloading LNGCs.

- An area which is sufficiently unaffected by passing shipping, especially when the delivery LNGC is alongside the FSRU and cargo is being transferred via Ship To Ship (STS) method.
- A configuration that allows for the Delivery LNGC to effect a safe approach and departure, when allowing for tidal flows.
- An area where the currents and winds are favourable to allow safe berthing of the LNGC alongside the FLNG.
- Soil conditions that allow for a suitable engineered system of moorings for the FLNG, including when the LNGC is alongside.
- A seabed that adequately allows for the gas pipeline to run from the FLNG to shore, and thence to the land based distribution network.

After considering the detail of all of the above, an FLNG site without a berth and inside a port area is likely to resemble the following design sketches:

**Figure 149 - Mooring position of FLNG inside a port area**

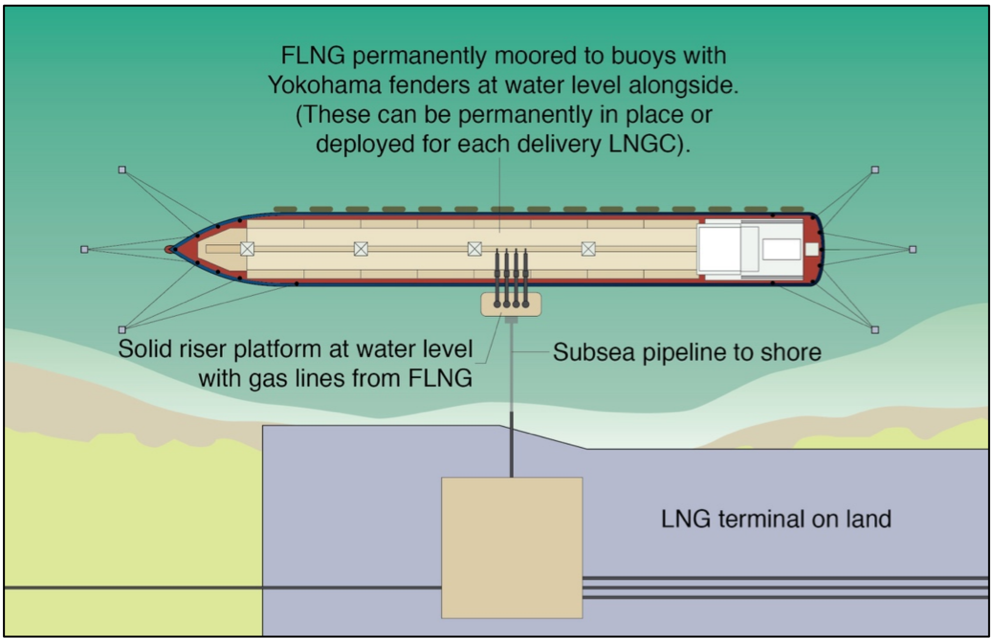


**Figure 150 - Method of FLNGC positioning**

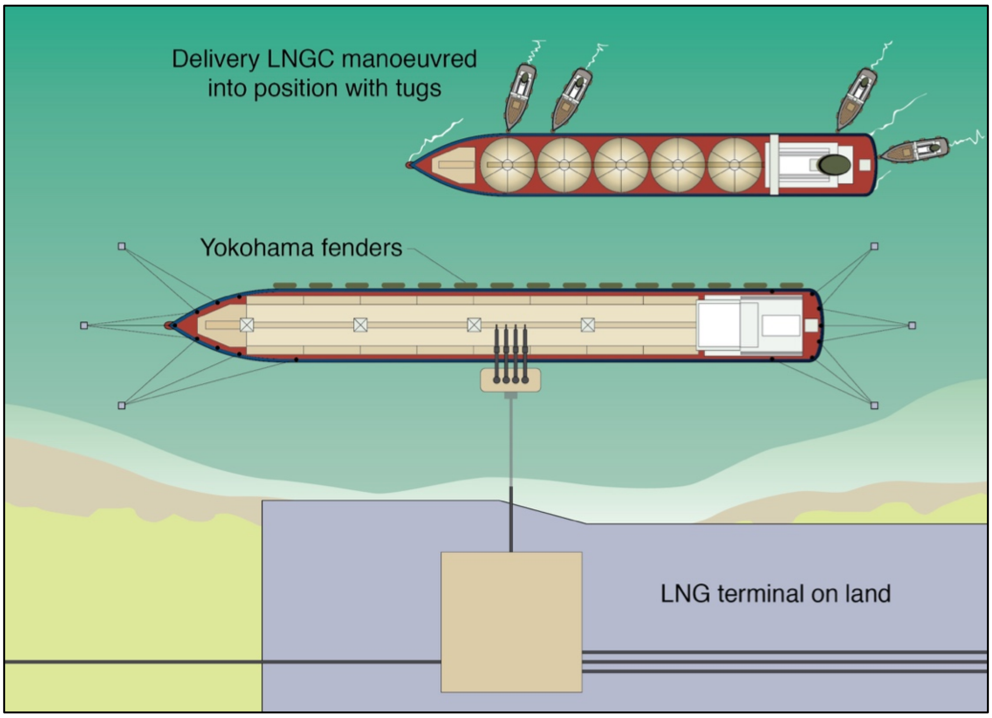



**Figure 151 - Mooring of FLNGC to FLNG**

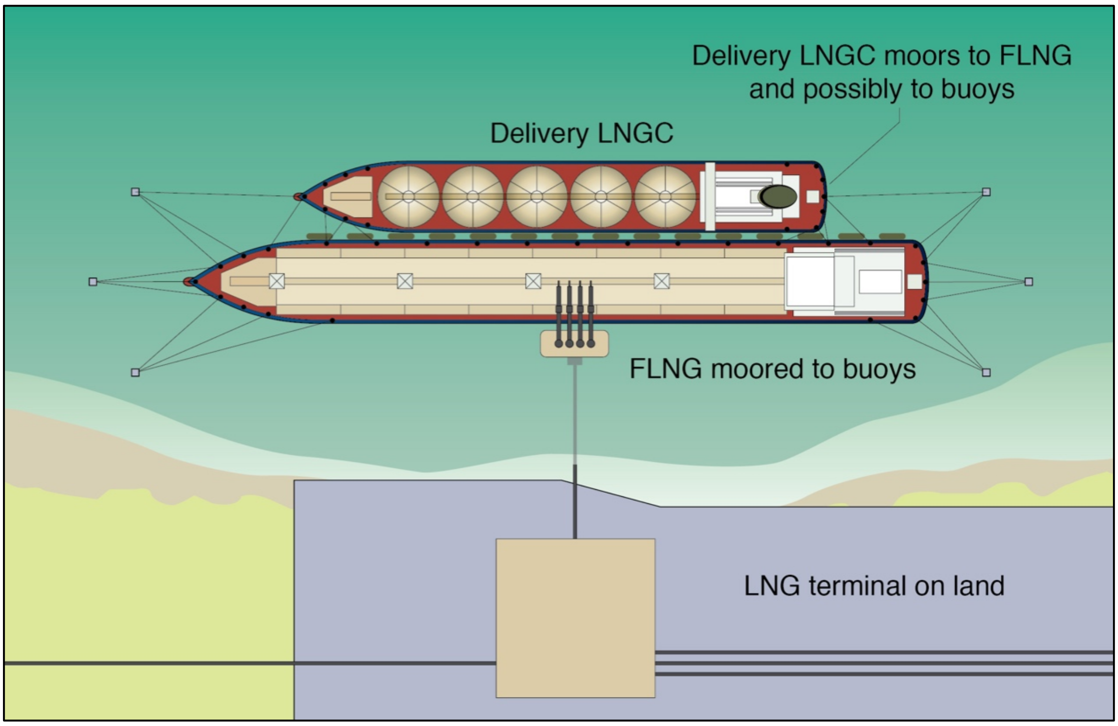


**Figure 152 - Ship To Ship (STS) transfer of LNG**

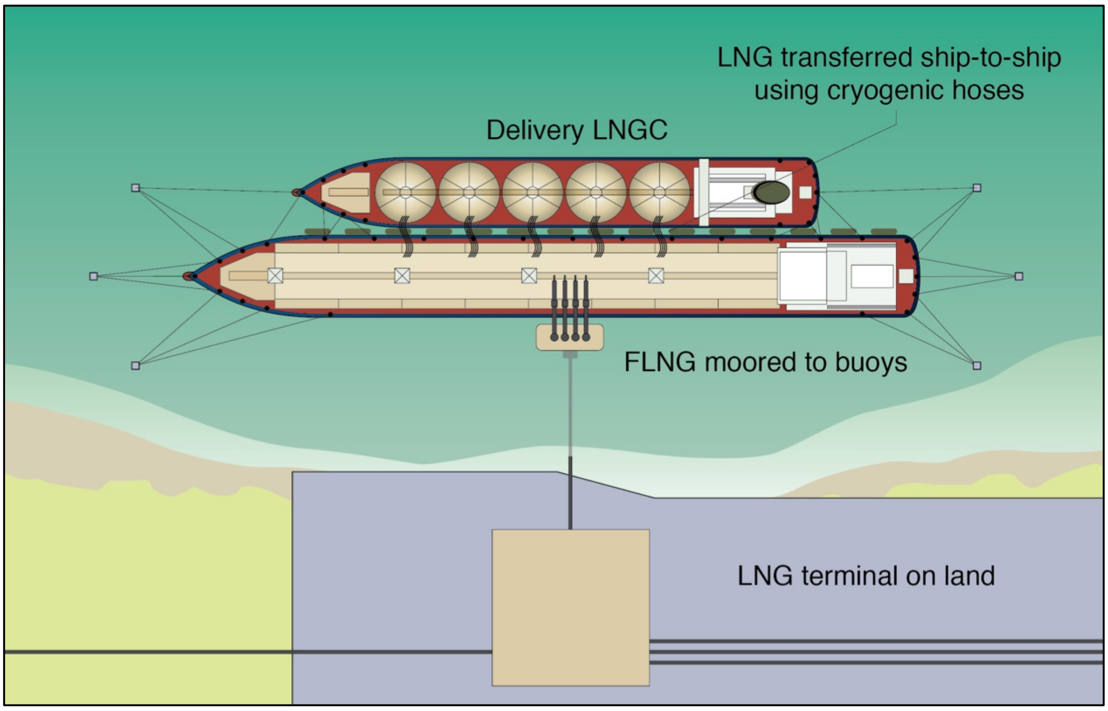
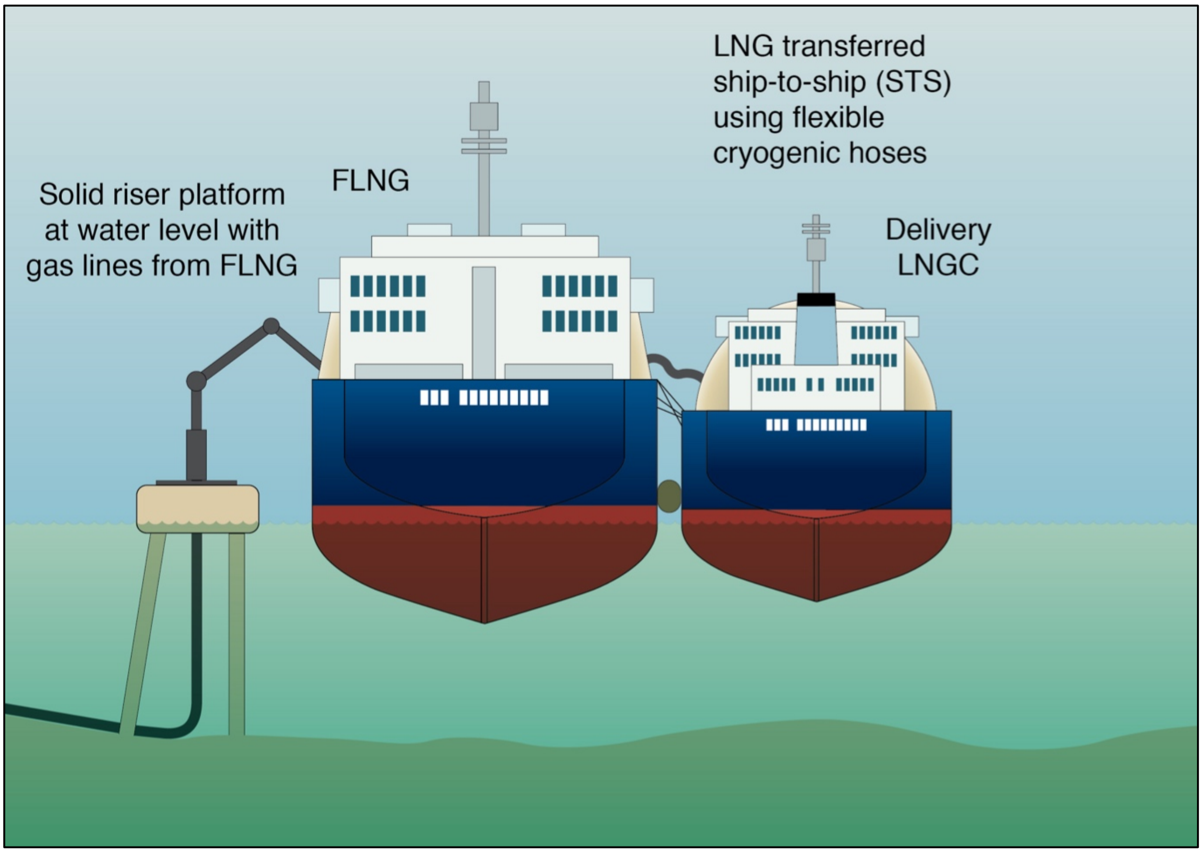



**Figure 153 - STS LNG transfer and onwards gas transfer from FLNG**



# B.4 Marine Access Review for Location 1 – Kyauk Phyu

## B.4.1 Navigational Suitability

Based on a review of UK Admiralty Chart No. 817 and information gathered during the in-country visit, the port has an existing deep-water channel with a depth of 22m. This seems to be the natural depth from open sea to the coastline, as well as the depth to which dredging has occurred within the port area (i.e. between the coast and the Maday Island Oil Terminal.

No data is available to confirm the navigable width of the channel but, as it is clearly capable of supporting navigation of large oil tankers (Very Large Crude Carriers, or VLCCs), it can be assumed that the channel width is also sufficient to support safe navigation of LNGCs.

**Figure 154 - Water depth at Location 1**

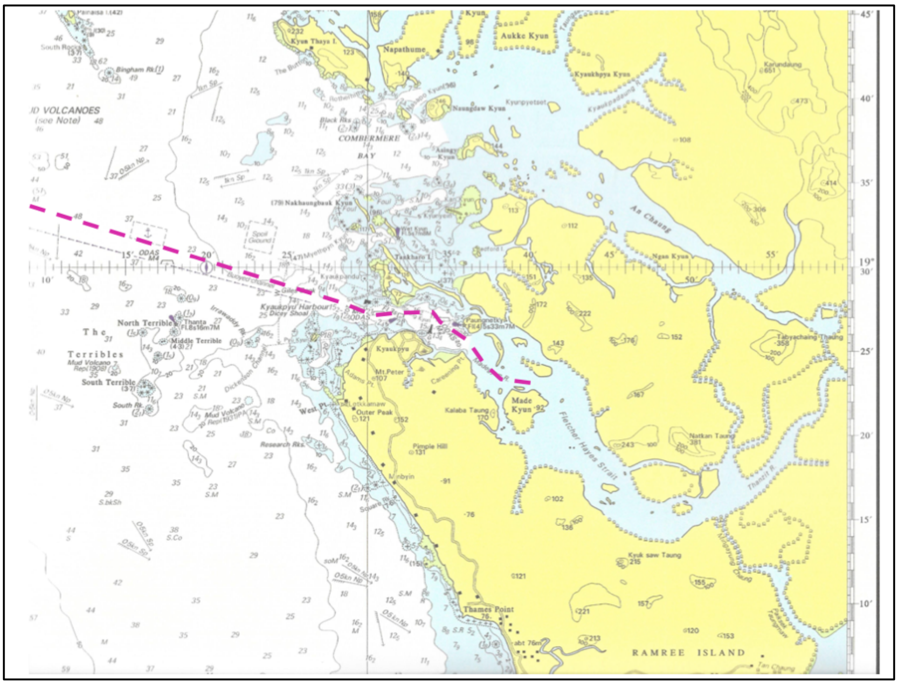


**Figure 155 - Google Map view of Location 1 potential turning circle**

In terms of the turning circle, this depends on the location of a terminal at the site. However, an examination of the chart and Google Earth indicates that a suitable turning circle either exists, or can be created, within the port area.

### B.4.2 Environmental Conditions

As can be seen in the Metocean section of this report, the site is fully exposed to the SW Monsoons, which blow across The Bay of Bengal for a significant part of each year. Wave and swell energy is almost entirely from the SW, so the challenge is to find a site within the port area where some shelter is derived from this wave energy.

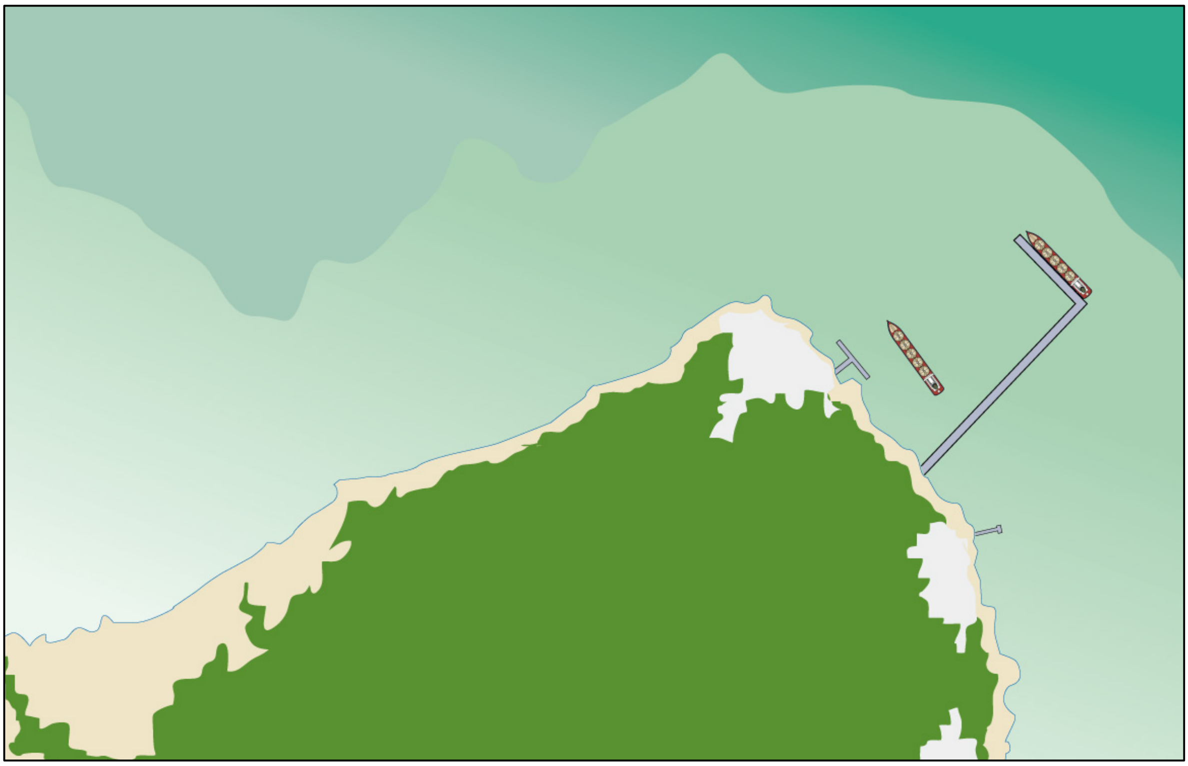
As can be seen from the following Figures, Kyauk Phyu town, port, and deep-water areas are all sheltered from the SW by the Kyauk Phyu headland which rises to over 150m above sea level. There will be some penetration and refraction of south westerly waves around the north end of Kyauk Phyu peninsular, and detailed local studies would be required to ascertain the places within the port which have the most favourable locations for an FSRU and STS operations. However, the fact that there is an existing port at the area, suggests that suitably benign conditions do exist east of Kyauk Phyu town.

### B.4.3 Berth and Terminal Options

Without knowing which land is available or suitable for building the LNG terminal, it is clearly not possible to know which berth options might be feasible for this site. However, to provide an indication of the type of concept that might be feasible for this site, the following sketches are provided. It assumes that suitable land is available adjacent to what appears to be an existing naval base, about 5km east of Kyauk Phyu town and port.

**Figure 156 - Potential land for LNG terminal development at Location 1**


**Figure 157 - Conceptual LNG infrastructure at Location 1**



A non-berth / "moored" concept could work equally well in this and in many other parts of the port area.

### B.4.4 Supporting Services

Normal port industry databases (such as Fairplay World Shipping and Ports Encyclopaedia) and web searches do not confirm that a “port authority” or similar marine regulatory body exists. However, it is clear that the port area of Kyauk Phyu does have significant current and planned marine activity.

A Web report[38] confirms that the Kyauk Phyu Special Economic Zone (SEZ) includes an on-going commitment to support the Sino-Myanmar Oil and Gas Pipeline (as evidenced by the Maday Island Oil Terminal), and alludes to a planned “Deep Water Port”.

It is therefore highly probable that some form of “port authority”, possibly under military jurisdiction, does exist, and will fulfil the regulatory functions and support services that a port requires, including:

- Conservancy (surveying of waterways; dredging; marking of navigational hazards; provision of navigation aids etc).
- Pilotage.
- Vessel Traffic Services (VTS).
- Oil spill response and other emergency services.
- Towage.

Google Earth imagery indicates that there are / were 5 tugs moored at a lay-by berth adjacent to the Maday Oil Terminal.

**Figure 158 - 5 Tugs Moored at Maday Oil Terminal**


Again, no detail can be found as to the technical specification or availability of these tugs, but the following points are positive indictors:

[38] *http://www.idsa.in/backgrounder/myanmar-in-chinas-push-into-the-indian-ocean_jmpaul_120316*

A. Measured by Google Earth tools, these tugs are each about 48m in length, which would suggest that they are capable of providing a bollard pull (BP) force of 45 to 60 tonnes when operated in the normal direct towage manner. Typically, a loaded LNGC would require about 180t to 240t of BP for safe berthing.
B. Subject to further investigation about the capability and availability of these tugs, the early suggestion is that suitable towage resources are available at Kyauk Phyu, with a total BP of approximately 250t.

Even if these tugs did prove to be suitable for LNG operations, it is not known if they are commercially available. However, it is probable that they currently have a very low level of utilisation so it would be worthwhile making enquiries at a later stage. Towage is always a high cost aspect of operating any LNG facility and utilising existing towage assets at a port is always going to be preferable to bringing in tugs from outside.

### B.4.5 Summary and Conclusions

Kyauk Phyu has most, possibly all, of the key basic requirements for building an LNG marine terminal:

- Water depth in the main navigation channel in excess of 14m.
- Channel width in excess of 5 x beam of the LNGC.
- Potential areas to define and locate a turning circle.
- Potential areas to define a “pocket” to moor an FLNG terminal which is accessible by delivering LNGCs, but clear of existing shipping.
- Sheltered locations with favourable wave/swell and wind environments (currents not examined).
- Probable marine regulatory body (port authority or similar).
- Pilotage service (as evidenced by existing VLCC traffic).
- Existing (potentially available) towage service.

Accordingly, this site can be considered to have a high level of potential feasibility to build an LNG marine terminal for either a trestle / berth concept of a moored FLNG concept.

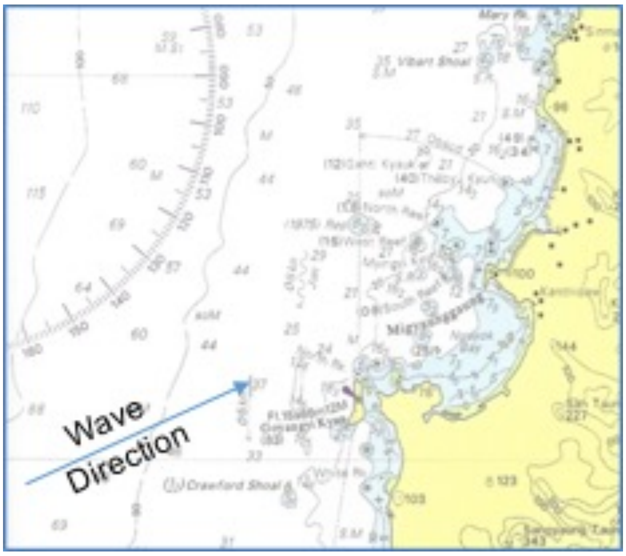
## B.5 Marine Access Review for Location 2 – Nga Yoke Kaung

### B.5.1 Navigational Suitability

Based on a review of UK Admiralty Chart No. 818, this site has deep water (in excess of 14m) from all directions right until the open bay naturally shallows over a 3-mile range into the west facing shoreline. There is no “channel” so the SIGTTO guidance on channel depth, channel width, and turning circles are not a factor.

However, it is here that the problems arise for Location 2.  As explained further below, this site is completely exposed to the dominant westerly and southwesterly waves and receives almost nil natural shelter from headlands. It is therefore going to be unsuitable without construction of an extensive breakwater or enclosed harbour and dredging. The only sheltered area in the west-facing bay lies in the extreme south end of the bay, where the water depth is about 1m.

**Figure 159 - Wave direction towards Location 2**




## B.5.2 Environmental Conditions

As with Kyauk Phyu, the site is exposed to the SW Monsoons, and the metocean data reflects a dominant wave and wind climate from the SW. Unlike Kyuak Phyu however, there is very little in the way of natural shelter. The very southern end of the bay probably does derive some limited shelter from the (unnamed) headland and from the off-lying Goyangyi Kyan island. Unfortunately, this potentially sheltered part of the bay is also the shallowest.

## B.5.3 Berth and Terminal Options

Although this is probably an environmental and financial “show-stopper”, the sketch below is provided to add context to the negative comments made in the preceding parts of this section. The sketch shows a conceptual design of a berth, which may derive a bit of shelter from the southern headland of the bay. Any place further north in the bay is highly unlikely to be suitable for either a berth concept or a moored concept FLNG terminal and this southern location is only accessed after extensive dredging shown.

**Figure 160 - Conceptual extent of dredging required at Location 2**

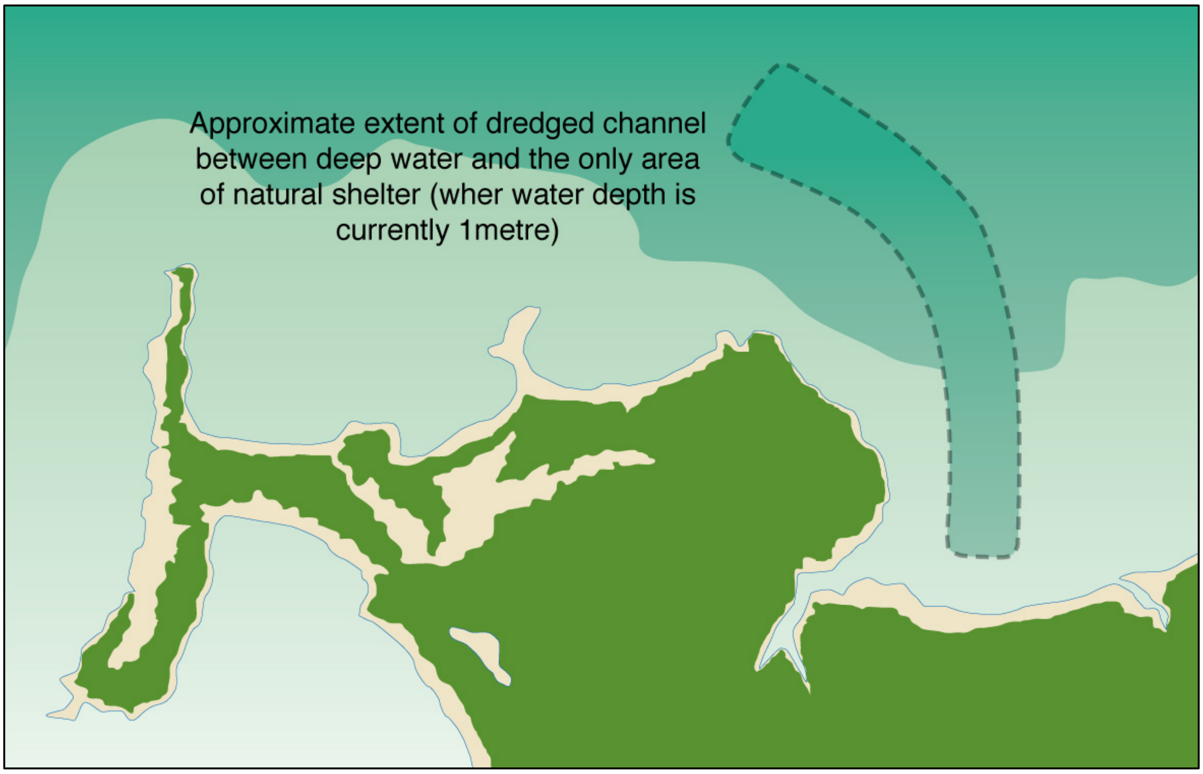
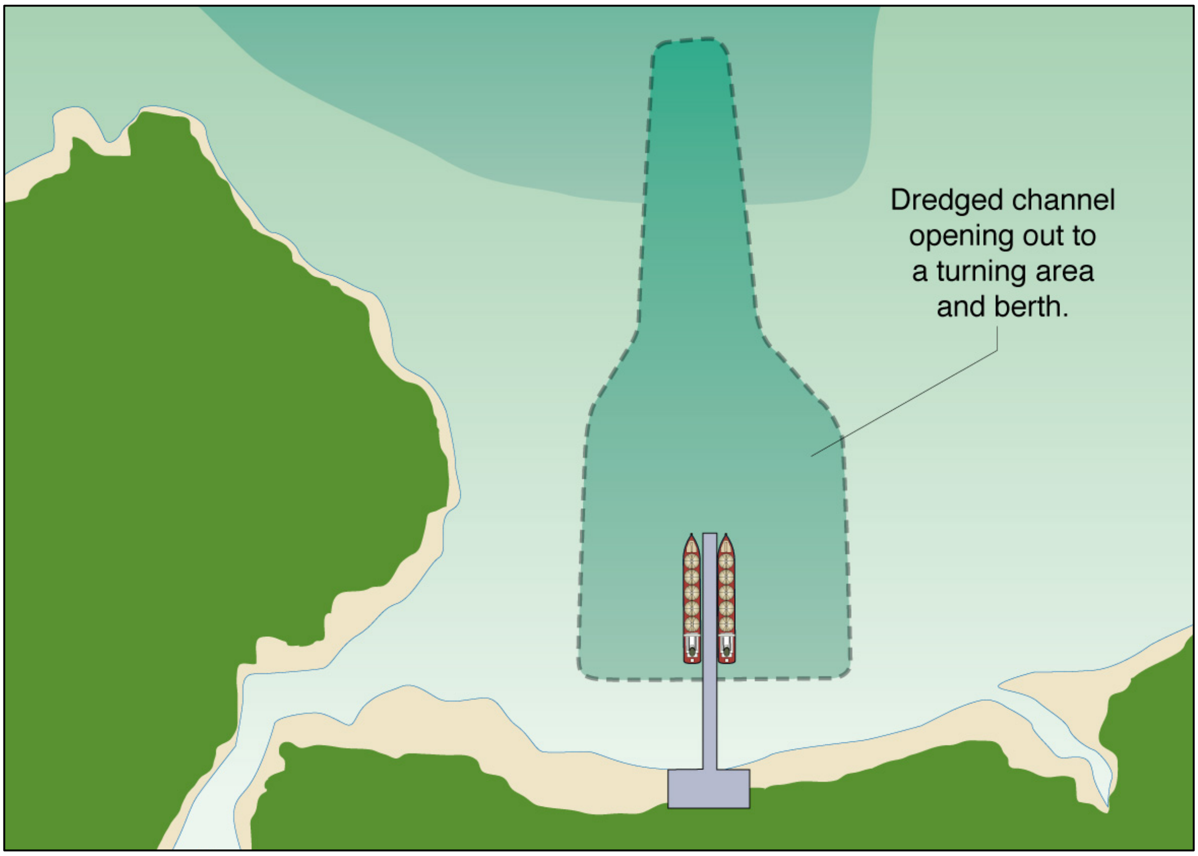



**Figure 161 - Secondary conceptual view of required dredging at Location 2**



### B.5.4 Supporting Services

No evidence can be found of any “port authority” or marine services at Nga Yoke Kaung. A marine jurisdiction / port authority could probably be put in place by means of Myanmar Government legislation, but key elements such as pilots and towage services would also have to be sourced. Tugs would have to be terminal-dedicated, or brought in for each ship movement.

### B.5.5 Summary and Conclusions

This site is not a port location and has almost nil natural shelter and no deep water, which makes it unsuitable for an LNG marine facility. To create a marine terminal at the one place which might derive some shelter from the nearest headland, extensive dredging and possibly some constructed breakwaters would be required. These environmental, financial, and technical constraints make the location an unattractive candidate.

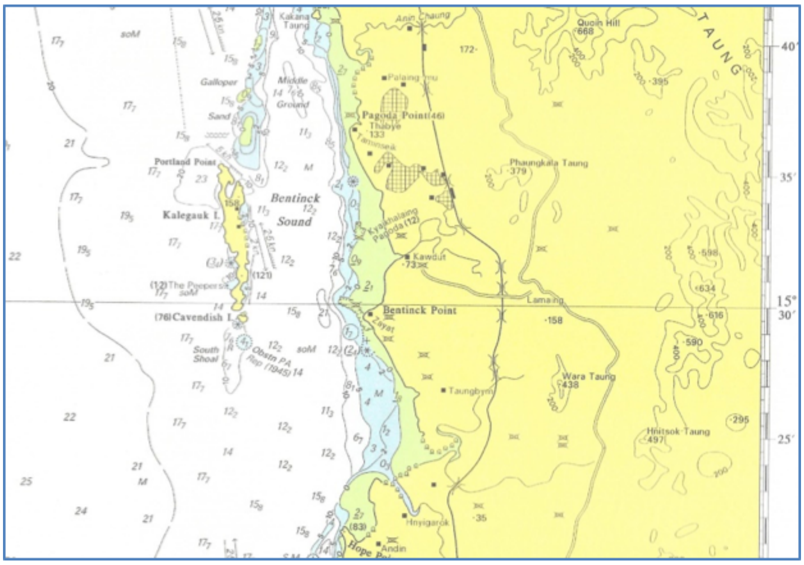
Additionally, the lack of any existing port jurisdiction or port services (pilotage and towage service) would mean that such services must be imported from a different location.

## B.6 Marine Access Review for Location 3

### B.6.1 Navigational Suitability

As with Location 2, this site is also at a coastal location, which is not currently a port. However, the difference with this Location is that, unlike Location 2, it has very good natural shelter from westerly and southwesterly wave actions and has naturally deep water.

**Figure 162 - Water depth surrounding Location 3**




The above sketch is an extract from UK Admiralty Chart No. 826, and shows that Kalegauk Island is separated from the mainland by a stretch of deep water about 5 miles wide (Bentinck Sound), which can be entered from both the north and the south directions. Within Bentinck Sound, the minimum charted water depths are 11.3m from the northerly direction, and 12.2m from the southerly direction.

Subject to a proper bathymetric survey, it may be possible to dredge to provide a channel to the required 14m water depth, in which case, the volume of dredging would be significantly less than for Location 2.

Alternatively, it is noted on the chart that the tidal ranges for Bentinck Sound are as follows:

**Table 48 - Tidal heights at Location 3**

| Heights In Metres Above Chart Datum | | | | |
|---|---|---|---|---|
| Tidal Condition | Mean High Water Spring Tides (MHWS) | Mean High Water Neap Tides (MHWN) | Mean Low Water Neap Tides (MLWN) | Mean Low Water Spring Tides (MLWS) |
| Tidal Height | 5.5 | 3.9 | 2.5 | 0.9 |

This means that, unless there are exceptional tidal conditions, the natural water depth will always be increased by between 0.9m and 5.5m. That being the case, navigational access via the southern end of Bentinck Sound is possible at all times other than at low water on spring tides. The statistical probability of an LNGC arrival at this state of tide is very low and, if it did occur, the ship need only wait a few hours until the tide rises to give the required water depth for berthing. In such cases, paying the Opex demurrage costs for the chartered LNGC is going to be considerably more cost-advantageous than the high Capex costs of dredging.

A berth concept could be constructed with a trestle out to deep water, so that only a berth “pocket” is required to allow the FSRU/FSU and the LNGC to stay afloat over the low water. However, a larger “pocket” would have to be defined and created for a “moored” FSRU/FSU concept. It is this larger pocket which has been used in the dredging cost estimates in section 7.

### B.6.2 Environmental Conditions

The metocean analysis for all of the sites is based on transferring offshore data in towards a nearshore location and, in the case of this site, the nearshore location is some 5 miles south of Kalegauk Island, at an indicative location where pilots might board and disembark from LNGCs.

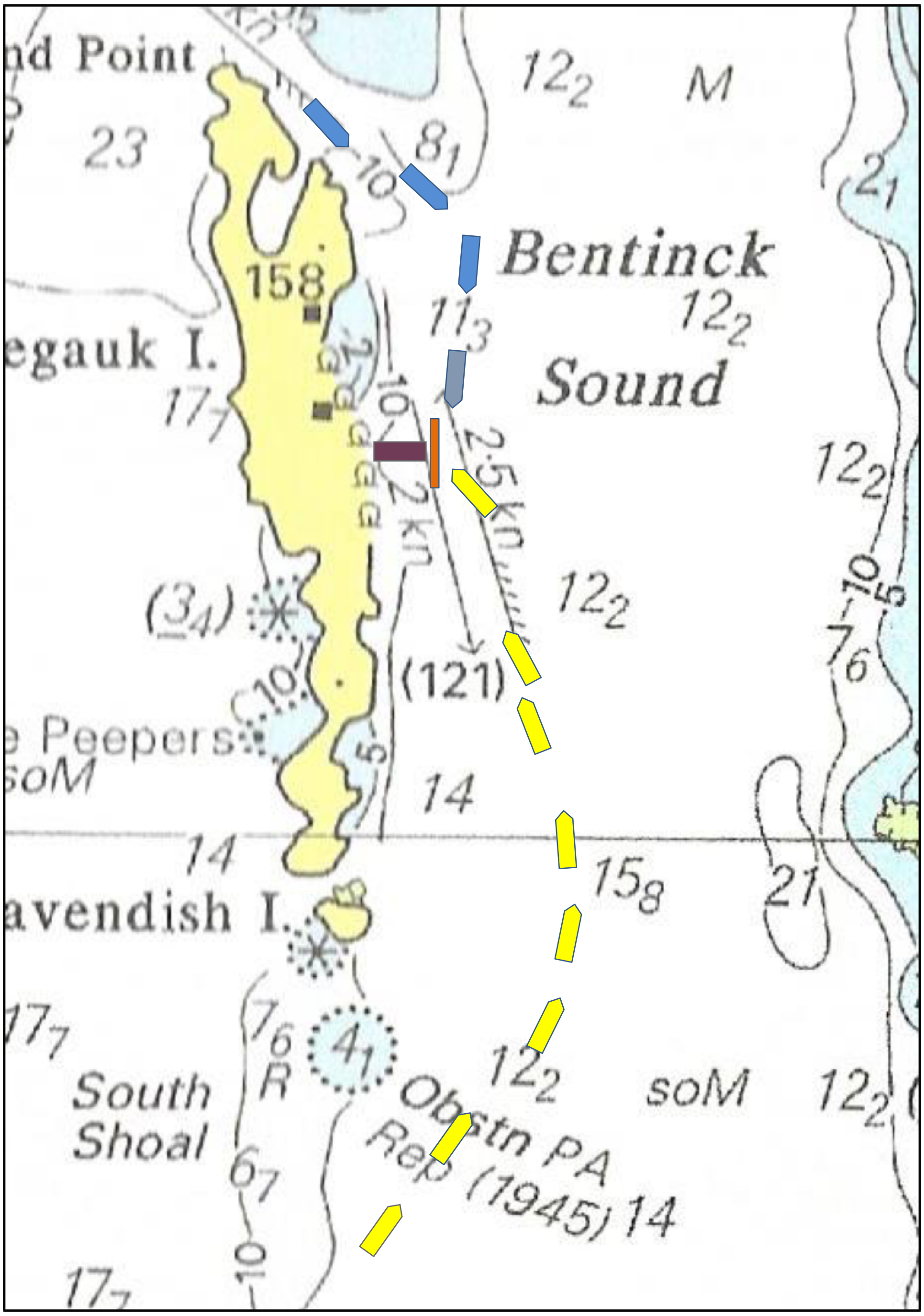
What cannot be derived from a metocean study is the wave climate on the sheltered side of an island. The parts of Kalegauk Island, which are most likely to be most sheltered, are towards the middle part of the east facing coast, where refracted wave action is less severe. However, it is understood that points towards the south and the north (as opposed to the middle), may have fewer environmental constraints.

As ever, local studies would be required to determine the optimum locations.

### B.6.3 Berth and Terminal Options

To take advantage of the favourable navigational access described above, the best place to site the LNG terminal would be somewhere on the eastern coast of the island. The exact location and length of trestle or moored concept would be a matter of optimisation at the design stage. A longer trestle from the shore to deep water would mean that nil dredging would be required. The sketch below illustrates LNGCs inward bound from both the southern and northern directions to a berth at an assumed location at the mid-point of the sheltered coast. The optimum location for the moored FLNG concept is likely to be in the same general area.

**Figure 163 - LNGC navigational routes into assumed Location 3 berth location**



### B.6.4 Supporting Services

As with Location 2, this coastal location has no regulatory "port authority" or port services in place, so it would be for the Myanmar government to establish an entity to manage marine activities in the area.

Port services would have to be brought in from another location. The nearest port is Moulmein (also known as Mawlamyine) approximately 50 nautical miles (5 hours transit time) away. However the trade at that port is largely small coastal vessels with large ships having to unload at anchor into barges. Investigations indicate that the port has only 1 tug of 550 horsepower, which is wholly inadequate for LNGCs. Yangon port is 120 miles away (about 10 hours transit time). No information on tug resources can be found but a web search advises that "*The Port of Yangon can receive vessels up to 15 thousand DWT and to 167 meters long with draft of nine meters*"[39] which again indicates that any towage facilities at this port will also be inadequate for handling LNGCs.

Singapore, one of the world's major ports, is over 1000 miles distance, a transit time of 3 ½ days. Whilst sourcing tugs from here is clearly fraught with logistical and financial challenges, it is reasonably certain that Singapore (which does have an LNG terminal at Jurong Island) does have the number and type of tugs which are capable of handling LNGCs.

### B.6.5 Summary and Conclusions

Although not an existing port location, the eastern / sheltered side of Kalegauk Island has very good natural attributes for an LNG terminal. The natural shelter is very good; and water depth is also good when taking into account the rise of tide; and there is unlikely to be any other shipping movements which would cause problems for the LNGCs.

In terms of marine jurisdiction and the establishment of a "port authority", The Myanmar Port Authority (MPA) is a government run agency that holds the responsibility of administering and regulating Myanmar's coastal ports. The MPA was founded in 1989 as a part of the Ministry of Transport and is currently based in Myanmar's former capital, Yangon. It can therefore be assumed that, with the appropriate national legislation, the MPA can assume effective marine jurisdiction over any of the sites where an LNG terminal is considered.

## B.7 Conclusion and Recommendations

### B.7.1 Conclusions

1. In circumstances where it is not possible or economically viable to develop a conventional berth concept terminal or an FLNG moored in the port area, an offshore concept may be possible. In this concept, the suitably adapted FSRU is tethered to a buoy (or system of buoys) or turret, and gas is sent ashore via a sub-sea pipeline which is also incorporated within the buoy or turret. Some examples are shown in the Figures below.

Designing, constructing, and operating an offshore FSRU facility is feasible, but the main problem with an offshore FLNG concept is its exposure to weather and the constraints around Ship to Ship (STS) deliveries of LNG. Near calm conditions are required for the berthing of the LNGC alongside the FSRU and especially during the transfer of cargo using flexible cryogenic hoses. The exact thresholds

[39] *http://www.worldportsource.com/ports/commerce/MMR_Port_of_Yangon_2341.php*

for safe operations would require further study but it is noted from the metocean study that the often quoted "industry threshold" of Significant Wave Height (Hs) of 1.5m for safe pilot boarding and landing is exceeded between 22% and 43% of the time. This would result in a very high level of downtime, especially during the SW Monsoon, when an offshore FSRU could not receive cargoes.

Accordingly, the offshore FSRU concept for the Myanmar coast is regarded as unsuitable, and the remaining conclusions are directed towards the merits of the three port and coastal locations.

**Figure 164 - Offshore FSRU Connected to Buoy System**


**Figure 165 - Offshore FSRU Connected to a Turret by Yoke, and Sending Gas Ashore**


2 It is considered that the key points of the three Locations are as follows:

**Table 49 - Summary of the suitability of Locations 1, 2 and 3**

| Criteria | Location 1 Kyauk Phyu | Location 2 Nga Yoke Kaung | Location 3 Kalegauk Island |
|---|---|---|---|
| Natural shelter with benign wave climate | Yes | No | Yes |
| Deep main channel (non tidally dependent) | Yes | No | No |
| Deep main channel (with usable tidal range) | Yes | No | Yes |
| Dredging required | Minor (berthing pocket only) | Very Extensive dredging required | Minor (berthing pocket only) |
| Potentially suitable site(s) for berth option | Yes | Highly doubtful | Yes |
| Potentially suitable sites for FSRU option | Yes | Highly doubtful | Yes |
| Existing port authority | Yes | No | No |
| Tugs potentially available | Yes | No | No |

3 As shown above, Location 2 is a poor option and Locations 1 and 3 have good potential, with Location 1 having the greatest potential from the marine perspective.

4 When considering further studies to examine Location 1 and Location 3 in greater detail, the following data would be essential:

a) Accurate bathymetry for the port approaches and the areas of interest for site selection.
b) Accurate environmental data for tidal range, wind, wave, currents, and visibility.
c) Further detailed local knowledge of the type which has not been available for this study including;
    - Data on shipping using the port and its channels.
    - Information on neighbouring port facilities and communities.
    - Confirmation on the jurisdiction and capabilities of the host port authority.
    - Confirmation on capability and availability of pilotage and towage services.

5 An ideal site within Location 1 or Location 3 would have characteristics whereby the winds and waves have a low threshold of exceedance for the following operations:

- Safe berthing and unberthing of LNGCs – 25 knots (12.9 m/s).
- Discontinue cargo transfer operations – 30 knots (15.4 m/s).
- Pilot boarding and disembarkation – Hs 1.5m to 2.0m.
- STS cargo transfer operations – Hs 1.0m.

## B.8 Costs Estimate

In terms of the main marine costs, research within the industry has led to the following estimations:

- Purchase cost of an LNGC of approximately 160,000m3 capacity – $200 million.

- Charter cost of an LNGC of approximately 160,000m3 capacity – $40k per day.
- Charter cost of an older LNGC of 135,000m3 capacity – $22k per day.
- Charter cost of an FSRU of approximately 170,000m3 capacity – $125k per day.
- Charter cost of 1 x 50t Bollard Pull tug (long term) – $5k.
- Charter cost of 1 x 50t Bollard Pull tug (spot charter) – $10k to $15k plus fuel.
- Mooring buoy system for a moored FLNG concept – $5 million.
- STS equipment (cryogenic hoses, Yokohama fenders etc.) – $15 million.

The other high cost item in any port development is dredging. The table below gives an initial estimate of the volumes of material that would require dredging at each of the Locations 1, 2 and 3. An estimate of $5 per cubic metre has been used but costs of environmental surveys and consents, and mobilisation / de-mobilisation have not been included.

**Table 50 - Initial costs of required dredging at Locations 1, 2 and 3**

| Location 1 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Component** | **Length (m)** | **Breadth (m)** | **Area (m2)** | **Depth Now(m)** | **Depth Reqd (m)** | **Difference (m)** | **Volume (m3)** | **Cost per m3** | **Total** |
| Channel | 0 | 0 | 0 | 22 | 14 | 0 | 0 | $5 | $0 |
| Pocket | 500 | 500 | 250,000 | 22 | 14 | 8 | 2,000,000 | $5 | $10,000,000 |
| | | | | | | | **2,000,000** | | **$10,000,000** |
| Location 2 | | | | | | | | | |
| **Component** | **Length (m)** | **Breadth (m)** | **Area (m2)** | **Depth Now (m)** | **Depth Reqd (m)** | **Difference (m)** | **Volume (m3)** | **Cost per m3** | **Total** |
| Channel | 5500 | 194 | 1,067,000 | 7 | 14 | 7 | 7,469,000 | $5 | $37,345,000 |
| Pocket | 500 | 500 | 250,000 | 1 | 14 | 13 | 3,250,000 | $5 | $16,250,000 |
| | | | | | | | **10,719,000** | | **$53,595,000** |
| Location 3 | | | | | | | | | |
| **Component** | **Length (m)** | **Breadth (m)** | **Area (m2)** | **Depth Now(m)** | **Depth Reqd (m)** | **Difference (m)** | **Volume (m3)** | **Cost per m3** | **Total** |
| Channel | 0 | 0 | 0 | 12.5 | 14 | 0* | 0 | $5 | $0 |
| Pocket | 500 | 500 | 250,000 | 12.2 | 14 | 1.8 | 450,000 | $5 | $2,250,000 |
| | | | | | | | **450,000** | | **$2,250,000** |

* Assumes that tidal range will be utilised to facilitate LNGC arrivals and departures, so no deepening of the navigational approaches is required

# Section C Supporting Information for Site Position Tool

The purpose of this section is to provide a detailed review of the background information in SPT-Stage 1 (Concept selection), SPT-Stage 2 (Traffic light selection) and SPT-Stage 3 (Discounted Expenditure)

## C.1 Concept selection questions and answers (Stage 1)

| **Q1: When should LNG import start?** | | |
|---|---|---|
| **Explanation** | **Options** | |
| *The implementation time of a LNG project depends on the technology involved. Some technologies require longer construction than others. Onshore infrastructure such as pipeline connections and jetties/moorings will require many months for completion Design, permitting and financing typically take 1 year* | | Within 2 years |
| | | 2 – 3 years |
| | | 3 – 4 years |
| | | 4 years or later |

| **Q2: What is the duration of LNG supply?** | | |
|---|---|---|
| **Explanation** | **Options** | |
| *There is a balance between operating costs and capital investment. More capital intensive technologies generally have a lower operating cost and therefore perform better over longer periods.* | | <3 years |
| | | 3 – 10 years |
| | | 10 - 15 years |
| | | >15 years |

| **Q3: What gas vaporisation rate is required?** | | |
|---|---|---|
| **Explanation** | **Options** | |
| *Floating LNG technologies are limited in their ability to export large volumes of gas particularly if the marine environment is sensitive or has limited water changes with oceans/seas* | | <100 mmscfd |
| | | 100 – 500 mmscfd |
| | | 500 – 800 mmscfd |
| | | >800 mmscfd |

| **Q4: What degree of ownership and control is required?** | | |
|---|---|---|
| **Explanation** | **Options** | |
| *LNG facilities can be built for an owner who has total control or alternatively leased from an infrastructure provider where control is very low. There are also options to purchase or transfer the asset to an owner at the end of the lease period* | | Own and control |
| | | Lease but purchase/transfer asset at end of lease (BOT/BOOT) |
| | | Lease the asset throughout its life |

| Q5: How much security of gas supply is required? | | |
|---|---|---|
| **Explanation** | **Options** | |
| *If a LNG carrier is unable to berth how many days must the LNG facility be able to produce gas for at its normal rate to supply the gas pipeline.* | | 2 days |
| | | 3 – 5 days |
| | | 5 – 10 days |
| | | >10 days |

## C.2 Traffic light questions and answers

### C.2.1.1 Getting LNG to the LNG facility

| Q1: How much dredging is required to create a channel to the terminal? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Navigable channel needs to be greater than 14 meters deep and at least 4 ship widths wide. The ship must be able to turn at the facility requiring a circle twice the ship's length and 14 m deep.* | Red | Major: > 10 million $m^3$ |
| | Amber | Significant: 2 million $m^3$ to 10 million $m^3$ |
| | Yellow | Minor: < 2 million $m^3$ |
| | Green | Access and turning without dredging |

| Q2: What Subsea pipeline length is required to connect a midwater or deepwater FSRU or LNGRV OR what Jetty length is required to be able to moor a near shore FSRU/LNG Carrier? | | | |
|---|---|---|---|
| **Explanation** | **Description of each traffic light colour** | | |
| *Distance of mooring in deep water from land (with at least 1 km of 15 m deep water land side of the mooring) .**OR*** *Distance of jetty from land to navigable channel.* | | **Subsea pipe** | **Jetty** |
| | Red | >20 km | > 3 KM |
| | Amber | 5 – 20 km | 1.5 – 3KM |
| | Yellow | 3 – 5 km | 250 meters – 1.5KM |
| | Green | < 3 km | < 250 meters |

| Q3: How much marine traffic is currently being experienced? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *How many ships may interfere with LNG carrier movements. Typically, large oil tankers, container and ferries have higher or equal priorities to LNG carriers,* | Red | Very heavy: > 3 vessels/day |
| | Amber | Heavy: > 3 vessels/week |
| | Yellow | Light: > 1 vessels/week |
| | Green | No Marine Traffic or VTS system in use. |

| Q4: Are there local visibility limitations? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Are there weather conditions such as snow, fog or heavy rain, etc that frequently reduce visibility to less than the stopping distance of the LNG carrier (1 – 2 nm).* | Red | Frequent > 10 days/year |
| | Amber | Infrequent 5 – 10 days/year |
| | Yellow | Very infrequent 1 – 5 days/year |
| | Green | None |

| Q5: Are there any other factors that limit the site? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Are there current or historical activities which may cause hazards to the LNG carrier in transit or which the LNG carrier might impose on others<br>Typical examples would include Military patrol and exercise zones, mine fields/munitions dumps, environmentally sensitive areas (marine nature reserves), important fishing grounds etc.* | Red | Many small, few medium or one large area close to or on the transit route |
| | Amber | Few small or one medium area close to or on the transit route |
| | Yellow | Single small area close to the transit route |
| | Green | None |

## C.2.1.2 Storing the LNG shipments

This section looks at issues that decide the long term availability of LNG from the terminal and its impact on the environment. The wind and wave conditions at the berth are crucial if any form of floating LNG facility is used and remain important if a fixed onshore terminal is selected.
Storage margins are the key mitigation for most negative events but are limited by technology.
Finally environmental, social and cultural impacts may decide whether a LNG facility at this location proceeds or not.

| Q1: What is the wave environment like? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *The height of waves is a good indication of the performance of a marine facility as frequent high waves will prevent the mooring of LNG carriers and may break mooring lines.* | Red | Rough<br>Waves frequently above 1.5/2 m |
| | Amber | Significant waves<br>Jetty: 90% of waves below 1.5 m<br>Offshore: 90% of waves below 2 m |
| | Yellow | Gentle<br>Jetty: 95% of waves below 1.5 m<br>Offshore: 95% of waves below 2 m |
| | Green | Benign<br>Jetty: 97% of waves below 1.5 m<br>Offshore: 97% of waves below 2 m |

| Q2: How variable is the wind/wave environment? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *LNG carriers and jetty moored FSRUs and FSU are best moored bow to the predominant wave direction. If the wave direction is variable a jetty moored approach may not be possible and weathervaning moorings or breakwaters will be required for protection* | Red | Wind/wave scattered across all/most directions |
| | Amber | Dominant direction (>50% of waves) but with large scatter |
| | Yellow | 90% of waves are from one direction or from neighbouring directions eg W plus SW and NW |
| | Green | Single direction with some variation |

| **Q3: Might the LNG facility be impacted by extreme weather?** | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Higher wind speeds produced by cyclones can delay unloading and cause flooding.* | | Very likely: >1/year |
| | | Likely: 1 in three years |
| | | Unlikely: 1 in ten years |
| | | Not likely: 1 in 100 years |

| **Q4: Will the site cause any destruction or exclusion to environmentally sensitive areas?** | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Will the local environment and the animals and plants within it be harmed or destroyed by the LNG development* | | Highly localised impact on an internationally important environment (eg RAMSAR site)<br>Small area of a nationally/state recognised national park or nature reserve impacted<br>Large area of local/community amenity impacted |
| | | Highly localised impact on a nationally/state recognised national park or nature reserve impacted<br>Small area of local community/amenity area impacted |
| | | Highly localised impact on local/community amenity area |
| | | No impact |

| **Q5: Will the site cause any destruction or exclusion to culturally and historically sensitive areas?** | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Will the social and cultural heritage of the local people, nation or feature that provides national or religious identity internationally be harmed or destroyed by the LNG development* | | Highly localised impact on an internationally important site (eg UNESCO World Heritage site). Small area of a nationally/state recognised landscape such as temple complex impacted. Large area of local/community amenity impacted |
| | | Highly localised impact on a nationally/state recognised landscape impacted<br>Small area of local community/amenity area impacted |
| | | Highly localised impact on local/community amenity area |
| | | No impact |

| Q6: Will the site development and operation impact the local community in any detrimental way? | |
|---|---|
| **Explanation** | **Description of each traffic light colour** |
| *Will local people who are resident in the area suffer any short or long term negative impacts from the project* | Forced, partial or total relocation of a village or town |
| | Forced relocation of a few properties<br>Long term impact (years) on mental or physical health and welfare by destruction, harm to business (eg farming, fishing, tourism) through increased traffic, noise, visual impact, etc. |
| | Short term impact (construction period) on mental or physical health and welfare by destruction/harm to business (eg farming, fishing, tourism) through increased traffic, piling, noise, visual impact, etc |
| | No impact or positive impact (eg employment, additional facilities) |

| Q7: Will the site development and operation increase the risk of harm/fatality to the local community? | |
|---|---|
| **Explanation** | **Description of each traffic light colour** |
| *Worst case LNG accident scenarios can, depending on the event, weather conditions and terrain, impact populations within 500 m of the site and potentially 1 km of the site. LNG sites should avoid these locations if possible.* | Large population >10,000, within 500 meters of site<br>Large institution containing individuals with limited mobility such as hospital, prison, care home, etc within 500 m of site |
| | Large population >10,000, within 1000 meters of site. Large institutions containing individuals with limited mobility such as hospital, prison, care home, etc within 1000 m of site. Significant population, 50-100 people within 500 m of the site. |
| | Few isolated farmers/housing within 500 m to |
| | Distant: >1.5km |

| Q8: Are there risks to the LNG facility from geological events? | |
|---|---|
| **Explanation** | **Description of each traffic light colour** |
| Poor ground conditions can initiate failures of structural elements in LNG facilities with the resulting leaks causing harm to the plant or individuals. Improvement options are available for all ground condition issues but generally require significant investment. | Ground acceleration >0.4 g, severe shaking and moderate to heavy damage<br>Sited over an active geological fault<br>Karst structures present |
| | Ground acceleration > 0.2 g, strong shaking and light damage |
| | Ground acceleration > 0.075 g, moderate shaking and very light damage |
| | Ground acceleration of < 0.075 g, shaking not felt and no damage |

### C.2.1.3 Getting LNG out

LNG is only useful to Myanmar if it can be exported on demand and reaches the power plants that will be using it. Like hydroelectric power there may be times that vaporisation cannot happen. The difficulty (capital and environmental/social impact costs and schedule) of getting gas from the LNG facility via a gas pipeline also needs to be considered. If the pipeline is full then little additional gas can be made available via LNG.

| **Q1: Can LNG be vaporised in sufficient volume and in an environmentally acceptable way?** | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Vaporisation of LNG causes cooling to the local environment which can particularly affect local fisheries. Locations with little water circulation can recycle cold requiring air or water heating.* | | No – major environmental impact from cold discharges. |
| | | Yes but with major limitations. |
| | | Yes with some limitations. |
| | | Yes with no constraints on daily operation. |

| **Q2: What is the onshore pipeline length?** | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *The longer the pipeline the more route challenges, costs and potential need for compression.* | | Very Long: > 500 km – For pipelines of this length compression would almost certainly be required. |
| | | Long: 250 to 500 km – The longer the pipeline route is the greater the need for compression or upsizing. |
| | | Moderate: 100 to 250 km – Technically, this should be relatively straightforward, although the longer the route the higher the costs. |
| | | Short: < 100 km – This is a relatively short pipeline, low costs and technically straightforward. |

| **Q3: What is the difficulty in laying the onshore pipeline?** | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *The construction of onshore high-pressure gas pipelines needs a ROW which provides the legal right to build the pipeline. If a ROW already exists both costs and uncertainty is reduced. Pipelines become more difficult to build when the pipeline route faces geographical hurdles such as mountains, major rivers, roads and railways of heavily wooded or swampy ground conditions* | | Very difficult: Building a pipeline through this terrain will be challenging and costs will be high and schedule extended. Typically a new route over very difficult terrain. |
| | | Difficult: There are major issues that will require innovative solutions to resolve. For example building the pipeline over a mountain range. |
| | | Some issues: There are minor issues that can be resolved using existing construction techniques. |
| | | Easy: There are no obvious barriers to constructing the pipeline. Typically, using an existing ROW with no obvious problems. |

| Q4: What is the offshore pipeline length? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *The longer the pipeline the more route challenges, costs and potential need for compression. Also whilst offshore compression is technically possible it is better to avoid it. Pipelaying technology also changes with pipeline diameter.* | Red | Very Long: > 500 km – For pipelines of this length compression would almost certainly be required. |
| | Amber | Long: 250 to 500 km – The longer the pipeline route is the greater the need for compression or upsizing. |
| | Yellow | Moderate: 100 to 250 km – Technically, this should be relatively straightforward, although the longer the route the higher the costs. |
| | Green | Short: < 100 km – This is a relatively short pipeline, low costs and technically straightforward. |

| Q5: **What is the difficulty in laying the offshore pipeline?** | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Whilst an offshore gas pipeline does not need a ROW like an onshore gas pipeline it does have other hazards to avoid. This would include geographical hazards as well as more localised hazards such as fishing rights etc.* | Red | Very difficult: It is unlikely the pipeline can be built through this terrain. Typically a new route over very difficult terrain. |
| | Amber | Difficult: There are major issues that will require innovative solutions to resolve. For example building the pipeline subsea crevices. |
| | Yellow | Some issues: There are minor issues that can be resolved using existing construction techniques. |
| | Green | Easy: There are no obvious barriers to constructing the pipeline. |

### C.2.1.4 Local Infrastructure

This section looks at local infrastructure to assess whether a suitable workforce and supporting services are available. It also looks at the ease of getting personnel and equipment to the site from international vendors both during construction and operation.

| Q1: Is there sufficient towage available to berth the LNG carrier? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *LNG carriers have relatively light cargoes and so sit higher in the water so are impacted more by winds. This makes the availability of sufficient (3 or 4) powerful (140-160 bollard ton total) tugs crucial* | Red | None available |
| | Amber | Neither size or number |
| | Yellow | Either size or number but not both |
| | Green | Correct number and size available |

| Q2: Is there currently any port rules and infrastructure appropriate to hydrocarbon importation at the proposed LNG site? | | |
|---|---|---|
| **Explanation** | | **Description of each traffic light colour** |
| *LNG carriers need to interact with other port users. This requires the development of port rules to segregate different ships according to employment and hazard and to control passing (speed and distance).* | | No infrastructure |
| | | Port with no rules |
| | | Established minor port with rules |
| | | Established major port with rules |

| Q3: Is there sufficient infrastructure to accommodate workers and their families, expatriates and vendor personnel? | | |
|---|---|---|
| **Explanation** | | **Description of each traffic light colour** |
| *Workers, whether expatriate or indigenous require local housing and facilities for families such as shopping, healthcare, police, education etc.* | | Bad: no housing, roads or industrial base. Frequent traffic jams. |
| | | Poor: Limited housing and support, few surfaced roads, heavy traffic, 1-2 factories |
| | | Limited: Adequate housing, some support, few/many surfaced roads, moderate traffic and range of industry. |
| | | Good: Good housing and support. All roads surfaced, light traffic, extensive industrial base and helipad available. |

| Q4: Is there emergency response and Health care capability? | | |
|---|---|---|
| **Explanation** | | **Description of each traffic light colour** |
| *Like all industrial facilities staff at LNG facilities may suffer from illness or be involved in accidents. The hazards of LNG require access to hospitals, fire services and other rescue services such as lifeboats and sometimes helicopters* | | None |
| | | Limited: No trauma centre, Small, poorly equipped/trained fire service, limited ambulances. |
| | | Good: Major health care, moderate size and adequately equipped/trained fire service, ambulances and lifeboats available. |
| | | Extensive: International health care, large & well equipped/trained fire service, helicopter rescue available. |

| Q5: Is the local skills and education infrastructure useful to the project? | | |
|---|---|---|
| **Explanation** | | **Description of each traffic light colour** |
| *Local people can be involved in the project either during construction and/or operation if they have the skills and basic education necessary for the potential job roles* | | Illiterate/Innumerate. |
| | | Literate/numerate, no skills: basic schooling, no industry |
| | | Literate/numerate, some skills: full schooling, major industry |
| | | Literate/numerate, highly skilled: university, hydrocarbon industry |

| Q6: Is there access to a major port with connecting roads? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Most specialist equipment and maintenance materials will need to be imported through an international port and then re-distributed by road, rail or barge* | | Distant: > 100 km and no major roads. |
| | | Far: > 50 km to roads requiring upgrading (width and strength) |
| | | Moderate: >30 km to roads requiring moderate improvements/poor rail links. |
| | | Close < 10 km to major trunk roads and good rail links. |

| Q7: Is there access to an international airport with road/rail links? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| *Some workers, particularly if the lease option is selected, will be expatriate and will need to fly in and out of Myanmar. Additionally specialist vendor servicemen will need to visit to commission and repair equipment items* | | Distant: > 100 km and no major roads. |
| | | Far: > 50 km to poor roads (unsurfaced) |
| | | Moderate: >30 km to good roads (surfaced) or poor rail links. |
| | | Close < 10 km to major trunk roads/motorways or good rail links. |

| Q8: How adequate is the marine infrastructure? | | |
|---|---|---|
| **Explanation** | **Description of each traffic light colour** | |
| Does the local port have services such as customs, storage warehouses, deep enough wharfs and large enough cranes capable of serving the LNG terminal through the import of materials during construction and operation | | Bad: nothing existing |
| | | Poor: Small port (no hydrocarbons) |
| | | Limited: Few support bases available for offshore industry. |
| | | Large port (no hydrocarbons) or small port with hydrocarbons |

## C.3 Schedule of Assumptions

The basis of the schedules used in the model are described in Section C1. These schedules include all activities from project inception through first LNG. The schedules shown differ from many proposed by industry sources who only consider the LNG component and exclude studies, jetty/mooring and connecting pipelines. The schedules of some fast to market technologies are diluted in Section C1 as the LNG technology is not the rate determining step, site based location factors are, for example, no existing jetty facilities have been identified so need to be built from scratch and the pipeline network needs significant reinforcement.

Many people assume that engineering is the rate determining step, this is only true after the FID has been taken. Before this permitting and financing dominate which is why Section C1 shows similar lead times for all options.

There is also the assumption that the LNG facility is the rate determining step. This may not be the case as long pipelines and more difficult marine facility schedules can challenge LNG development schedules.

# Section D Overview of the Project Team

## D.1 MJMEnergy Limited

***MJMEnergy*** is a UK-based firm providing technical and commercial consultancy throughout the world with a clear focus on natural gas and LNG related projects. Over the last few years MJMEnergy has advised on the commercial, operational and regulatory aspects of LNG imports throughout the world. In Pakistan MJMEnergy provided technical and commercial support to the GoP and SSGC (the incumbent monopoly), facilitating the first LNG imports into Pakistan via a FSRU. MJMEnergy has also advised on FRSU LNG import projects in Chile (ECL) and Ghana (VRA), working with ECL in developing Terminal-User-Agreements (TUA's) in Chile and an RFP for VRA in Ghana. MJMEnergy worked on a number of land-based LNG import projects in Greece, Singapore, the UK and the Netherlands. Finally, MJMEnergy recently published a major study of world LNG supplies, examining the current and future potential of LNG supplies from over twenty-eight different countries over the period 2015 – 2035. MJMEnergy also has a well-established training business providing capacity building to clients throughout the world, including LNG training to clients from one day overviews of the global LNG market through to five day courses on LNG economics, markets and modelling. In addition to the main team engaged with this project, we also have a strong back office team providing support to the project team in terms of project administration and technical support.

## D.2 Penguin Energy Consulting Limited (PEC)

***Penguin Energy Consulting (PEC)*** is a UK-based, independent energy industry techno-commercial consultancy and training provider. PEC has been involved in 46 LNG projects in 28 countries over 20 years, which has included onshore and offshore liquefaction and regasification facilities, small scale LNG, and peak shaving units. Project roles have included technology development, concept and feasibility studies, site selection, owner's engineer, commercial support, safety, environmental aspects and training. Penguin Energy Consultants Ltd has contracts and a relationship with the Society for Gas as a Marine Fuel for development of expertise and regulations concerning the use of natural gas, primarily as LNG, for marine fuel.

## D.3 ECA

***Economic Consulting Associates Limited (ECA)*** was formed in 1997 to provide economic and regulatory consulting services to industry and government. ECA's team and approach are based on many years' experience of carrying out economic and policy analysis, in the UK and worldwide. ECA specialises in advising on economics, policy and regulatory issues in the utilities industries, with particular expertise in the gas sector. The firm has a total of 20 professional staff members, based in offices in London, Bangkok, and New Zealand. All staff members hold qualifications in either or both of economics and engineering. ECA has undertaken over 450 assignments in over 50 countries around the world having worked with over 30 regulatory authorities and over 15 national utilities.

## D.4 Drennan Marine Consultancy Ltd

Drennan Marine Consultancy Ltd is a LNG marine specialist with experience working in over 20 countries worldwide and is well used to ranking multiple locations in a structured and consistent way against relevant marine criteria including natural shelter, navigational risk and the capability of local services. As a qualified Master Mariner, Tom has a complete understanding of the needs and preferences of the LNG industry in terms of suitable LNG sites.