Pilot study on the use of LNG as a fuel for a high speed passenger ship from the Port of Spain ferry terminal in Trinidad and Tobago

Report to
Trinidad and Tobago Port Authority and
Trinidad and Tobago Inter-Island Transportation Company
prepared with funding from the
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IMO Integrated Technical Cooperation Fund

December 2013

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26 June 2013

Pilot study on the use of LNG as a fuel for a high speed passenger ship from the Port of Spain ferry terminal in Trinidad and Tobago

This report presents the results of a pilot study on the use of LNG as fuel for high speed passenger ships from the Port of Spain ferry terminal in Trinidad and Tobago. The study was initiated by IMO following the conclusions of a workshop and report on the feasibility of LNG fuelled short sea and coastal shipping in the Wider Caribbean Region. A number of shipping segments were identified suitable for introduction of LNG as fuel and the specific ferry service between the Trinidad and Tobago islands was considered a particularly interesting potential pilot route for introduction of LNG. This pilot study provides background data to the operators of the Trinidad and Tobago high speed ferry services for decision support and detailed business case analyses. The pilot study may also serve as guidance for other potential followers and early adopters of LNG as a ship fuel.
SUMMARY

This pilot study on the use of LNG as fuel for high speed passenger ferries between the sister islands Trinidad and Tobago provides decision support and background information to the operators of the ferry services for detailed business case analyses. The study may also serve as guidance for other early adopters of LNG as a ship fuel.

SSPA has compiled information from site visits, meetings and analyses and the report includes six main chapters addressing the background, route specific conditions, LNG supply chain, regulations, safety issues, cost estimations, and recommendations.

The present fleet of high speed ferries comprises two diesel powered aluminium wavepiercing catamarans that service the route with two to three roundtrips per day. Short travel time, low fare and regularity are appreciated by the travellers. The service is considered a national interest, and is subject to governmental financial support.

The following three optional LNG supply chains have been analysed and compared in terms of their capacity, cost and safety:
- LNG road truck from an existing LNG plant to the bunkering of the ferry at berth
- Local, small-scale liquefaction plant and supply by truck or pipeline to the ship
- LNG bunker barge from an LNG export terminal to bunkering of the ferry at berth

Transportation from the source and bunkering by road truck offers the lowest supply cost, but is limited with respect to capacity. Concerns were also identified with respect to the present road standard and risks for delays and traffic accidents. Local, small-scale liquefaction plants may also offer competitive options and by establishment in Tobago, advantages may be gained by more spacious terminal areas compared with the Port of Spain terminal. The LNG bunker barge option is favourable from a safety perspective, but requires large investments in loading facilities and is therefore only competitive if additional LNG customers are projected to be serviced in Port of Spain.

No regulative showstoppers have been identified for the reconstruction or newbuilding of LNG fuelled, high speed ferries, but the process requires close cooperation between the ship designers, flag state authority, classification society, and the operator. The cost for reconstructing the existing high speed craft is high, and includes the replacement of existing diesel engines with less bulky gas turbines and the installation of vacuum insulated LNG fuel tanks on the car deck.

The prospects for finding solutions that combine high environmental performance and reduction of overall operational costs via reduced governmental fuel oil subsidy expenditures are good, but the initial costs are high, and the investment strategies should include long term potentials for expanding the LNG fuel market.

For other stakeholders and member states that are conducting similar pilot studies on ship conversion or replacement, it is recommended to include careful LNG supply chain assessment, and the importance of early cooperation with projected LNG suppliers and a continuous dialogue with regulative authorities is stressed in order to minimise project risks and to ensure successful operation with LNG as ship fuel.
# ABBREVIATIONS AND DEFINITIONS

<table>
<thead>
<tr>
<th><strong>Abbreviation</strong></th>
<th><strong>Explanation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>ADR</td>
<td>International Carriage of Dangerous Goods by Road (European Agreement)</td>
</tr>
<tr>
<td>BOG</td>
<td>Boil Off Gas, evaporated LNG formed above the tank level surface in LNG tanks</td>
</tr>
<tr>
<td>CAPEX</td>
<td>Capital Expenditures</td>
</tr>
<tr>
<td>CARICOM</td>
<td>Caribbean Community and Common Market</td>
</tr>
<tr>
<td>CFR</td>
<td>The Code of Federal Regulations (U.S.)</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
</tr>
<tr>
<td>CH₄</td>
<td>Methane</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>CTS</td>
<td>Container to Ship (LNG bunkering mode)</td>
</tr>
<tr>
<td>DMA</td>
<td>Danish Maritime Authority</td>
</tr>
<tr>
<td>DNV</td>
<td>Det Norke Veritas</td>
</tr>
<tr>
<td>dwt</td>
<td>Dead Weight Tonnage (tot weight of a ship’s cargo, fuel, etc.)</td>
</tr>
<tr>
<td>ECA</td>
<td>Emission Control Area</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>EMSA</td>
<td>European Maritime Safety Agency</td>
</tr>
<tr>
<td>ESD</td>
<td>Emergency Shut Down system</td>
</tr>
<tr>
<td>ESD2</td>
<td>ERS linked to the ESD system</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EUR</td>
<td>Euro currency</td>
</tr>
<tr>
<td>Ex-zone</td>
<td>Flammable gas atmosphere with special requirements for electrical equipment</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode and Effect Analysis</td>
</tr>
<tr>
<td>FO</td>
<td>Fuel oil, all types of oil based marine fuels used today such as MDO, MGO, HFO</td>
</tr>
<tr>
<td>FOB</td>
<td>Free On Board, fuel price condition defined by the Incoterms 2010, International Chamber of Commerce</td>
</tr>
<tr>
<td>GHG</td>
<td>Green House Gas, emissions of GHG gaseous substances influences the greenhouse effect and contributes to global warming and the climate change</td>
</tr>
<tr>
<td>GL</td>
<td>Germanischer Lloyd</td>
</tr>
<tr>
<td>GT</td>
<td>Gross Tonnage (an index of ship’s overall internal volume)</td>
</tr>
<tr>
<td>HAZID</td>
<td>Hazard Identification</td>
</tr>
<tr>
<td>HFO</td>
<td>Heavy Fuel Oil</td>
</tr>
<tr>
<td>IGC</td>
<td>International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk</td>
</tr>
<tr>
<td>IGF code</td>
<td>The forthcoming International Code of Safety for Ships Using Gases or other Low Flashpoint Fuels</td>
</tr>
<tr>
<td>IMDG</td>
<td>International Maritime Dangerous Goods Code</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organisation</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Explanation</td>
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<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>ISO</td>
<td>International organization for standardization</td>
</tr>
<tr>
<td>ITPS</td>
<td>Intermediate tank via pipeline to ship</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
</tr>
<tr>
<td>MARPOL</td>
<td>International Convention for the Prevention of Pollution from Ships</td>
</tr>
<tr>
<td>MDO</td>
<td>Marine Diesel Oil</td>
</tr>
<tr>
<td>MGO</td>
<td>Marine Gas Oil</td>
</tr>
<tr>
<td>mmpta</td>
<td>million tonnes per annum</td>
</tr>
<tr>
<td>mmcfd</td>
<td>million cubic feet</td>
</tr>
<tr>
<td>NFPA</td>
<td>The National Fire Protection Association (U.S.)</td>
</tr>
<tr>
<td>NCV</td>
<td>Net calorific value</td>
</tr>
<tr>
<td>NG</td>
<td>Natural Gas, a fossil fuel consisting primarily of methane, but commonly also includes some higher hydrocarbons carbon dioxide and nitrogen</td>
</tr>
<tr>
<td>NGC</td>
<td>The National Gas Company of Trinidad and Tobago</td>
</tr>
<tr>
<td>NOx</td>
<td>Nitrogen Oxides</td>
</tr>
<tr>
<td>OPEX</td>
<td>Operating Expenditures</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>SCR</td>
<td>Selective Catalytic Reduction (NOx reduction for exhaust emissions)</td>
</tr>
<tr>
<td>SECA</td>
<td>Sulphur Emission Control Area</td>
</tr>
<tr>
<td>SGMF</td>
<td>Society For Gas as a Marine Fuel</td>
</tr>
<tr>
<td>SO2</td>
<td>Sulphur Dioxide</td>
</tr>
<tr>
<td>SOLAS</td>
<td>The International Convention for the Safety of Life at Sea</td>
</tr>
<tr>
<td>SOx</td>
<td>Sulphur Oxides</td>
</tr>
<tr>
<td>STCW</td>
<td>International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers</td>
</tr>
<tr>
<td>STS</td>
<td>Ship to ship bunkering (LNG bunkering mode)</td>
</tr>
<tr>
<td>ToR</td>
<td>Terms of Reference</td>
</tr>
<tr>
<td>TTD</td>
<td>Trinidad and Tobago Dollar currency</td>
</tr>
<tr>
<td>TTIT</td>
<td>The Trinidad and Tobago Inter-Island Transportation Company Ltd.</td>
</tr>
<tr>
<td>TTS</td>
<td>Truck to ship bunkering (LNG bunkering mode)</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>UNECE</td>
<td>United Nations Economic Commission for Europe</td>
</tr>
<tr>
<td>USD</td>
<td>US Dollar currency</td>
</tr>
<tr>
<td>WCR</td>
<td>Wider Caribbean Region</td>
</tr>
</tbody>
</table>
CONVERSION FACTORS

The following conversion factors and units have been used in the calculations presented in the report.

<table>
<thead>
<tr>
<th>Conversion factors</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>Density of LNG</td>
<td>0.43 tonne/m³</td>
</tr>
<tr>
<td>NCV of LNG (Net calorific value)</td>
<td>13.7 MWh/tonne</td>
</tr>
<tr>
<td>NCV of LNG (Net calorific value)</td>
<td>46.746 MMbtu/tonne</td>
</tr>
<tr>
<td>Density of MDO</td>
<td>0.89 tonne/m³</td>
</tr>
<tr>
<td>NCV of MDO</td>
<td>11.6 MWh/tonne</td>
</tr>
<tr>
<td>1 MMBtu (million British thermal unit)</td>
<td>0.293 MWh</td>
</tr>
<tr>
<td>1 GJ (Giga Joule)</td>
<td>277.78 kWh</td>
</tr>
<tr>
<td>1 MMBtu (million British thermal unit)</td>
<td>1.0546 GJ</td>
</tr>
<tr>
<td>1 m³</td>
<td>35.315 cft</td>
</tr>
<tr>
<td>1 cft (cubic feet)</td>
<td>0.028317 m³</td>
</tr>
<tr>
<td>1 m³</td>
<td>264.17 gallon</td>
</tr>
<tr>
<td>1 gallon</td>
<td>0.003785 m³</td>
</tr>
<tr>
<td>1 m³</td>
<td>6.2898 oil barrel</td>
</tr>
<tr>
<td>1 oil barrel</td>
<td>0.15899 1 m³</td>
</tr>
<tr>
<td>EUR/USD</td>
<td>1.3</td>
</tr>
<tr>
<td>TTD/USD</td>
<td>0.156</td>
</tr>
<tr>
<td>ROI, rate of interest</td>
<td>8 %</td>
</tr>
</tbody>
</table>
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Acknowledgements

SSPA Sweden AB and White Smoke AB acknowledge the Port Authority of Trinidad and Tobago (PATT) and its ferry operating company Trinidad and Tobago Inter-island Transportation Company Ltd. (TTIT), for their productive and efficient contribution to the data collection of for this study and for facilitating of meetings with various local stakeholders in Trinidad and Tobago. In particular, Mr. Leon Grant, Deputy Chief Executive Officer, and his Executive Secretary, Ms. Josanne Phillips, have been actively supporting the work, and facilitated meetings and workshops.

The consultants and the PATT representatives have also been actively supported by representatives from the Maritime Services Division of the Ministry of Works and Transport and by Mr Colin P. Young, IMO Regional Maritime Adviser, in their efforts to establish contacts with relevant local stakeholders and to organise meetings. Mr. Felton L. Gilmore, IMO Consultant, RAC/REMPEITC-Carib, has also actively contributed to the preparations and coordination of the activities arranged during the course of the pilot study.
1 INTRODUCTION

1.1 Background

The International Maritime Organization (IMO) has a special responsibility for the regulation of international shipping, safety at sea, and the prevention of marine pollution. There are four designated Emission Control Areas (ECAs) in effect globally including the US Caribbean Sea ECA which entered into force in January 2013. The ECA designation has proven effective for the reduction of harmful emissions from ships and the improvement of air quality. More ECA designations are therefore being discussed, and the entire Wider Caribbean Region (WCR), might be covered by ECA requirements in the future. One ECA compliance strategy is based on a shift from conventional oil fuel to LNG for propulsion of the ships. This strategy is considered specifically attractive in the WCR due to LNG's availability in this region and the favourable price situation of LNG in this region compared to other global natural gas markets. In the WCR a shift from conventional oil fuel to LNG may be economically motivated even without any SECA requirements and the environmental benefits is then to be seen as an extra bonus.

In 2012, the IMO financed a feasibility study on LNG fuelled short sea and coastal shipping in the WCR (SSPA, 2012). The feasibility study was conducted by SSPA Sweden and White Smoke and concluded that the prospects for introduction of LNG as ship fuel in the region were favourable. The report was presented at a workshop arranged by RAC-REMPEITC-Caribe in Trinidad and Tobago and the workshop meeting recommended that a regional pilot programme for the testing and implementation of LNG as a ship fuel in the WCR should be initiated and supported. The Port Authority of Trinidad and Tobago (PATT) was identified as a potential candidate for running such a pilot program in cooperation with the Maritime Services Division of Trinidad and Tobago and the regional IMO office. Trinidad and Tobago’s request for funding of the project was supported from the IMO's Integrated Technical Cooperation Fund and in 2013 SSPA Sweden AB was assigned the tender from IMO for the pilot study.

This report presents the result of the pilot study conducted by the consultant SSPA Sweden with its sub-consultants White Smoke and LDG during the fall of 2013. Statements and recommendations are formulated by the consultants and do not necessarily reflect the opinion of the local recipient or the financing parties.
1.2 Objectives of the pilot study

The objective of the study is to identify, outline and recommend a way forward for the accomplishment of a pilot implementation of an LNG fuelled, high speed passenger ship operating from the Port of Spain ferry terminal. The report provides background data for a detailed business case to be elaborated by the Port Authority PATT and TTIT and to facilitate further preparation of detailed specifications and processes for realisation of the pilot project.

An increased use of LNG instead of traditional bunker oil as fuel for ships will reduce the harmful emissions of sulphur oxide, nitrogen oxide, and particles, and thereby to improvement of air quality and health in coastal societies that are exposed to ship emissions. The dissemination of this report might also provide guidance and encouragement for potential followers to consider and initiate further projects on LNG fuelled ship services in the WCR.

1.3 Scope and methodology contribute

The scope of this pilot study on the use of LNG as ship fuel for high speed ferries operating from the Port of Spain ferry terminal includes six main components that are listed and structured in the report chapter numbers below. Two on-site visits for meetings and collection of information were conducted by the consultants in September and November 2013, and analyses have been performed in Sweden by SSPA, White Smoke, and LDG.

<table>
<thead>
<tr>
<th>Component of ToR /Report chapter number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component 1 / Chapter 2 Current traffic and future requirements</td>
<td>Identify, with the involvement of the Port Authority of Trinidad and Tobago, the requirements for an LNG fuelled fast passenger ship operation from the Port of Spain Ferry Terminal including the current and forecasted passenger numbers and current and prospective routes.</td>
</tr>
<tr>
<td>Component 2 / Chapter 3 LNG supply chain and bunkering infrastructure</td>
<td>Identify and appraise the terminal infrastructure facilities required to support a fast passenger ship operation at the Port of Spain Ferry Terminal fuelled by LNG and including the supply of LNG to the port and bunkering of the ship.</td>
</tr>
<tr>
<td>Component 3 / Chapter 4 Regulatory design requirements</td>
<td>Identify the design requirements for the proposed fast passenger ship under the international regulatory regime pertaining to the carriage and storage of LNG as a fuel for ships with a specific reference to its use and storage on a fast passenger ship operating to and from the Port of Spain Ferry Terminal.</td>
</tr>
<tr>
<td>Component 4 / Chapter 5 Safety issues and risk assessment</td>
<td>Identify and appraise the potential risks for passengers, ship crew and terminal of using LNG as a fuel for a fast shipping operating to and from the Port of Spain Ferry Terminal.</td>
</tr>
<tr>
<td>Component 5 / Chapter 6 Cost estimations for newbuildings, retrofit and LNG infrastructure</td>
<td>Identify costs, that can be used by the Port Authority of Trinidad and Tobago as part of a business case, including for ship construction and delivery, costs for provision of an LNG ship bunkering facility, crew training costs, costs for maintenance etc. This should include an appraisal of retrofitting ships to use LNG as a fuel for existing ships operating from the Port Authority of Trinidad and Tobago.</td>
</tr>
<tr>
<td>Component 6 / Chapter 7 Reporting of results and recommendations</td>
<td>Submit a draft report four months after the start date of the project on or before 22 November 2013.</td>
</tr>
</tbody>
</table>
2 Current traffic and future requirements

2.1 Ports and marine infrastructure in Trinidad and Tobago

The main port for passenger ferry traffic is located in the capital, Port of Spain. The port is administrated by the Port Authority of Trinidad and Tobago (PATT), and accommodates the following two ferry terminals and ferry services:

- The Port of Spain ferry terminal – TTIT, Inter-island ferry services
- The Water taxi terminal – Water taxi services

PATT is organised under the Ministry of Transport, and along with Port of Spain, PATT is responsible for administering nine more ports and some small harbours in Trinidad and Tobago according to the table below.

Table 2 Ports in Trinidad and Tobago under administration of Port Authority of Trinidad and Tobago

<table>
<thead>
<tr>
<th>Location/name of port</th>
<th>Type of port</th>
<th>UN port code¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port of Spain</td>
<td>Seaport</td>
<td>TT POS</td>
</tr>
<tr>
<td>Point-a-Pierre Harbour</td>
<td>Seaport</td>
<td>TT PTP</td>
</tr>
<tr>
<td>Port of Scarborough</td>
<td>Harbour</td>
<td>TT SCA</td>
</tr>
<tr>
<td>Port of Chaguaramas</td>
<td>Harbour</td>
<td>TT CHA</td>
</tr>
<tr>
<td>Port of Tembladora</td>
<td>Pier, Jetty or Wharf</td>
<td>TT TEM</td>
</tr>
<tr>
<td>Port of Brighton (La Brea)</td>
<td>Pier, Jetty or Wharf</td>
<td>TT LAB</td>
</tr>
<tr>
<td>Port of Cronstadt Island</td>
<td>Pier, Jetty or Wharf</td>
<td></td>
</tr>
<tr>
<td>Crown point Harbour</td>
<td>Harbour</td>
<td></td>
</tr>
<tr>
<td>Galeota Point Harbour</td>
<td>Harbour</td>
<td>TT PTG</td>
</tr>
<tr>
<td>Port of Point Fortin</td>
<td>Pier, Jetty or Wharf</td>
<td>TT PTF</td>
</tr>
</tbody>
</table>

In addition to the PATT ports, there are also a number of important industrial ports in Trinidad and Tobago. The following three ports are interesting with respect to this study.

Point Lisas is the second largest port after Port of Spain and its administration is organized under the Ministry of Trade and Industry by the Point Lisas Industrial Port Development Corporation Ltd. (PLIPDECO).

¹ Code for Trade and Transport Locations (UN/LOCODE), ref (UNEC)
Pointe-à-Pierre is the main oil terminal used for transportation to and from the state-owned company, Petroleum Company of Trinidad and Tobago Ltd. (PETROTRIN).

The Point Fortin LNG terminal is part of the Atlantic LNG Company of Trinidad and Tobago. The main owners of Atlantic are international energy majors but the government of Trinidad and Tobago holds, via its National Gas Company (NGC) and its subsidiary Trinidad and Tobago LNG Ltd., 11.11 % equity in Atlantic LNG train No. 4. There is at present no port facility for small-scale export or for loading small LNG carriers or bunker vessels.

<table>
<thead>
<tr>
<th>Location/name of port</th>
<th>Administration</th>
<th>UN port code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port of Point Lisas</td>
<td>PLIPDECO</td>
<td>TT PTS</td>
</tr>
<tr>
<td>Pointe-à-Pierre oil terminal</td>
<td>PETROTRIN</td>
<td>TT PTP</td>
</tr>
<tr>
<td>Point Fortin LNG terminal</td>
<td>Atlantic LNG Company of Trinidad and Tobago</td>
<td>TT PTF</td>
</tr>
</tbody>
</table>
2.2 Trinidad and Tobago inter-island ferry services, TTIT

The inter-island ferry services, operated by Trinidad and Tobago Inter-island Transportation Company Ltd. (TTIT), include passenger and car ferry services between the two sister islands. The TTIT fleet is operating from the Port of
Spain ferry terminal to Scarborough in Tobago with two high speed vessels and one conventional roro-vessel.

There has been regular passenger traffic on the Trinidad–Tobago route from 1901. In the 1960s, roro-ferries were introduced. A first trial with high speed services was done in 1994, but it was not until 2005 that regular high speed ferry services took over the main part of the passenger traffic. Since 2007, the government of Trinidad and Tobago has owned, through PATT and TTIT, the two high speed ferries T&T Express and T&T Spirit, which are now in service on the route.

2.2.1 Present fleet of vessels

The Trinidad and Tobago Inter-Island Transportation Company Ltd. is operating two high speed catamarans and one conventional roro-vessel:

- The T&T Spirit, (Incat No. 060, 765 passengers/200 cars),
- The T&T Express, (Incat No. 046, 840 passengers/200 cars), and
- A conventional roro-vessel (Warrior Spirit, 3314 dwt, built 1980).

The roro-vessel Warrior Spirit is complementing the high speed passenger services. Basic data of the high speed ferries are given in the sections below. Some data are also presented for the roro-vessel even though they are not of direct interest with regard to this LNG pilot study.
T&T Spirit

The High Speed Craft (HSC) named, T&T Spirit was commissioned in July 2007. The vessel was originally designed for and operated by the US Army Tank-Automotive Command and was then reconstructed to service regular inter-island passenger traffic. Originally constructed in 2002 and just as the T&T Express, it is an aluminium wavepiercer catamaran by Incat with No. 060 and has main particulars according to the table below.

Table 4 Main particulars of the HSC T&T Spirit

<table>
<thead>
<tr>
<th>T&amp;T Spirit</th>
<th>Particulars</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of build</td>
<td>2002</td>
<td>InCat Australia Pty Ltd, Moonah, Australia</td>
</tr>
<tr>
<td>Ship yard’s Id</td>
<td>No. 060</td>
<td></td>
</tr>
<tr>
<td>Length (overall), LOA</td>
<td>97.2 m (319 feet)</td>
<td></td>
</tr>
<tr>
<td>Beam (overall), B</td>
<td>26.0 m (85 feet)</td>
<td></td>
</tr>
<tr>
<td>Draft loaded), T</td>
<td>3.43 m (11.2 feet)</td>
<td></td>
</tr>
<tr>
<td>Displacement (light/loaded)</td>
<td>1056/1800 m³</td>
<td></td>
</tr>
<tr>
<td>Gross tonnage GT</td>
<td>6558</td>
<td></td>
</tr>
<tr>
<td>Service speed</td>
<td>40 knots</td>
<td></td>
</tr>
<tr>
<td>Total Power</td>
<td>4 x 7080 kW</td>
<td>4 x Ruston 20RK270 Diesel engines</td>
</tr>
<tr>
<td>Gearbox reduction ratio</td>
<td>1:1.824</td>
<td>4 x RENK ASL 60</td>
</tr>
<tr>
<td>Waterjets</td>
<td>2 x 2 two in each hull</td>
<td>4 x LIPS, Type LJ145D</td>
</tr>
<tr>
<td>Auxiliary Machinery, genset</td>
<td>4 x 265 kW</td>
<td>4 x Cummins N14</td>
</tr>
<tr>
<td>Capacity (crew + passengers)</td>
<td>900 persons</td>
<td></td>
</tr>
<tr>
<td>Vehicle capacity</td>
<td>Approximately 200</td>
<td>380 lanemetres</td>
</tr>
<tr>
<td>Fuel Capacity</td>
<td>190 m³ (normal bunker)</td>
<td>2 x 210 m³ (long range fuel tankage)</td>
</tr>
<tr>
<td>Classification society</td>
<td>DNV</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2 T&T Spirit leaving Port of Spain for Tobago, November 2012

Figure 3 T&T Spirit, general arrangement outboard side and passenger deck top view

Figure 4 T&T Spirit berthing with stern at car ramp and passenger ramp in Port of Spain ferry terminal
T&T Express

The T&T Express was purchased to TTIT and put into service in December 2006. Before entering into service, it was refurbished after 10 years of operations in Australia, Nova Scotia, and the Bahamas. The government of Trinidad and Tobago owns the ship via PATT and the operator TTIT but the operational management and manning for T&T Express and T&T Spirit is performed by the Canadian company Bay Ferries on behalf of the owner. The vessel is an aluminium wavepiercer catamaran constructed by Incat with No. 046, and has main particulars according to the table below.

Table 5 Main particulars of the HSC T&T Express

<table>
<thead>
<tr>
<th>T&amp;T Express</th>
<th>Particulars</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of build</td>
<td>1997</td>
<td>InCat Australia Pty Ltd, Moonah, Australia</td>
</tr>
<tr>
<td>Ship yard’s Id</td>
<td>No. 046</td>
<td></td>
</tr>
<tr>
<td>Length (overall), LOA</td>
<td>91.3 m (300 feet)</td>
<td></td>
</tr>
<tr>
<td>Beam (overall), B</td>
<td>26.0 m (85 feet)</td>
<td></td>
</tr>
<tr>
<td>Draft (light/loaded), T</td>
<td>2.9/3.7 m (9.5/12.1 feet)</td>
<td></td>
</tr>
<tr>
<td>Displacement (light/loaded)</td>
<td>900/1400 m³</td>
<td></td>
</tr>
<tr>
<td>Service speed</td>
<td>42 knots</td>
<td></td>
</tr>
<tr>
<td>Gross tonnage GT</td>
<td>5617</td>
<td></td>
</tr>
<tr>
<td>Total Power</td>
<td>4 x 7080 kW</td>
<td>4 x Ruston RK270 Mk2 Turbo Diesels</td>
</tr>
<tr>
<td>Gearbox reduction ratio</td>
<td>1:1.824</td>
<td>4 x RENK ASL 60</td>
</tr>
<tr>
<td>Waterjets</td>
<td>2 x 2 two in each hull</td>
<td>4 x LIPS, Type LJ145D</td>
</tr>
<tr>
<td>Auxiliary Machinery, genset</td>
<td>4 x 240 kW</td>
<td>4 x Caterpillar 3406B/3408</td>
</tr>
<tr>
<td>Capacity (crew + passengers)</td>
<td>873 persons</td>
<td></td>
</tr>
<tr>
<td>Vehicle capacity</td>
<td>Up to 240</td>
<td></td>
</tr>
<tr>
<td>Fuel Capacity</td>
<td>4 x 14 m³ integral alu tanks</td>
<td>2 x 170 m³ (long range fuel tankage)</td>
</tr>
<tr>
<td>Classification society</td>
<td>DNV</td>
<td></td>
</tr>
</tbody>
</table>
A general arrangement, outboard side and top view, are shown in the figure below.

Figure 5 T&T Express, general arrangement outboard side and top view

Figure 6 T&T Express at berth in Scarborough, November 2013
Warrior Spirit

The traditional roro-vessel Warrior Spirit is primarily used for transportation of cargo between the sister islands. Transportation of food, construction material and fuel from Trinidad to Tobago is regularly conducted by trucks carried on board the Warrior Spirit.

Table 6 Main particulars of the Warrior Spirit

<table>
<thead>
<tr>
<th>Warrior Spirit</th>
<th>Particulars</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of build</td>
<td>1980</td>
<td>Societe Nouvelle des Ateliers et Chantiers du Havre - Le Havre</td>
</tr>
<tr>
<td>Ship yard’s Id</td>
<td>253</td>
<td></td>
</tr>
<tr>
<td>Length (overall), LOA</td>
<td>126 m</td>
<td></td>
</tr>
<tr>
<td>Beam (overall), B</td>
<td>21 m</td>
<td></td>
</tr>
<tr>
<td>Draft, T</td>
<td>6.3 m</td>
<td></td>
</tr>
<tr>
<td>Displacement (loaded/light)</td>
<td>8215 / 5556 m³</td>
<td></td>
</tr>
<tr>
<td>Service speed</td>
<td>17 knots</td>
<td></td>
</tr>
<tr>
<td>Gross tonnage GT</td>
<td>11 457</td>
<td></td>
</tr>
<tr>
<td>Total Power</td>
<td>11 023 kW</td>
<td></td>
</tr>
<tr>
<td>Auxiliary Machinery, genset</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>Capacity (crew +passengers)</td>
<td>48 cabins</td>
<td>105 berth + 96 driver berths</td>
</tr>
<tr>
<td>Classification society</td>
<td>Bureau Veritas</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7 Warrior Spirit approaching the ferry terminal in Port of Spain
2.2.2 Port infrastructure

Port of Spain ferry terminal

The Port of Spain ferry terminal is located south of the main deep water basin close to the city centre and is surrounded by busy streets and a ship repair yard in the north west and the CARICOM Wharf on the east side. The entrance from land to the ferry terminal is situated close to a busy street junction between South Quay, Beetham Highway and Wrightson Road and vehicles entering or leaving the ferry terminal often have to queue. The road and park areas inside the terminal area are limited, so queuing often delays the unloading of cars. Persons travelling with vehicles as well as passengers without cars are required to be at the ferry terminal two hours in advance of the scheduled departure time, and the check-in counter closes 30 minutes prior to departure.

In the sea chart in the figure below, the ship contour of a high speed vessel (red contour) is marked in the position of the ferry berth, and another contour (green) is marked at the roro-vessel berth.

![Figure 8 Sea chart of the Port of Spain (Grier basin) showing the location of the TTIT ferry terminal with high speed ferry berth (the red contour represent TT Spirit) and the roro-berth (the green contour representing Warrior Spirit) (Chart extracted from British Admiralty sea chart No. 474)
Figure 9 Port of Spain ferry terminal berth layout and vehicle traffic flows (PATT, 2013)

Figure 10 Port of Spain ferry terminal entrance from the city

Figure 11 Port of Spain ferry terminal with St. Vincent jetty (left) and terminal building (centre)
Scarborough ferry terminal

The figures below illustrate the ferry terminal in Scarborough. The layout is much more spacious than the ferry terminal in Port of Spain.

Figure 12 Extract from the sea chart of the Port of Scarborough Tobago showing the location of the TTIT passenger terminal with high speed ferry berth (Chart extracted from British Admiralty sea chart No. 477)

Figure 13 Port of Scarborough berth layout (PATT, 2013)
2.2.3 Route and schedule

The conventional roro-vessel makes one return trip per day, and each of the two high speed ferries normally make one return trip and stay overnight in Port of Spain and Scarborough respectively. In the high season, on Fridays, and other occasions with many travellers, one of the vessels makes two return trips per day. With both the high speed vessels in service, it is possible to do two round trips per vessel during the daytime. Therefore, the system is very flexible, and allows for an increased capacity in peak periods.

The graph below shows a graphic example of the schedule for TTIT’s three vessels, and the inclination of the lines corresponds to the vessels’ speeds.

![Time schedule graph Thursday 10 Oct](image)

**Figure 14** Normal sailing schedule weekdays with two high speed vessels and one conventional roro-vessel. The distance from Port of Spain to Scarborough is 92 nautical miles and the speed is about 39 knots for a 2½ h trip. Example from 10 – 11 October 2013.

Normal high speed services, with one return trip from each port can be maintained also with only one high speed ferry according to the graphical example below. This single high speed ferry schedule does not, however, allow for extra trips in the daytime and is sensitive in terms of reliability and disturbances.

The morning departure from Tobago at 06:30 and the afternoon departure from Port of Spain at 17:00 are not changed in the two schedules, indicating the importance of these daily tours in particular for people from Tobago visiting Port of Spain for a day trip.
2.2.4 Passenger statistics

The high speed ferry services are highly appreciated by the travellers. Since 2007, when the high speed ferries were introduced, the number of passengers has increased from about 400 000 per year to more than 1 000 000 per year today. There are no predictions available on future passenger development but it is generally anticipated that the number of travellers will continue to grow.

In 2012, the total number of passengers for the fleet of three vessels was 1 023 961 and the first seven months of 2013 indicate a slight increase compared with 2012 according to the graph in the figure below.
The week of Easter and the holiday season from July to August are the peak seasons in passenger traffic.

Key features of the high speed ferry services that are particularly appreciated by the passengers are considered to be:

- Short travel times
- Low fares
- High frequency
- Reliability and regularity
- Comfort

Environmental performance may also be presented as an attractive feature for passengers and public opinion if LNG is introduced as fuel instead of MDO. The air quality in the terminals during departure and arrival as well as the atmosphere on open deck areas during transit will be significantly better when exhaust smell and visible smoke will be eliminated with LNG fuelled ferries.

2.3 Water taxi services operating from the Port of Spain water taxi terminal

2.3.1 Present fleet and terminals

Starting in 2008, the National Infrastructure Development Company Ltd. (NIDCO) introduced the Water taxi services as an alternative mode for passenger transportation with the objective to ease traffic congestion along major routes on land. Today the water taxi fleet comprises the four sister ships: Calypso Sprinter, Carnival Runner, Paria Bullet and Trini Flash. The Water taxi terminal and base port is located at the south east end of the Kings Wharf in Port of Spain.

![Figure 17 The Water taxi terminal in Port of Spain, entrance form the city to the left. The photo to the right shows the four vessels of the fleet berthed in San Fernando.](image-url)
Table 7 Main particulars of NIDCO’s fleet of high speed ferries

<table>
<thead>
<tr>
<th>Main particulars of NIDCO’s water taxi vessels Calypso Sprinter, Carnival Runner, Paria Bullet, Trini Flash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length L</td>
</tr>
<tr>
<td>Passenger capacity</td>
</tr>
<tr>
<td>Speed</td>
</tr>
</tbody>
</table>

Figure 18 The Calypso Sprinter and Carnival Runner berthed in Port of Spain

2.3.2 Routes and time tables

The Water taxi services operate between Port of Spain and San Fernando on weekdays. On weekends, this service also includes additional trips between Port of Spain and Chaguaramas.

The weekday schedule includes three morning departures, (06:00, 06:45, and 08:00) and one afternoon departure (16.30) from San Fernando to Port of Spain. In the opposite direction from Port of Spain, there is one morning departure (07:00) and three afternoon departures (15:30, 16:30, and 17.30) to San Fernando.

On the weekends, the schedule includes one morning departure from San Fernando (09:30) to Port of Spain and one afternoon departure from Port of Spain (06:30) to San Fernando. In addition, the ferries conduct three return trips between Port of Spain and Chaguaramas. Each single trip between Port of Spain and Chaguaramas takes 30 minutes and a total of two vessels conduct two 45-minute and six 30-minute trips per day on the weekends.

With the present time schedules, NIDCO’s fleet of high speed ferries has the operational capacity to increase its services, and discussions are currently underway regarding new routes and additional ports of call in the Gulf of Paria. Possible future plans of diversification of the Water taxi services also include the implementation of charters, tours and advertising opportunities.
2.3.3 Fuel consumption and possibilities for future use of LNG as ship fuel

In the present time schedule with two of the Water taxi vessels in operation, the average fuel oil consumption is 3.56 tonnes per day per vessel.

The ships are relatively new and reconstruction for LNG fuel is presently not considered feasible. Moreover the engine supplier has no plans to offer conversion kits for the specific main engine types. Replacement of existing diesel engines and installing new dual-fuel engines would imply difficulties with regard to weight and space. The owner, NIDCO, presently has no plans for acquiring new vessels and does not consider LNG retrofit installation attractive.

Nevertheless, LNG-fuelled Water taxi vessels might offer an environmentally attractive alternative for the reduction of traffic and congestion problems on the road and on land in the long-term, when the company replaces the vessels of the Water taxi fleet.

2.4 Environmental performance and exhaust emissions

TTIT’s present fleet of high speed ferries are operating with Marine Diesel Oil (MDO) as fuel. In contrast to Marine Gas Oil (MGO), which contains only distilled products, the MDO is a blend of distilled products and some residual fractions. MDO may have a sulphur content up to 2% but a typical value of about 1% sulphur is here assumed representative for comparative calculations of emissions from MDO and LNG fuelled high speed ferries.

2.4.1 Fuel oil consumption and emissions from current ferry services

The recorded consumption data (TTIT, 2013) of TTIT’s current fleet of high-speed ferries and the typical general specific emission figures for the category of diesel engines installed in those ships were used to calculate the following rough estimations of annual emissions of characteristic exhaust gas components. The sulphur content of the MDO is assumed to be 1%.

<table>
<thead>
<tr>
<th>Fuel consumption tonnes of MDO/year</th>
<th>Emission of CO₂ tonnes per year</th>
<th>Emission of SO₂ tonnes per year</th>
<th>Emission of NOₓ tonnes per year</th>
<th>Emission of PM tonnes per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>19300</td>
<td>61500</td>
<td>771</td>
<td>1160</td>
<td>21</td>
</tr>
</tbody>
</table>

2.4.2 Possible reduction of emissions by the introduction of LNG fuel

Based on the estimated consumption of LNG if TTIT’s current fleet of high speed ferries would be reconstructed with LNG fuelled gas turbines as main engines and on typical general specific emission figures for LNG fuelled gas turbines, the following rough estimation of annual emissions of characteristic
exhaust gas components has been calculated. It should be noted that the annual fuel consumption in terms of total energy content will increase when the diesel engines are replaced by gas turbines because of the lower rate of efficiency in gas turbines compared with diesel engines.

Table 9 Annual quantities of exhaust gas components from TTIS’s high speed ferries operated by LNG

<table>
<thead>
<tr>
<th>Fuel consumption tonnes of LNG/year</th>
<th>Emission of CO₂ tonnes per year</th>
<th>Emission of SOₓ tonnes per year</th>
<th>Emission of NOₓ tonnes per year</th>
<th>Emission of PM tonnes per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 300</td>
<td>52 600</td>
<td>0</td>
<td>569</td>
<td>0</td>
</tr>
</tbody>
</table>

Comparisons between the two tables above, reveal that the use of LNG as fuel for the high speed ferries will eliminate the emissions of sulphur oxide (SOₓ) and virtually eliminate the emissions of particulate matter (PM). Furthermore, the emission of nitrogen oxide (NOₓ) will be significantly reduced, but the indicated figure is considered conservative. Further NOₓ reductions may be obtained if the gas turbine is equipped with water or steam injection. By installing of such devices, the annual NOₓ emissions from the LNG fuelled gas turbines may be reduced to less than 200 tonnes². Exhaust heat recovery and water or steam injection may also contribute to higher efficiency and lower specific consumption for the gas turbine installation.

Comparison of the carbon dioxide (CO₂) emissions indicates a reduction of about 15 %, even though the efficiency rate is lower for the gas turbines than it is for the diesel engines.

Figure 19 Comparison of annual fuel consumption and emissions for a fleet of two high speed ferries powered by diesel engines and MDO and by gas turbines and LNG respectively

² The NOₓ emission figure in Table 9 is based on a specific emission factor of 7 g/kWh but the specific emission of 1-2 g/kWh may be gained with water or steam injection (Siemens, 2008).
From a local environmental and health perspective in Trinidad and Tobago, the reduction of the particulate matters, PM is considered the most important factor of improvement by introducing LNG as fuel for the high speed ferries. Reduced concentrations of PM in the air in urban areas and cities that are exposed to heavy traffic, such as Port of Spain, can often be translated into figures of saved lives and averted fatalities.

Presently, no decision has been made to designate the waters where the TTIT high speed ferries are operating as an emission control area (ECA), so there will be no international compulsory requirements calling for reduced SO\textsubscript{x} or NO\textsubscript{x} emissions from the ferries in the near future. However, there are a number of new ECAs in force around the world, and more stringent emission requirements will come into effect in these from 2015. In the future, it is possible that the entire Caribbean Ocean and WCR will become an ECA.

Reconstruction for LNG fuel operation or newbuilding will facilitate compliance with future ECA requirements and with diesel/LNG dual-fuel systems installed, the attractiveness and value of the ships will be higher also in a second hand market.
3 LNG supply chain and bunkering infrastructure

3.1 General requirements of a supply chain for LNG as marine fuel

There are several aspects to consider when designing a supply chain for LNG as marine fuel. Some important aspects are:

- Reliability
- Safety
- Security of supply
- Flexibility
- Capacity
- Operational cost
- Investment costs

Different stakeholders may prioritise these aspects differently but none of the aspects can be excluded.

From the ship owner’s perspective, three aspects are predominant: the price of the fuel free on board (FOB), the reliability of the supply chain, and the capacity of the supply chain in relation to the demand. If the LNG fuel price is much higher compared to other alternatives, then LNG is uncompetitive and will most likely not be selected as a fuel. In addition, if there are insufficient volumes of LNG and the bunkering vessel cannot bunker the required amount of fuel when needed, then consequences may be severe for LNG as a marine fuel.

Compared with traditional oil based ship fuels, the equipment and resources used in an LNG supply chain are more complex and more expensive, both in terms of CAPEX and OPEX, primarily due to the cryogenic temperatures of LNG. Therefore, the optimisation of all relevant aspects is important to keeping down the costs without compromising safety and security.

Another important difference between LNG as marine fuel and the traditional, oil-based ship fuels is that LNG has to be handled with care due to its perishable characteristics. The composition of LNG may change if it is handled incorrectly, making it less valuable or even useless as marine fuel. It may also generate negative environmental impact and pose significant risks to people when LNG vaporisation creates high pressure.
3.2 Supply chains

Before the start-up meetings and workshop in September 2013, 28 possible supply chains were outlined by the consultant team as a starting point for the discussions. A graphical presentation of all the supply chains is presented in Appendix 2. All supply chains were designed in line with the principal supply chain displayed in Figure 20 below.

Figure 20 Initial hypothesis of a supply chain of LNG as marine fuel to the high speed vessels in Port of Spain

Due to the fact that Trinidad and Tobago accommodates one of the largest LNG production plants in the world with an annual capacity of approximately 15 mmpta of LNG, the Atlantic LNG facility in Point Fortin was considered the obvious choice for a LNG source for all supply chains. However, the workshop and meetings in September 2013 made clear that some limitations on the possibilities for using Atlantic LNG as the source of LNG exist. At present, domestic redistribution of LNG is outside the scope of the mandate of Atlantic LNG (Ramlakhan, 2013).

For this type of pilot study, it is important to establish feasible conditions for the source of the LNG supply at an early stage. Especially for studies addressing vessels with pure gas (non-dual-fuel) engines, alternative sources of supply may also need to be considered to minimise risks and to secure a continuous supply of LNG fuel at favourable conditions.

Based on the initial information retrieved from the different stakeholders, two of the 28 identified supply chains where at an early stage of the project selected for further evaluation. Due to the sourcing issue mentioned above, an additional third supply chain was developed. All three supply chains are thoroughly described in sections 3.5 to 3.7.

3.3 Possible bunkering solutions

Just like the bunkering of traditional oil fuels, LNG bunkering may be performed in different ways. At present, most LNG bunkerings are made either from truck to ship or from small intermediate bunker terminals. During the development of the different supply chains as described in Appendix 2 the following bunkering solutions were considered: truck to ship (TTS), intermediate tank via pipeline to ship (ITPS), ship to ship (STS), and container to ship (CTS).
3.3.1 Truck to ship (TTS)

The most common LNG bunkering method today is truck to ship. It is a feasible option as long as the volumes are reasonably small. A tank truck can carry up to approximately 22 tonnes of LNG depending on the capacity of the tank truck, national transport and vehicle regulations, road infrastructure and the standard of the roads to be used. If the receiving vessels require large quantities (>50 tonnes), then other bunkering methods are usually more suitable.

![Figure 21 Truck to ship bunkering (TTS) of LNG from two trailers in parallel (Photo courtesy: Skangass AS)](image)

The largest benefits of TTS operations are a limited initial investment and that the necessary investments are possible to use also for other purposes, such as local energy distribution. This makes the TTS method a very good start-up solution for LNG bunkering.

The limited capacity of the truck is, however, the most obvious limitation in this bunkering solution. Another disadvantage is that TTS operations may have an impact on the possibilities of parallel operations, because the bunkering operation has to be carried out on the quay side of the vessel and thus might interfere with cargo and passenger handling.

Bunkering locations are not fully flexible, because the location has to be connected to a road that is suitable for the transportation of LNG from the source.

3.3.2 Intermediate tank via pipeline to ship (ITPS)

Another commonly used bunkering solution is bunkering by pipeline directly from an intermediate LNG tank. Depending on the requirements and logistical options, the size of such tanks may vary from as small as a few tonnes to more than 50 000 tonnes. The LNG can be supplied to the intermediary tank via
truck, barge, ship, or local production directly from the gas grid depending on the required volumes, availability, etc. It may also be possible to use an import or export terminal as a direct source for ITPS bunkering.

One limitation to this solution is that it is technically and operationally challenging to have long pipelines, which implies that the tank has to be located in the proximity of the berth where the bunkering operation shall be performed. It is, however, not always possible to do this since the available space in combination with safety requirements and other on-going activities in the port can induce restrictions. The ITPS method also has limitations in its flexibility, because the bunkering position is fixed. Therefore, the solution is most likely to be used for a port or berth with a stable and long-term demand for bunker delivery or used when a local LNG bunker demand coincides with other consumers, making it possible to co-use the necessary infrastructure.

3.3.3 Ship to Ship (STS)

Both TTS and ITPS have clear limitations regarding capacity and flexibility. To avoid these, a more feasible option for LNG bunkering is by ship-to-ship operation, similar to how most fuel oil is supplied to ships today. The solution is flexible when it comes to both capacity and location, and an LNG bunker vessel or barge can be used to bunker most kinds of vessels. STS also has disadvantages, because the initial investment in a bunker vessel is significant, and it may be difficult to find alternative assignments for the bunker vessel when the LNG bunker demand is limited.

If a barge is used, then it may either be self-propelled or un-propelled using one or several tugs when moving.
3.3.4 Container to ship (CTS)

A solution that is commonly discussed but not yet fully developed or in use is container-based solutions whereby special LNG fuel containers are used both for transportation from the LNG source as well as for fuel storage on board the LNG fuelled vessel. Designed in line with standard ISO containers, the supply chain may utilise an already existing distribution infrastructure.

A standard 40’ ISO container is able to handle approximately 17 tonnes of LNG. (MarineServiceGmbH, 2013)
The benefit of the solution is combined utilisation with existing distribution systems for containers. The main drawbacks are the high cost and high weight per tonne of LNG as well as some ambiguities when it comes to the regulations for shipboard use as fuel.

### 3.4 Demand estimation for TTIT’s high speed ferry services

If related directly to the total daily consumption of MDO, as presented in section 2.4.1 of the existing TTIT vessels, the LNG demand is estimated to be approximately 42 tonnes per day. This number is considered accurate if pure gas or duel fuel piston engines are used as main engines for two new vessels or the two converted vessels.

Due to weight and space issues of the presently available dual-fuel and pure gas engines it is deemed necessary to use NG fuelled gas turbines if converting the T&T Spirit. For the same reason it is most likely that any new built high speed ferry also will use gas turbines as main engines.

This has a significant impact on the fuel consumption, because the efficiency of gas turbines generally is lower than for piston engines. Due to this, the estimated daily consumption is increased to approximately 60 tonnes LNG per day, 30 tonnes per return trip.

Based on the present time table (described in section 2.2.3) has been assumed that each supply chain should be able to deliver 30 tonnes of LNG as bunker, twice a day, to the ferry terminal either in Port of Spain or in Scarborough.

It is also assumed that the vessels are of dual-fuel type and that the minimum storage capacity of LNG on board is approximately 35 tonnes or approximately 81 m$^3$ LNG if the vessels shall be able to operate on LNG only. The estimated consumption is concluded in Table 10.

<table>
<thead>
<tr>
<th>Ferry</th>
<th>Daily tonnes</th>
<th>Daily MMbtu</th>
<th>Weekly tonnes</th>
<th>Weekly MMbtu</th>
<th>Annually tonnes</th>
<th>Annually MMbtu</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>30</td>
<td>1 400</td>
<td>210</td>
<td>9 800</td>
<td>11 000</td>
<td>514 000</td>
</tr>
<tr>
<td>No. 2</td>
<td>30</td>
<td>1 400</td>
<td>210</td>
<td>9 800</td>
<td>11 000</td>
<td>514 000</td>
</tr>
<tr>
<td>Total</td>
<td>60</td>
<td>2 800</td>
<td>420</td>
<td>19 600</td>
<td>22 000</td>
<td>1 028 000</td>
</tr>
</tbody>
</table>

Each vessel needs to be bunkered between each round trip implying that if both vessels are in operation one bunkering will take place at night and one during the day in the selected bunkering port. Based on the present time table, more thoroughly described in section 2.2.3, the bunkering time slot in Port of Spain is between 10:00 and 16:00 (daytime) and 19:30 until 5:30 (night-time).
The bunkering time slot in Scarborough is between 10:00 and 15:00 (daytime) and from 20:30 until 5:30 (night-time).

When the ferries are operated in line with the normal time schedule, there is at least five hours to perform each bunkering operation. Five hours are considered more than enough independently of selected bunkering method. This also implies that there will be enough time to perform each bunkering operation without passengers on-board and with no parallel cargo handling which is considered preferable from a risk and safety perspective.

During irregular situations when only one ferry is in operation, the situation changes. The available bunkering time is then shorter, depending on scheduling, and may be less than one hour. In such cases bunkering during cargo operation and with passengers on board is a necessity. If not accepted by local authorities or feasible from a safety point of view, this may require that MDO is used as fuel during periods with only one vessel in operation.

In the following sections, the three identified supply chain options are discussed and outlined with respect to the actual demands of the TTIT fleet.

### 3.5 Supply chain 1 - Truck Delivery

The first supply chain to be assessed is a fully truck based solution using LNG semi-trailers both for transporting LNG from the source to the ferry terminal as well as for the bunkering operation itself.

![Supply chain 1](image)

**Figure 25 Supply chain 1**

#### 3.5.1 Source

As source of the supply chain, two possible locations are used. The first is Atlantic LNG in Point Fortin and the second is the possible new small/mid-scale production plant in La Brea which is under discussion (Hosein, 2013). If Atlantic LNG is to be used, their mandate has to be updated to allow distribution of LNG domestically.

#### 3.5.2 Required equipage and staff

The main equipment required for this supply chain is a suitable number of semi-trailers. It has been difficult to establish the maximum capacity for an LNG semi-trailer operated on Trinidad and Tobago since a special permit procedure is required for all vehicles with a gross weight above 15 tonnes. Since no road
based LNG transportation has been done on Trinidad and Tobago there is no prejudice available.

Therefore it has been assumed that the Trinidad and Tobago authorities will approve LNG trailers similar to what is used both on the US and European market implying that the maximum capacity of an LNG semi-trailer is 20-22 tonnes of LNG. The loading and discharging time of one semi-trailer is 1 hour.

Figure 26 A typical European Truck/LNG Semi-trailer combination (Photo Courtesy Skangass AS)

In addition to these semi-trailers a number of towing trucks is needed. It is assumed that such towing trucks are possible to charter from local trucking companies.

At the LNG source a truck loading facility has to be established with the ability to fill an LNG semi-trailer tank in a safe and efficient way. Preferably it will be able to load the trailers with LNG close to atmospheric pressure and with a temperature close to -162°C.

Both loading of the truck and the bunkering operations will be operated by the truck driver with assistance from the staff at the LNG production plant during loading and from the crew of the vessel during bunkering.

3.5.3 Scheduling

Due to the highly congested traffic in the Port of Spain area, as well as the narrow and undeveloped road network south of San Fernando, it is presently very difficult to estimate the time for an LNG semi-trailer to be towed from the selected LNG source to the ferry terminal in Port of Spain.

Fortunately there is an on-going project to extend the present highway south of San Fernando all the way down to Point Fortin making the traffic situation...
much less challenging to evaluate. According to NIDCO (NIDCO, 2013) the highway is supposed to be completed in March 2015 and all presented scheduling is based on that the new road is ready.

The following table conclude the estimated travel times between the two possible sources of LNG and the Ferry Terminal in Port of Spain.

Table 11 Estimated transit times from source to Port of Spain ferry terminal

<table>
<thead>
<tr>
<th>Route</th>
<th>Peak hours</th>
<th>Off peak hours</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic - POS Ferry terminal</td>
<td>3h</td>
<td>2h</td>
<td>85 km</td>
</tr>
<tr>
<td>La Brea - POS Ferry Terminal</td>
<td>3h</td>
<td>2h</td>
<td>70 km</td>
</tr>
</tbody>
</table>

To supply the required 30 tonnes of LNG for each bunkering, two semi-trailers are required. As long as the ferries are operated in normal operation mode, with one bunkering at night and one bunkering during the day, the full supply chain requires only two semi-trailers.

---

3 Weekdays 06:00-10:00 and 14:00-19:30
The following timetable is suggested to be used during normal operation:

### Table 12 Proposed time schedule for two LNG semi-trailers supplying the high speed ferries with fuel

<table>
<thead>
<tr>
<th>Activity</th>
<th>Trailer 1</th>
<th></th>
<th>Trailer 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start hour</td>
<td>Activity time (h)</td>
<td>Start hour</td>
<td>Activity time (h)</td>
</tr>
<tr>
<td>Loading</td>
<td>21:30</td>
<td>1</td>
<td>22:30</td>
<td>1</td>
</tr>
<tr>
<td>Transit</td>
<td>22:30</td>
<td>2</td>
<td>23:30</td>
<td>2</td>
</tr>
<tr>
<td>Bunkering</td>
<td>00:30</td>
<td>1</td>
<td>01:30</td>
<td>1</td>
</tr>
<tr>
<td>Transit</td>
<td>01:30</td>
<td>2</td>
<td>02:30</td>
<td>2</td>
</tr>
<tr>
<td>Waiting</td>
<td>03:30</td>
<td>4½</td>
<td>04:30</td>
<td>4½</td>
</tr>
<tr>
<td>Loading</td>
<td>09:00</td>
<td>1</td>
<td>10:00</td>
<td>1</td>
</tr>
<tr>
<td>Transit</td>
<td>10:00</td>
<td>2</td>
<td>11:00</td>
<td>2</td>
</tr>
<tr>
<td>Bunkering</td>
<td>12:00</td>
<td>1</td>
<td>13:00</td>
<td>1</td>
</tr>
<tr>
<td>Waiting</td>
<td>13:00</td>
<td>5½</td>
<td>14:00</td>
<td>4½</td>
</tr>
<tr>
<td>Transit</td>
<td>19:30</td>
<td>2</td>
<td>19:30</td>
<td>2</td>
</tr>
<tr>
<td>Waiting</td>
<td>-</td>
<td>-</td>
<td>21:30</td>
<td>1</td>
</tr>
</tbody>
</table>

The time table is designed to avoid transit during rush hours as well as bunkering with passengers on board.

#### 3.5.4 Other consideration

To open up for truck based distribution of LNG in Trinidad and Tobago will also make it possible to distribute LNG for other purposes. Even if Trinidad has a rather extensive pipeline system for natural gas it may be economically feasible to use truck distribution of LNG for remote consumers on Trinidad, or even on Tobago.

#### 3.6 Supply chain 2 - Local production

The second supply chain is based on a local production and storage facility in the vicinity of the ferry terminal, connected directly to the natural gas grid. If it is possible to locate the facility in or close to the ferry terminal, bunkering could be done directly from the facility via pipeline (ITPS) as described schematically in Figure 28.
If it is not possible to locate the facility close to the ferry terminal it is suggested that LNG is to be transported from the facility to the ferry terminal by truck where the bunkering will be performed TTS. This version of the supply chain is described schematically in Figure 29.

An advantage of both the 2a and 2b supply chains is that local production and storage plant could be located both in the vicinity of the Port of Spain Ferry terminal but also in the vicinity in the Scarborough terminal adding the possibility to introduce LNG as a possible mode of energy distribution in Tobago.

### 3.6.1 Source

The supply chain needs to be fed from any pipeline with available capacity. The daily consumption of natural gas is estimated to approximately 84 000 m³/day or 3.0 mmcf/d.

At present such pipelines are available close to the ferry terminal in Port of Spain. A main 16” feeder pipe of natural gas is connected to the power plant operated by The Power Generation Company of Trinidad and Tobago passing not far from the ferry terminal itself.

Due to the on-going activities at the power plant it could be a suitable location for either a small-scale LNG production and storage facility or the connection of a dedicated feeder pipeline, supplying the facility located at the ferry terminal. From the power generation plant it is about 1 200 metres to the ferry terminal.

In Tobago a suitable connection point is the Cowe Eco-industrial estate located at the Tobago gas pipeline receiving plat in the Lowlands. The distance from the estate to the Scarborough ferry terminal is approximately 7 500 metres. The Cowe Eco-industrial estate is also considered as a suitable place for a local production and storage facility.
3.6.2 Required equipage and staff

The local production and storage facility has to be able to produce approximately 60-70 tonnes of LNG per day. There are a number of different suppliers and solutions available at the market. According to Galileo (Gandulfo, 2013) their Cryobox™ solution operates autonomously with no need to be continuously manned. It is however assumed that a supervision and maintenance organisation related to the production and storage facility has to be available.

A suitable size of storage capacity is estimated to 145-165 m³ which is equal to the estimated consumption of two ferries per day.
Supply chain 2a requires an additional pipeline from a suitable connection point to the ferry terminal. It is estimated that such pipeline need to be 1 200 metres if the local production and bunkering shall take place in the Port of Spain ferry Terminal. If Tobago is selected, the pipeline is estimated to 7 500 metres. The production and storage facility also needs to be equipped with a bunkering station similar to the one showed in Figure 22 on page 36.

During bunkering the bunkering facility is required to be manned with a dedicated shore based person or by the crew from the ferry itself.

For supply chain 2b the local production and storage facility needs to be located close to a connection of the main pipeline and it needs to be equipped with a truck loading facility. The LNG supply from the facility will then be done by the same type of LNG semi-trailers as per supply chain 1. It is assumed that independently of selected location, the requirement of trucking is limited to only one LNG semi-trailer which has to be reloaded twice for each bunkering operation. Both loading of the truck and bunkering will be operated by the truck driver with assistance from the crew of the ferry during bunkering.

### 3.6.3 Scheduling

For supply chain 2a the requirements of scheduling is limited. The vessel may bunker when suitable. The bunkering time is estimated to 1 hour.

For supply chain 2b the bunkering time is still rather flexible as long as the distance from the local production and storage facility is limited. The required time for bunkering is considerable longer though since the LNG semi-trailer needs to be reloaded once during each bunkering operation. Therefore it is estimated that each bunkering will take approximately 4 hours: 2 hours is spent on bunkering, 1 hour of reloading and 1 hour is allocated for transit between the local production and storage facility and the ferry terminal.

### 3.6.4 Other consideration

As stated above this is the only of the three described supply chain options that may be located in Tobago. The benefit of a Tobago located solution is that LNG may be distributed locally in Tobago supplying natural gas as energy to different consumers in Tobago without the investments in a gas grid on the island.

### 3.7 Supply chain 3 - Bunker barge

The third supply chain is based on an un-propelled barge with dual purposes. The barge is used both to source LNG and as bunkering vessels doing ship-to-ship bunkering in Port of Spain.
3.7.1 Source

As source of this supply chain two possible locations are used. The first is Atlantic LNG in Point Fortin and the second is the possible new small/mid-scale production plant in La Brea currently under discussion. For all scheduling purposes Atlantic LNG will be used as reference.

3.7.2 Required equipage and staff

A suitable capacity of the barge is 1500 m$^3$ of LNG, corresponding to approximately 600 tonnes of LNG. The size of the barge will be approximately 50 x 22 metres with shallow draft. The barge will be equipped with two LNG tanks of 750 m$^3$ and with its own power production plant to provide power to cargo pumps, a bow thruster and miscellaneous systems.

The barge will be moved by a standard harbour tugs available in the area. When connected to the barge the service speed is estimated to 7 knots in normal weather conditions. Since the barge has a bow thruster it is assumed that the tug/barge unit will have enough manoeuvrability to do efficient bunkering operation in the Port of Spain Ferry terminal. It is assumed that the local authorities will not require any special certificates for the crew of the tug in relation to the LNG transportation and bunkering.

The barge itself needs to be manned with a cargo master responsible for all loading and bunkering operation. It is assumed that the local authorities only require his/her presence during cargo operations and that they accept that the barge is unmanned when moored in Port of Spain or during transit. If not, the OPEX cost of the barge will increase.
At the LNG source a small-scale jetty is required for loading of LNG. The jetty only needs to be approximately 70 metres long and with a minimum draft of approximately 3 metres.

### 3.7.3 Scheduling

By sea the distance between Port of Spain and Atlantic LNG is approximately 30 nautical miles. With a speed of 7 knot and some spare time for manoeuvring etc. it is assumed that a trip in either direction takes approximately 5 hours.

With a daily consumption of 60 tonnes the barge need to be refilled at the source every 10th day. Depending on both the design of the loading facility at the source and the design of the loading system and tanks on the barge, the loading time may differ. It is assumed that 5 hours is a reasonable loading time implying that a roundtrip with loading at source will take approximately 15 hours. As long as the high speed ferries follow normal operation there is enough time to do the reloading trip without missing a bunkering occasion.

A tentative schedule for a barge based LNG fuel supply chain is outlined in the table below.
Table 13 A suitable 10 days rolling schedule

<table>
<thead>
<tr>
<th></th>
<th>Day 1-9</th>
<th>Day 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connecting tug barge in Port of Spain</td>
<td>03:30</td>
<td>-</td>
</tr>
<tr>
<td>Start bunkering</td>
<td>04:30</td>
<td>04:30</td>
</tr>
<tr>
<td>Stop bunkering</td>
<td>05:30</td>
<td>05:30</td>
</tr>
<tr>
<td>Waiting</td>
<td>4½ h</td>
<td>4½ h</td>
</tr>
<tr>
<td>Start Bunkering</td>
<td>10:00</td>
<td>10:00</td>
</tr>
<tr>
<td>Stop Bunkering</td>
<td>11:00</td>
<td>11:00</td>
</tr>
<tr>
<td>Disconnecting barge</td>
<td>12:00</td>
<td>-</td>
</tr>
<tr>
<td>Transit to Atlantic LNG</td>
<td>-</td>
<td>5 h</td>
</tr>
<tr>
<td>Start loading</td>
<td>-</td>
<td>16:00</td>
</tr>
<tr>
<td>Stop loading</td>
<td>-</td>
<td>21:00</td>
</tr>
<tr>
<td>Transit to Port of Spain</td>
<td>-</td>
<td>5 h</td>
</tr>
<tr>
<td>Waiting</td>
<td>-</td>
<td>2½ h</td>
</tr>
<tr>
<td>Start Bunkering</td>
<td>-</td>
<td>04:30</td>
</tr>
</tbody>
</table>

Based on the schedule above the tug is needed 12 hours per day during day 1-9 and 24 hours during day 10.

3.7.4 Other consideration

The main benefit of supply chain 3 is that it also offers the possibility to serve other vessels visiting the Bay of Paria area with LNG as marine fuel. At present the demand is non-existing but this may change rapidly if the foreseen international development concerning LNG as marine fuel commence in line with expectations.
4 Regulatory design requirements

4.1 Regulatory gaps and development of new frameworks

The development of LNG as marine fuel still is in its early stage and the availability of international accepted and ratified rules and regulations for the design and operation of LNG fuelled vessels as well as LNG bunkering facilities is limited. In addition to this the availability of nationally applicable rules, guidelines and standards for small-scale handling and transportation of LNG in Trinidad and Tobago is incomplete due to the fact that LNG has never been handled outside the premises of Atlantic LNG.

This chapter primarily includes selected examples and descriptions of rules, regulations, guidelines and standards that are recommended for application and may facilitate development of both the LNG fuelled high speed vessels as well as the supply chain of LNG as marine fuel.

Due to the unclear regulatory situation it is important to understand that any project have to be developed in close cooperation between the different stakeholders and authorities and that a consensus of the selection and application of suitable rules and regulation has to be reached as early as possible in the process.

In the safety assessment presented in Chapter 5 it is presumed that each element of the LNG bunkering chain is designed and operated in line with relevant rules, regulations, guidelines or standards as mentioned in this chapter. The same presumption applies to the cost estimations presented in chapter 6.

4.2 High speed vessels

At present there are no internationally applicable rules neither for the design of LNG fuelled vessels in general nor for LNG fuelled high speed vessels. This implies that it is up to the maritime competent authority of Trinidad and Tobago to decide which rules to apply for a conversion of the existing vessel as well as for a newbuilding as long as the new or converted vessels fly the flag of Trinidad and Tobago. If not flying the flag of Trinidad and Tobago the decision of applicable rules and regulations will be done by the selected flag state but the flag state of Trinidad and Tobago will have to consider the conditions carefully as the vessel will be operated domestically in Trinidad and Tobago.

The sections below summarize some of present rules and guidelines applicable for high speed vessels and that in combination may constitute a set of relevant rules and regulation for the design of LNG fuelled high speed vessels within the next few years. The regulations may be applicable regardless if the pilot project results in newbuilding or conversion of existing vessels. Some information is
also included on future regulations under development and their expected finalisation dates.

4.2.1 Resolution MSC.285(86)

Based on the rules and regulations developed in Norway primarily by the Norwegian Maritime Authority and DNV during the early 2000s, IMO in June 2009 adopted Resolution MSC.285(86), also known as the interim IGF guidelines. The document includes design criteria as well as operational and educational rules and regulations for LNG fuelled vessels. The document is only published as guidelines and is put in force by the IMO member states and therefore does not constitute an official IMO code. Nevertheless it is in principle applied on all LNG fuelled vessel in operation or under construction today.

4.2.2 Class rules

All major classification societies have its own rules concerning the design of LNG fuelled vessels. In principle all of them are based on the IMO Resolution MSC.285(86) but there are differences in the interpretation and application. Today DNV is the classifications society who has classified the most LNG fuelled vessel but also GL, ABS and Lloyd’s Register have LNG fuelled vessels in their class.

4.2.3 The forthcoming IGF code

Following the adoption of Resolution MSC.285(86) in 2009, IMO has together with its member states worked with the development of the first fully applicable code for LNG fuelled vessels, The IGF code. When ready, it will become an amendment to SOLAS. Originally it was intended to be amended to SOLAS in 2013 then entering into force during 2015 but for various reasons it is delayed. At present the most plausible timetable indicates that the code will be amended into SOLAS during 2015 and, if accepted by all parties entering into force at the earliest during 2017 (Hughes. E, 2013) (Safety4Sea, 2013).

As soon as it has entered into force it is compulsory for all vessels built (keel laid) or undergoing a major conversion after the date that the amendment entered into force and flying a flag of a contracting party of the SOLAS convention.

4.2.4 International Code of Safety for High-Speed Craft, HSC Code

During the high speed vessel boom during the 1990s, the need for a code specifically addressing light high speed vessels was highlighted. This resulted in the development and introduction of the IMO International Code of Safety for High-Speed Craft, 1994 (1994 HSC Code) (resolution MSC.36(63)). A new

For the T&T Spirit built in 2002 it is the 2000 HSC Code that applies.

4.2.5 Education of crew

At present "The International Convention on Standards of Training, Certification, and Watch keeping for Seafarers" also known as the STCW convention does not include any requirements for education and training of crew on LNG fuelled vessels (STCW, 2011). The process to include such regulation is on-going but it is still unclear when relevant requirements will be amended and put in to force. Until then it is up to each flag state to decide how the crew on LNG fuelled vessels flying their flag is to be trained and educated. (Hughes. E, 2013)

Chapter 8 of Resolution MSC.285(86) specifies the basics of the educational requirements of the crew on board an LNG fuelled vessel. In addition DNV has published a document called “Competence Related to the On Board Use” (DNV, 2013). These two documents are considered a suitable framework for the elaboration educational requirements for high speed LNG fuelled vessels operating between Trinidad and Tobago.

4.2.6 HSC Francisco

The only LNG fuelled high speed vessel in operation today is the Buquebus´ operated Francisco delivered by Incat in August 2013. It is operated between Buenos Aires in Argentina and Montevideo in Uruguay. Classified by DNV flying the Uruguayan flag it is an important reference for any development of LNG fuelled high speed vessels independently if the vessel is new built or converted.

According to DNV (Allwood. T, 2013) the vessel was issued with certificate of equivalence to the HSC requirement of carrying fuels with flash point below 35 °C. This equivalence was based on compliance with Resolution 285(86).

According to DNV there where some significant challenges due to the fact that Resolution 285(86) includes a number of demands not suitable for high speed vessels as well as the fact that gas turbines are not included in the Resolution. Therefore the overall compliance was achieved by use of safety cases, FMEA, and compliance with Resolution 285(86) (IMO, 2009).

4.2.7 Defining applicable design requirements for LNG fuelled HSC

There are no specific rules neither for LNG fuelled vessels in general nor for LNG fuelled high speed vessel in particular. Conversion of an existing vessels or a newbuilding therefore requires special considerations. The key to success is
cooperation between the different stakeholders and authorities related to the project.

From a regulatory perspective the Maritime Service Division of Trinidad and Tobago has the overall responsibility to approve the design and operation of such a vessel. Another important key stakeholder is the selected classification society whose knowledge and expertise ensure a solid background information of the formal decisions made by the flag state.

Other important stakeholders may include the companies and organisations involved in the supply chain of fuel, the ship owner and ship operator, emergency response organisations, road administration, police, rescue services authorities, planning and building authorities, equipment suppliers, the selected yard, designers etc.

4.3 Bunkering and local distribution facilities

The newly established Society for Gas as a Marine Fuel (SGMF) have published a document called Standards and Guidelines for Natural Gas Fuelled Ship Projects (SGMF, 2013). The document includes a useful review of relevant codes, rules, guidelines etc. to be applied for various links of the supply chain of LNG as marine fuel.

For each of the three suggested supply chains described in Chapter 3, a number of different equipage are needed to be able to supply LNG to the vessels. Relevant rules and regulations are summarized in the above mentioned document for most types of useful equipment.

Another useful document is the DNV GL recently published Recommended Practice (RP) document for authorities, LNG bunker suppliers and ship operators with guidance on development and operation of liquefied natural gas bunkering facilities (Lie Strom, 2013). It summarizes DNVs recommendations on how to establish a supply chain of LNG as marine fuel.

More general information is also provided in the book; An introduction to LNG bunkering (Nigel, 2013).

4.3.1 Trucks

The main code regulating road traffic in Trinidad and Tobago is the Motor vehicles and road traffic act (Act). It regulates all kind of vehicles with a maximum gross weight of less than 15 tonnes. All other vehicles are defined as special vehicles and require special permit. The permit is issued by the Ministry of Transport (Jones. J, 2013).

At present there are no general regulations available for road based LNG transportation on Tad and Tobago. Traditionally Trinidad and Tobago have used American rules and regulations for new application on shore (Tulsie. K,
2013). In this case the most adequate rules to apply are the CFR 49 which regulates both design and operation of LNG trucks and semitrailers (CFR49). Another possible legal framework to consider for application is the European ADR regulation published by UNECE (UNECE, 2013) with a similar scope as the CFR 49.

4.3.2 Other LNG bunkering modes and operations
For the design of intermediate LNG terminals and for bunker barges as well as for LNG bunkering operations a summary of relevant regulations and guidelines may be found in the document; Standards and Guidelines for Natural Gas Fuelled Ship Projects published by Society for Gas as a Marine Fuel, SGMF (SGMF, 2013).
5 Safety issues and risk assessment

5.1 Risk assessment methodology for LNG bunkering of ferries

There are already more than 83 LNG fuelled vessels\(^4\) in operation or on order worldwide, and a rapid increase is anticipated for the next decade (DNV, 2013). Different types of LNG supply chains are in use, but there are not yet established standards for LNG bunkering installations and procedures; however, but standardisation and harmonisation are important for the expansion of the LNG fuelled fleet. A number of guidelines and recommended practices have been presented by ISO and other recognised organisations and indicate the direction of future standards and regulations that are now under development and being processed for international adoption.

The risk assessment methodology applied in this study is in part based on established general safety assessment methodologies outlined by IMO (IMO, 2007) and ISO (IEC/ISO, 2009) as well as on the new guidelines particularly addressing installation and operation of LNG bunkering facilities presented by OGP (OGP, 2013), ISO (ISO, 2013) and DNV-GL (DNV-GL, 2013).

No national regulations or established practices for the accomplishment of safety assessment, applicable specifically for LNG bunkering facilities, have been identified in the Trinidad and Tobago regulative framework.

At this stage of the pilot study, including optional LNG supply chains as well as newbuilding and retrofit options, qualitative and comparative risk aspects have been specifically addressed and considered in the recommendations and output of this study. For later design and engineering phases, more detailed risk assessments will need to be conducted in order to specify and verify that adequate safety levels have been met.

The figure below schematically illustrates how the presented optional LNG supply chains have been compared from a safety perspective including hazards due to interactions with the surroundings and LNG transfer interfaces in the supply chain associated with potential release of LNG.

Leakages, unwanted release of LNG and other hazards in the supply chain of LNG as fuel for ships may occur during the transfer of LNG from one transportation mode to another or from a tank to the ship. The focus of the study is, therefore, directed to such interfaces. A number of critical interfaces associated with release and fire hazards have been identified and described and exemplify how these hazards can be quantified in terms of accident probabilities and consequences. The output of the risk assessment process

\(^4\) Excluding LNG carriers and inland waterway vessels, October 2013
includes recommendations to ensure adequate risk control primarily directed towards the prevention of LNG release and control of ignition sources.

The structure of the risk assessment process includes basic components according to the figure below.

**Figure 35** Comparative risk assessment of the presented optional LNG supply chains with respect to hazards due to interactions with the surroundings and the LNG transfer interfaces associated with potential release of LNG

**Figure 36** General structure of risk assessment approach
One of the primary output results for the risk assessment of an LNG bunkering system and facility is the establishment of adequate safety zones for LNG bunkering operations. The safety zone is the area around the bunkering station on the receiving vessel where only dedicated and essential personnel and activities are allowed during bunkering. Corresponding safety zones may also need to be established for other LNG transfer interfaces of the LNG supply chain, and it may also be relevant to establish additional exclusion zones outside the safety zone where other categories and third parties must not have access. In addition to the safety zone around the bunkering site, it may also be necessary to establish a security zone around the bunkering facility and vessel where ship traffic and other activities are monitored.

The site selection for bunkering operations and bunkering facilities as well as possible intermediate storage tanks also require careful zoning and consideration of risk distances to other activities and areas with public access, roads and residential areas.

Zoning considerations and classifications are also important with regard to type and location of electrical installations at the bunkering facility and standards such as the IEC EN 60079 (IEC, 60079) and corresponding national standards.

The draft guidelines from OGP (OGP, 2013) suggest two different approaches for conducting the risk assessment. These recommendations depend on the characteristics and complexity of the bunkering system and facility. For the non-complex base case, a set of 24 functional requirements, based on internationally recognised standards and good engineering practices, is formulated. If these 24 functional requirements are met and if there is no cargo handling conducted in parallel with the bunkering and no passengers on board the receiving vessel during bunkering operation, a qualitative risk assessment may be sufficient.

If the bunkering concept deviates from the non-complex base case or if all 24 functional requirements have not been met or if cargo handling is conducted in parallel, a more comprehensive quantitative risk assessment (QRA) approach should be undertaken. If passengers will be present on board the receiving vessel during LNG bunkering, acceptance from national competent authorities and all other stakeholders is also required.

There are two options for defining the design release scenario of adequate safety designs. The first and simplest way is the deterministic approach, where a conservative maximum credible accidental release is defined on the basis of the characteristics of the bunkering system. This option takes into account such factors as hose dimension, flow rate, pressure, temperature and ESD design. The second, and more sophisticated way, is to apply a probabilistic approach, where the cumulative consequences of a number of possible different leakage scenarios are summarised, e.g. by the use of an event tree model.
If a quantitative risk assessment (QRA) approach needs to be applied, the zoning considerations and definitions of safety zones are normally based on probabilistic approaches including detailed LNG dispersion, vapour cloud modelling and fire calculations for derivation of heat radiation risk contours around the bunkering site.

5.2 Experience of risks and risk control for LNG bunkering

A number of LNG fuelled passenger vessels are in operation today, most of them in Norway. A lot of experience has been gained from the operation of these ferries representing different ship sizes, engine types and bunkering concepts. A number of examples and experience from LNG fuelled ferries are described in Appendix 3.

5.2.1 Safety records from LNG bunkering operations

LNG bunkering to ships is relatively new, and available accident records cannot be used to derive accurate accident statistics and probability figures. Most experience from small-scale LNG loading and unloading operations by use of trucks and flexible hoses comes from Norway, where more than 50,000 operations have been conducted without any serious accidents or significant releases recorded (Gasnor, 2012). In Norway through June 2012 only two minor LNG releases and onshore spills have been reported during ship bunkering. These were due to leakages from a valve and a hose resulting in a spill of approximately 1 litre.

12 years of accident statistics for road transportation of LNG for other industrial purposes in Norway include one case of hose leakage (2 litres) during truck loading. Two cases of ditching/crashes with LNG trucks have also been recorded, but without any LNG spills, further the LNG trailers were recovered (Karlsen, 2012).

5.3 Environmental and climatological conditions

LNG bunkering safety assessment have been conducted for a number of different locations, ports and ship services, but it is always important to adapt to and take into account the local specific conditions. Some main characteristics of the local environmental and climatological conditions considered in the risk assessment for the presented LNG supply chain options and bunkering arrangements are described below.

5.3.1 Prevailing wind conditions

The prevailing wind direction is easterly. The wind rose in the figure below indicates that about 85% of the daytime observations in Port of Spain show wind directions between north east and south east. The statistics are based on
observations recorded between February 2004 and September 2013 daily from 7 to 19 local time. Corresponding wind speed observations show monthly average values between 4 – 6 m/s (6-12 knots) (Windfinder, 2013).

Figure 37 Windrose Port of Spain, distribution of wind directions (Windfinder, 2013)

5.3.2 Prevailing sea conditions

Due to the predominant easterly winds, the wave conditions in the Gulf of Paria and the waters around Port of Spain are calm. For the route from Trinidad to Tobago and the sea conditions outside Scarborough, wave statistics for the Caribbean Ocean may provide reasonably representative figures. The diagram below shows the distribution of significant wave height over time. It indicates that the wave height is below 2 m about 50% of the time and higher than 2 m for 50%. Significant wave heights above 6 m are very rare, occurring less than 0.5% of the time.

It can be noted that no high speed ferry departure has been cancelled due to excessive wave heights or extreme wind conditions in recent years.

Figure 38 Statistics on observed significant wave heights in the Caribbean ocean (BMT, 1986)

5 Area 47, BMT Global wave statistics
5.3.3 Extreme weather phenomena and natural disaster risks

During the hurricane season between June and November, various types of cyclone wind phenomena may occur, classified and characterised as follows:

- Tropical depression – sustained wind speed ≤ 10 – 17 m/s (≤ 20 -34 knots)
- Tropical storm - sustained wind speed ≤ 18 – 33 m/s (≤ 35 - 64 knots)
- Hurricane - sustained wind speed > 33 m/s (> 64 knots)

Tropical storms and hurricanes are relatively rare and the figure below indicates that 6 tropical storms (blue) and 1 severe hurricane (red) occurred within 60 nautical miles from Trinidad (StormCarib, 2011) during the period from 1944 – 2010.

![Statistics on tropical storms and hurricanes in Trinidad from 1944 – 2010](image)

5.3.4 Other extreme conditions and phenomena

Heavy rainfall occasionally cause flooding of the streets in Port of Spain, which may affect land based traffic and transports to the terminal area.

5.4 Identified hazards associated with the proposed activities and facilities

General safety issues and potential hazards associated with the presented LNG supply chain options and bunkering activities and facilities were discussed at a meeting at the Port Authority of Trinidad and Tobago in Port of Spain on September 18. Representatives from PATT, TTIT, competent authorities, operators, gas companies and other stakeholders involved in planning and regulating issues regarding the ferry services participated in the meeting. Based on hazard identification experience from other LNG establishment projects and with input from the discussions in Port of Spain, a number of hazards and
potential accident scenarios have been identified for the presented LNG supply chains and bunkering arrangements, respectively.

Each of the hazards and accident scenarios are briefly described below and denoted with an identification number, where the first digit refers to the supply chain option number and the second digit is a serial number.

The identified hazards described below primarily represent events with leakage of LNG or gas release occurring during transfer of LNG from one storage vessel to another. It is well verified that hazards and potential leakage or release situations occasionally occur under such circumstances but practically never occur when the LNG is stored in a closed tank.

The indicative maximum spill quantities estimated for the various events are rough estimations representing worst case scenarios and should be refined when a detailed design is outlined. For the risk assessment phase, credible spills scenarios based on small leakages rather than complete tank ruptures should be analysed, and the resulting LNG releases may be in the order of one tenth compared with the indicated worst cases.

5.4.1 Supply chain 1- Truck delivery

The first case is based on truck delivery of LNG bunker at the quayside of the ferry berth in the Port of Spain ferry terminal. One tank truck may supply a maximum of approximately 20-22 tonnes, and hence two trucks are needed for a supply of 30 tonnes in one hour. Experience from LNG bunkering of the Viking Grace and the Fjordline ferries demonstrates that two trucks may conduct bunkering simultaneously at a high rate by using a common T-connection manifold. For the bunkering scenario outlined in chapter 3, it is, however, assumed that the trucks will bunker the ferry one by one, as the available time slot for bunkering is not critically short.

Hazard No. 1.1 – Traffic accidents with LNG truck with leakage/fire

The two LNG trucks will conduct two return trips each from Point Fortin or La Brea to the Port of Spain ferry terminal. The four movements with loaded LNG trucks per day to Port of Spain represent an increment of the number of hazardous cargo transports in Trinidad. According to the suggested transport schedule for the LNG trucks, morning as well as afternoon rush hours are avoided but the transport may still be associated with risks for traffic accidents resulting in leakage and fire in the LNG truck. High speed ditching or collisions may damage tank vents or valves resulting in limited LNG releases and fire. Large scale tank rupture is not considered a credible result of a traffic accident.

It is presupposed that the Port of Spain ferry terminal is accessible for transport of dangerous cargo such as LNG by roads and streets, without restrictions or requirements for using specific dedicated hazmat roads.
Hazard No. 1.2 – Leakage of LNG and ESD activation during bunkering

Bunkering from the LNG truck to the ferry is conducted via a flexible hose. The truck is parked on the quay side close to the ferry’s bunker station. The hose dimension used for LNG trucks typically has a diameter of 2½ inch (DN65)\(^6\) and a maximum bunkering flow rate is assumed to be 40 m\(^3\)/h (flow speed in hose about 3.5 m/s). A leakage from a flange, valve or from a crack in the hose will immediately be detected by the bunkering supervisor or by gas detectors at the ferry’s bunker station. The Emergency Shutdown System (ESD) in the tank truck will be activated automatically or manually.

Assuming that the ESD will be activated with pump shut down and valves closed in 4 seconds, a maximum leakage from a 10 m long hose is estimated to be 76 litres of LNG corresponding to 46 m\(^3\) of natural gas when evaporated. This maximum outflow can only be manifest with a most unlikely guillotine type of hose break where the flow rate continues during the ESD time and the entire content in the hose is released. The outflow from a flange or valve failure would be significantly lower, and a credible hose damage scenario with a crack or hole in the hose (crack length 1/3 of the hose diameter) would also result in a significantly smaller outflow.

5.4.2 Supply chain 2a - Local production close to ferry terminal

A local liquefaction plant and storage tank with a capacity 180 m\(^3\) will be located in the vicinity of the ferry terminal and connected via a vacuum insulated cryogenic pipeline to a fixed LNG bunkering manifold at the ferry berth. Due to the limited space in the present ferry terminal, it is not anticipated that it would be possible to locate the liquefaction plant and storage tank in the ferry terminal area, but possible feasible areas may be found at the South quay, within the Sea Lots area or possibly north west of the terminal area if the present ship yard activities are relocated in the future. The pipeline length from the South quay would be approximately 500 m, and from the present ship repair yard about 250, m while the distance from Sea Lots would be closer to 1 000 m.

The bunkering pipeline is assumed to be designed with double walled vacuum insulated tubes and with a system for recirculation of LNG in order to keep the pipes continuously cold. The intermediate storage tank design is assumed to be one horizontal or vertical semi-pressurised vacuum insulated tank with a total capacity of 180 m\(^3\). Connections for filling, ship bunkering and vapour return will be arranged as well as equipment for pressure build up for regulation of tank pressure. Transfer of LNG during bunkering may be achieved by pressure differences or by an LNG pump. The bunkering line may be arranged by a fixed pipe system from the tank in combination with a short flexible hose connection.

\(^6\) Equivalent European designation \textit{DN} (diamètre nominal) in which sizes are measured in millimetres
to the ship or by fixed pipes combined with a small-scale loading arm on the quayside at the ferry berth.

**Hazard No. 2a.1 - Leakage from the local small-scale liquefaction plant or tank**

The LNG production capacity and flow from the plant to the tank is small compared with the flow rates present during the bunkering phase. The plant and intermediate storage tank will require a construction permit from local authorities, and associated risk assessment procedures may stipulate a minimum distance to other building and areas of 50 – 100 m, containment bunds and continuous manning, etc.

**Hazard No. 2a.2 – Leakage from bunkering pipeline due to heating and pressurisation**

Even if the pipe is well insulated, a continuously circulating partial flow is needed to compensate for heat exchange and prevent increasing pressure of the LNG in the pipe. Unintentional closing of valves in the circulation flow may generate heating and pressurisation of the LNG contained in the pipeline. Arrangements with pressure monitoring, safety valves, vent masts and redundant circulation systems will be required.

**Hazard No. 2a.3 – Leakage from bunkering pipeline due to lack of monitoring or sabotage**

If the pipelines are long and cannot be continuously monitored by security guards, intentional damage or sabotage actions may lead to release of LNG. Automatic pressure monitoring and leakage detection will close the flow and isolate the leakage.

**Hazard No. 2a.4 – Leakage from bunkering pipeline, manifold or hose connection during bunkering and ESD activation**

When bunkering from the intermediary storage tank via the pipeline, leakage may occur in valves, fixed pipeline sections, manifold or loading arms at the ferry berth or in flexible hose connections utilised for the last section to the flange in the ferry’s bunker station. The pipe/hose dimension used for this bunkering arrangement typically has a diameter of 4 inches (DN100) and a maximum bunkering flow rate, which is assumed to be 60 m$^3$/h (flow speed in pipe/hose about 2.1 m/s). A leakage from a flange, valve or from a hole in the pipe or crack in the hose will immediately be detected by the bunkering supervisor or by gas detectors at the ferry’s bunker station and the Emergency Shutdown System (ESD) will be activated automatically or manually.

If the bunkering arrangements also include utilisation of the LNG circulation pipeline for return flow of Boil Off Gas (BOG) from the receiving LNG fuelled ferry, leakage scenarios may also involve release of BOG. The flow of the BOG is, however, significantly smaller than the bunkering rate.
Assuming that the ESD will be activated with pump shut down and valves closed in 4 seconds, a maximum leakage from a 10 m long hose is estimated to 148 litres of LNG corresponding to 89 m$^3$ of natural gas when evaporated. This maximum outflow can only be manifest with a most unlikely guillotine type hose break where the flow rate continue during the ESD time and the entire content in the hose is released. The outflow from a flange or valve failure or pipe would be significantly lower.

5.4.3 Supply chain 2b - Small-scale local production and trucking to PoS

If the small-scale local production facility is located more than 500 - 1000 m from the Port of Spain ferry terminal, it is likely that truck delivery and TTS bunkering is becoming more attractive and efficient than supply chain 2a. The investment and operational costs for such an LNG pipeline exclusively used for fuelling the ferries will be high compared with the cost of an LNG truck.

Identified hazards and accident scenarios for this LNG supply include the following hazards, the scenarios may occur both in Port of Spain or in Scarborough:

**Hazard No. 2b.1 – Leakage from the local small-scale production plant**

This hazard is similar to the Hazard No. 2a.1

**Hazard No. 2b.2 – Traffic accident with LNG truck with leakage/fire**

This hazard is similar to Hazard No. 1.1

**Hazard No. 2b.3 – Leakage from bunkering hoses/pipes during TTS bunkering**

This hazard is similar to Hazard No. 1.2

5.4.4 Supply chain 3 - Bunker barge

With a bunker barge capacity of 1 500 m$^3$ of LNG in two horizontal semi-pressurised vacuum insulated tanks the barge may need to return to its loading terminal every tenth day in order to be able to supply 60 tonnes per day to the ferry terminal. The bunker vessel will moor alongside at the outside of the receiving ferry. Any potential interference with activities and handling of cargo or passengers on the quay side is thereby prevented.

**Hazard No. 3.1 – Navigational/maritime accident with bunker vessel or barge**

The bunker barge is supposed to regularly do sea voyages to an LNG export facility (in Point Fortin) and it will also conduct daily movements from its own dedicated berth in the Port of Spain to the ferry terminal for bunkering the ferries. The manoeuvring and mooring of the bunker barge alongside the high speed ferries involves turning manoeuvres close to other vessels and possibly also by use of more than one tug vessel. These manoeuvres may involve collision risks that may cause damage to the bunker barge, ferry or tug. It is considered very unlikely that any credible collision scenario may involve energy
levels high enough to cause damages jeopardising the integrity of the LNG containment on the bunker barge or on the ferry.

**Hazard No. 3.1 – Drift off or break away scenario with activation of the ESD2**

Ship to ship (STS) bunkering requires that the relative motions between the ships are controlled and kept within the operational envelope specified for the bunkering arrangement. Excessive relative motions may be induced by large wave action, mooring failure or by collision/contact from third party vessels. If such an event occurs, the STS bunkering arrangement includes an ESD2 device with a dry breakaway coupling disconnecting the bunker line between the ships. The free ends of the breakaway couplings are automatically closed and the released amount of LNG is very small.

**Hazard No. 3.2 - Leakage from bunkering line during ship bunkering and activation of the ESD1**

Bunkering from the LNG bunker barge to the ferry is conducted via a flexible hose. The bunker vessel is moored alongside the ferry close to the ferry’s bunker station. The hose dimension used for LNG hose is assumed to have a diameter of 2½ inch (DN65) and a maximum bunkering flow rate is assumed to be 40 m³/h (flow speed in hose about 3.5 m/s). A leakage from a flange, valve or from a crack in the hose will immediately be detected by the bunkering supervisor or by gas detectors at the ferry’s bunker station and the Emergency Shutdown System (ESD) in the LNG bunker barge will be activated automatically or manually.

Assuming that the ESD will be activated with a pump shut down and valves closing in 4 seconds, a maximum leakage from a 10 m long hose is estimated to be 76 litres of LNG corresponding to 46 m³ of natural gas when evaporated. This maximum outflow can only be manifest with a most unlikely guillotine type hose break where the flow rate continues during the ESD time, and the entire content in the hose is released. The outflow from a flange or valve failure would be significantly lower and a credible hose damage scenario with a crack or hole in the hose (crack length 1/3 of the hose diameter) would also result in a significantly smaller outflow.
5.4.5 Maximum spill in case of guillotine hose rupture

The probability of a guillotine hose rupture is extremely low, and credible accidental events with LNG releases are more likely to start with a small leakage from cracks or holes in the hose or from leaking flange gaskets. Normally such leakages are easily detected visually by formation of frost, snow, and white vapour.

Table 14 Summary for comparative calculation of maximum LNG release in the ship bunkering phase

<table>
<thead>
<tr>
<th>Supply chain option and ship bunkering</th>
<th>LNG bunker hose inner diameter</th>
<th>LNG bunker hose length between ESDVs</th>
<th>LNG bunkering flow rate</th>
<th>ESD shut down time</th>
<th>Max release if guillotine rupture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Truck (two trucks shuttling)</td>
<td>2½ inch DN65</td>
<td>10 m</td>
<td>40 m³/h</td>
<td>4 seconds</td>
<td>76 litres</td>
</tr>
<tr>
<td>2a Local production. Pipeline bunkering</td>
<td>4 inch DN100</td>
<td>10 m</td>
<td>60 m³/h</td>
<td>4 seconds</td>
<td>148 litres</td>
</tr>
<tr>
<td>2 b Local production. Truck bunkering</td>
<td>2½ inch DN65</td>
<td>10 m</td>
<td>40 m³/h</td>
<td>4 seconds</td>
<td>214 litres</td>
</tr>
<tr>
<td>3 LNG bunker barge. Ship to ship</td>
<td>4 inch DN100</td>
<td>10 m</td>
<td>120 m³/h</td>
<td>4 seconds</td>
<td>76 litres</td>
</tr>
</tbody>
</table>

Comparative calculations for credible design LNG releases can be derived on the basis of the above figures assuming a leakage from a hose crack with a length corresponding to 1/3 of the hose diameter. Further an LNG temperature of -150°C and a pressure of 4 bars may be assumed. These assumptions regarding leakage size, temperature and pressure are considered to be conservative figures tend to overestimate release quantities and flashing behaviour.

5.4.6 Ranking of identified hazard

The LNG transfer interfaces taking place in the ferry terminal are considered more important from a safety point of view because of the number of simultaneous activities going on in the area and the number of passengers and vehicles that are present.

The LNG tank truck accident was considered high ranking during the workshop in Port of Spain and is, therefore ranked high in the list below. The other hazards are indicatively ranked with regard to the associated maximum LNG releases in case of a guillotine hose break.
Table 15 Summary and indicative ranking of identified hazards

<table>
<thead>
<tr>
<th>Hazard Id Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard No. 1.1</td>
<td>Traffic accident with LNG truck with leakage/fire</td>
</tr>
<tr>
<td>Hazard No. 1.2</td>
<td>Leakage of LNG during bunkering and ESD activation</td>
</tr>
<tr>
<td>Hazard No. 2a.1</td>
<td>Leakage from the local small-scale liquefaction plant or tank</td>
</tr>
<tr>
<td>Hazard No. 2a.2</td>
<td>Leakage from bunkering pipeline due to heating and pressurisation</td>
</tr>
<tr>
<td>Hazard No. 2a.3</td>
<td>Leakage from bunkering pipeline due to lack of monitoring or sabotage</td>
</tr>
<tr>
<td>Hazard No. 2a.4</td>
<td>Leakage from bunkering pipeline, manifold or hose connection during bunkering and ESD activation</td>
</tr>
<tr>
<td>Hazard No. 2b.1</td>
<td>Leakage from the local small-scale production plant</td>
</tr>
<tr>
<td>Hazard No. 2b.2</td>
<td>Traffic accident with LNG truck with leakage/fire</td>
</tr>
<tr>
<td>Hazard No. 2b.3</td>
<td>Leakage from bunkering hoses/pipes during TTS bunkering</td>
</tr>
<tr>
<td>Hazard No. 3.1</td>
<td>Navigational/maritime accident with bunker vessel or barge</td>
</tr>
<tr>
<td>Hazard No. 3.2</td>
<td>Leakage from bunkering line during ship bunkering and activation of ESD1</td>
</tr>
</tbody>
</table>

5.5 Risk assessment

The basic risk assessment and management approach is based on objectives to prevent LNG release and to control the ignition sources in case LNG is released. If situations regarding release of LNG are defined as top events, fault tree structures and preventive safety barriers to the left and event tree structures with mitigating safety measures on the right, can be illustrated and modelled according to the bowtie approach shown in the figure below.

![Figure 40 The bowtie approach with safety barriers](image-url)
For each of the prioritised accident scenarios a quantitative risk assessment may be conducted as soon as more detailed information on the technical layout and capacities have been outlined in the design phase. Probabilities and consequences for the identified scenarios will be estimated and described but at the present preliminary design stage, only some general figures and qualitative considerations are presented.

Consequences of LNG leakage scenarios are primarily analysed in view of potential fire scenarios where heat radiation may lead to injuries or fatalities of port personnel, ship crew, passengers or other third party persons. Environmental or economic consequences may also occur, but these are usually less critical than human life and health safety aspects.

5.5.1 Hazards associated with road accidents with LNG truck

Collisions or ditching accidents may occur but, based on experience and by safe design, leakage and fire scenarios are considered unlikely.

**Probability**

A large number of LNG tank trucks are operating in the world today and show excellent safety records. A few tank truck accidents with liquefied gas have been reported and have gained a lot of media interest. Most of these accidents, however, were not LNG but other flammable gases like LPG. One of the most well investigated accidents involved a Spanish LNG tank truck exploding on 22 June 2002 near Tivissa in Catalonia. The accident involved a tank design, which was not specifically intended for transportation of LNG and is not in use today for road transportation of LNG. In the double walled vacuum insulated tank, the distance between the inner and outer tanks was filled with polyurethane foam that melted when heated and the liquid thereby formed a heat bridge from the outer to the inner tank shell.

**Consequences**

If leakages occur, it is important to secure the surroundings, evacuate people in the vicinity and prevent the introduction of ignition sources. Even if there is no damage to the LNG tank, fire may occur involving the truck fuel. The tank design has a high level of passive fire protection, but cooling may be important to prevent heating of the tank contents.

5.5.2 Hazards associated with leakage from LNG hoses or loading arms

Most of the identified accident scenarios are associated with leakages from hoses or loading arm connections or valves. These hazards are, therefore, discussed together below, presenting examples of general failure probabilities and consequences.
Probability

The following figures for failure probabilities have been presented and used for safety assessment of LNG terminals.

- Rupture of flexible LNG hose: Probability $5.4 \times 10^{-7}$ per hours of use
- Leakage from flexible LNG hose: Probability $5.4 \times 10^{-6}$ per hours of use
- Rupture of fixed loading arm: Probability $3 \times 10^{-8}$ per hours of use
- Leakage from fixed loading arm: Probability $3 \times 10^{-7}$ per hours of use

The above figures (Fluxys, 2012) indicate that rupture failures are about 10 times less probable than hose/pipe crack/hole leakage failures. Leakage scenarios are, therefore, usually considered important design cases in safety assessment of LNG transfer installations and operations.

The listed probability figures also indicate that the failure frequency of fixed arms should be about 10 lower than for flexible hoses. The figures are, however, based on a limited amount of historically registered failure statistics, and operators using flexible hoses for LNG handling today apply stringent quality control and claim that flexible hoses also show excellent performance and low failure frequencies. Fixed arm solutions for LNG bunkering purposes may require a large number of rotatable swivels with ceilings that also require regular checks for wear and tightness.

Consequences

The outflow quantity from hose or pipe leakages is, of course, dependent on the size of the leakage. For hose and pipe leakages, a crack length of 1/3 of the hose/pipe diameter or a leakage hole diameter of 1/10 of the hose/pipe diameter is often used as a credible reference damage for outflow calculations. In addition to the size of the leakage, the following parameters are also important for estimation of the total outflow from the leak and the leakage rate:

- ESD activation time
- ESD shut down time
- Hose/pipe dimensions, diameter and length from ESD valves
- Flow rate of LNG in transfer line
- Pressure and temperature of LNG in transfer line

The time for detection of leakage and activation of the ESD may vary greatly depending on the type of detection devices and function of the ESD, which may include manual or automatic systems. In small-scale systems, the design may allow immediate closure of the ESD valves, but in large scale systems pumps and valves must be ramped down successively over a period of time in order to
avoid excessive surge pressure. Large scale systems typically have a 28 second shut down time, whilst small-scale system may be closed off in a few seconds.

For small-scale bunkering activities like the described LNG truck or LNG barge bunkering with flow rates ranging from 40 – 120 m³/h and typical hose dimensions of 4 – 6 inches, the ESD time is often dominated by the component related to detection or reaction of the leakage, which may be up to 10 seconds. The component related to valve closing can be estimated to 2 s for DN25, 5.2 s for 2½ inch (DN65) and 8 s for a 4 inch (DN100) valve (LNGA, 2010).

In case of a hose/pipe rupture it is obvious that the total outflow volume will be a function of hose diameter, length, flow rate and the shut down time. For leakage scenarios the pressure will influence the leakage rate significantly and the rate will be a function of the specific hole diameter or crack length. In addition the temperature will affect the character of the outflow so that a “warm” LNG (for example at -140°C) may appear as a two-phase spray where the liquid LNG is immediately evaporated whilst cool LNG (-160°C) may remain liquid with potential pool formation when released. These different characters may also influence the character of the potential fire if the leak is ignited.

In addition to the quantity of released LNG, the potential consequences of fire scenarios in terms of heat radiation will be different if the outflow is ignited immediately or if the ignition is delayed. In detailed risk analyses, various established gas dispersion/fire and heat radiation models are applied to estimate radii for specific critical radiation levels at representative weather/wind conditions.

The figure below is a schematic illustration of calculated heat radiation levels, and it indicates how these are applied in the risk control phase for defining safety zones and risk distances.

The maximum radii of heat flux threshold levels for the various fire scenarios (pool fire, jet flame or flash fire) are often plotted in a map as isoline contours for 5, 12 or 15 kW/m². Predominant wind conditions are taken into account and potential heat shielding or barrier effects from building, ship freeboard side, may also be considered in the model calculations, as illustrated above.

A level of 5 kW/m² is often used, e.g. in NFPA 59A, as the criterion for determining the hazard distance to people exposure from an LNG fire.
5.6 Risk control

The four cases outlined for optional and stepwise expansion of development of LNG bunkering arrangements in the Port of Spain ferry terminal generate different requirements for safety zones and risk distances primarily in relation to the quantities of LNG handled. When the risk levels are estimated for the respective cases, it is presupposed that a number of important risk control options are in place and have been adapted to the specific bunkering arrangement and risk profile. The detailed layout and design may be different for the different cases, but a number of common risk control options can be identified for small-scale bunkering arrangements as well as for large scale bunkering terminals. The examples listed below are not intended to show a complete list but provide an overview of examples of important risk control options to be elaborated on and implemented for LNG bunkering facilities in the Port of Spain. The checklist of 24 essential safety functions given in (ISO, 2013) provides additional information.
5.6.1 Operational procedures

Safety procedures including checklists and detailed sequential descriptions of all phases of the bunkering operation from mooring to departure of the receiving vessel will be established. Roles and responsibilities for all involved staff ashore on the quayside, the crew on the receiving vessel, bunker vessel and tank truck driver should be clearly defined and well known. The entire bunkering operation must be surveyed by a dedicated watch.

Established routines are necessary for ship specific safety assessment and permit procedures when new LNG receiving vessels are to be bunkered. Routines for safety assessment are also required if LNG bunkering are to be introduced and conducted at new sites or berths in the Port of Spain.

5.6.2 Technical measures and devices

All LNG bunkering equipment and procedures will be designed so as not to allow any emission of methane during normal bunkering operations. This implies, for example, that the following measures and devices will be used:

- Use dry disconnect couplings to prevent any spill when decupling
- BOG return or pressure control system for receiving ships and for filling of land based intermediate storage tanks. No planned venting of BOG from tank ullage
- Natural gas purging and nitrogen inerting system of LNG hose and piping systems when bunkering is completed

In order to prevent accidental spills due to human handling failure or mistake, the ships’ LNG bunkering station as well as the supply services or bunker terminal in the port must have standardised connections for LNG fuel with a mechanical single action coupler without any need for manual bolting. To the extent possible, failsafe system design should be applied to minimise influence of mistakes by operators.

The bunkering system shall be designed with double safety barriers in order to prevent any spill due to a single failure.

In case of excessive relative motion of the LNG receiving vessel, or if a leakage is detected in the LNG transfer or BOG return line, an emergency shutdown, the ESD system must be in place. The ESD control system between shore and ship systems shall be linked and bunkering shutdown can be initiated either from the LNG supplier side or from the LNG receiving vessel by automatic failure detection system or by manual control. The ESD link and routines shall include possibilities for direct communication.

The ESD, pump, valve and piping design will allow for immediate shut down during bunkering operations without risk for excessive surge pressure. For
small-scale bunkering systems 0-5 seconds, and for large system 10 seconds, may be considered as target values.

The ESD system will include a dry break-away coupling (ESD2) to prevent spillage or damage to other equipment in case of dislocation or drift off of the receiving vessel or relative motions exceeding the operational envelope of the bunker connection.

All LNG fuelled vessels to be bunkered, the bunker vessel and land based facilities for supply of LNG bunker shall be designed to withstand any cryogenic damage in case of exposure of LNG spills. These design requirements include the use of cryogenic safe construction materials (for first and second barriers), drip trays to be fitted and water curtains to be used along the hull side.

5.6.3 Training and education

For officers and crew certificated according to the IGC code on LNG bunker vessels there are stringent and well-defined requirements for training, competence and operational experience at sea. For non-self-propelled LNG bunker barges, the IGC code does not apply, and the manning and qualification requirements are less stringent. Qualification requirements for chief officers in LNG fuelled ships are under development.

LNG tank truck drivers also have specific training on LNG transfer and bunkering operations and emergency procedures in case of spills or accidents. For operational staff of the LNG bunkering facilities in the port there are no detailed prescribed regulations for training or education. For safe operation of LNG bunkering in the Port of Spain, it is, however, of utmost importance that also the land based staff involved in LNG bunkering operations is well trained and qualified to handle all normal procedures and take action in case of emergencies.

For each vessel to be bunkered and for each site or berth where bunkering operations are going to take place, all involved staff and crew must be familiar with checklists, procedures and safety routines. Regular training and drills involving bunkering personnel as well as port safety officers and municipal rescue services are recommended. It is also recommended to elaborate a short LNG bunkering familiarisation training/information for other personnel and operational staff in the port.

5.6.4 Emergency preparedness and contingency plans

Emergency preparedness procedures for any type of possible incident and accidental event during bunkering operations should be established in the Port of Spain and coordinated with the municipal rescue services of the city. Corresponding preparedness should, of course, also be arranged in Scarborough if LNG bunkering is to take place there. The preparedness shall
include a plan for change in safety alert levels and a plan for safe evacuation of the bunkering site/terminal and adjacent areas at risk.

5.6.5 Public participation and hearing
Handling of LNG as fuel is a new activity in most ports, and the public sometimes react with uneasiness due to a lack of knowledge and unrealistic perception of the risks associated with LNG. Public consultation is an important part of the permit procedure and EIA process in most countries and normally the public will be informed early in the decision-making process. Adequate information on the risks as well as on the environmental benefits to the public by consultation and hearings may be important in order to prevent delayed processing and to sustain focus on relevant safety issues.

5.7 Risk evaluation
In the risk evaluation phase the identified and quantified output from the risk assessment phase is evaluated and compared with established risk acceptance criteria or target levels of tolerable risks. Some countries have established risk acceptance criteria to be applied and validated by quantitative risk assessments for infrastructure and industrial development projects. Such criteria usually specify both societal and individual risk levels and define ranges where safety measures should be taken to reduce risk levels to “as low as reasonably practicable” (ALARP). The numerical figures of the limiting levels vary slightly from different countries and industrial organisations but may serve as a basis for risk evaluation and identification of hazardous activities and operations.

It is also important to note in this context that quantitative risk assessments QRAs are always associated with assumptions and numerical inaccuracies.

5.8 Comparison of the LNG supply chains from a safety perspective
This risk assessment addresses general safety issues and outlines a basic structure to be applied in the formal permit application process including safety assessment of the first step of the LNG bunkering plans for the Port of Spain.

This study identifies a number of critical interfaces associated with the potential release of LNG and fire hazards and exemplifies how these hazards can be quantified in terms of accident probabilities and consequences. Based on established practices and best available technology considerations, a number of important risk control options are also described and recommended. The importance of standardisation of LNG bunkering couplings
and safety hardware is stressed as well as training needs and other soft safety aspects.

All the identified and described LNG supply chains and LNG bunkering arrangements are considered feasible from a safety point of view, but additional quantitative studies are recommended to be conducted when the design of LNG supply chain and the ferry concept have been elaborated on in greater detail.

5.8.1 LNG bunkering in Port of Spain ferry terminal

The TTS LNG bunkering concept is considered to be possible to design and arrange in Port of Spain to meet a high level of safety if bunkering is conducted without passengers on board the vessel. With passengers on board or disembarking/embarking, it is not recommended to conduct TTS LNG bunkering with the present terminal layout in Port of Spain. The unprotected passenger gangways and traffic situation close to the present bunkering location may cause hazardous situations, introduction of ignition sources and difficulties with evacuation of passengers in case of incidents or emergencies.

A designated ITPS LNG bunkering concept is not recommended with the present terminal layout in Port of Spain, irrespective if bunkering is to be conducted with or without passengers on board, as there is no obvious site in the terminal area where an intermediate storage tank can be located with safe separation from traffic and passenger flows and adjacent port activities. With a modified terminal layout allowing for more space, in the future possibly also incorporating the neighbouring shipyard area, it may be possible to accommodate an ITPS facility for LNG bunkering of the ferries. If an ITPS LNG bunkering concept is to be designed for parallel bunkering and passenger and cargo handling, a detailed risk assessment will be needed in the design phase to ensure safe pipe design and routing and barriers for protection and separation of cars and unprotected passengers and staff in the port.

An STS LNG bunkering concept is considered less difficult from a safety point of view provided that the bunker station on the ferry can be arranged so that the bunker barge can moor alongside and still remain at a distance from the quay and loading ramps of the ferry. The bunkering area will then not be accessible to passengers, and the bunker barge will be free to depart without any interaction with other port activities. It is possible that safety measures, zoning and barriers may be designed in order to allow LNG bunkering with passengers on board and parallel cargo handling but this will need to be subject to detailed risk assessment studies. Adequate safety zones and risk distances need to be determined from credible design LNG releases and depend on the bunkering flow rate and other bunkering characteristics.

The figure below illustrates the differences between the TTS and STS LNG bunkering in terms of interference with loading ramps and passenger access.
areas based on a tentative 25 m radius safety zone around the LNG tank truck and the ferry bunker station and a corresponding zone around an STS LNG bunkering amidships of the high speed ferry. The yellow area indicates a radius of approximately 100 m, showing that the terminal building and other buildings in the ship yard area are located within 100 m from the indicated TTS LNG bunkering site.

Figure 42 Comparison of indicative 25 m safety zones in Port of Spain for TTS and STS bunkering

5.8.2 LNG bunkering in Scarborough ferry terminal in Tobago

The TTS LNG bunkering concept is considered possible to design and arrange in Scarborough to meet a high level of safety. If the bunkering station on the vessel is located as today’s fuel oil bunker station near the aft passenger ramp, it would not be possible to bunker LNG with passengers on board or during embarking/disembarking or cargo handling. If the bunker station for LNG fuelledfuel is located amidships on port side it may, however, be possible to arrange LNG bunkering in parallel with cargo handling and with passengers on board.

The quay areas alongside and in front of the berthed high speed ferry in Scarborough are relatively large, have good access for vehicles and the distances to other buildings and residential areas are approximately 100 m or more. The spacious quay areas may also allow for the design of a designated ITPS LNG bunkering facility in Scarborough. If an ITPS LNG bunkering concept is to be designed for parallel bunkering and passenger and cargo handling, a detailed risk assessment will be needed in the design phase to ensure safe
barriers for protection and separation of passengers, staff and other cargo handling activities in the port.

The figure below illustrates how TTS LNG bunkering may be conducted amidships on port side with tentative 25 m radius safety zone around the LNG tank truck and the ferry bunker station that does not interfere with the car ramps and passenger gangways at the aft of the ship. The yellow area indicates a radius of approximately 100 m, showing that there are only a few buildings partly inside this area and most of the areas are open quay areas.

Figure 43 An indicative 25 m safety zone surrounding an TTS LNG bunkering arrangement in Scarborough ferry terminal
6  Cost estimations for newbuildings, retrofit and LNG infrastructure

6.1  Newbuilding

6.1.1  Francisco

The only LNG fuelled high speed vessel present is the previously mentioned Francisco, built by Incat in Australia and operated by Buquebus between Argentina and Uruguay. No official price is available, but according to several informal sources, the indication of the price delivered was around 130 million USD.

This price is estimated to be approximately 30 % higher than a diesel fuelled vessel of the same size and capacity which is a somewhat higher ratio than for other ship types that are generally estimated to be 10-20% more expensive if LNG fuelled than if equipped with conventional diesel engines.

The relatively high additional cost for the LNG fuelled vessel in this case may be related to the fact that no vessel similar to the LNG fuelled HSC Francisco has ever been designed and constructed. Therefore a lot of development work was needed, and the shipyard and other involved stakeholders were more risk exposed than for conventional newbuilding projects.

6.1.2  Replacement vessels

If TTIT decides to invest in one or two LNG fuelled newly built replacement vessels with similar capacity and performance as the present vessel, the newbuilding price is estimated to be approximately 100 million USD each. If compared with the Francisco, the speed requirements are lower for the evaluated route, reducing the cost for machinery and fuel storage systems. Another cost reducing benefit is that thanks to the building of the Francisco, there is more experience available today reducing some of the risks related to the design and construction of LNG fuelled HSC.

6.2  Conversion of T&T Spirit

It has been deemed possible yet challenging to convert the T&T Spirit to be able to operate as a duel fuel vessel. The main consequence would be that she would lose a significant part of her high vehicle capacity (>1.8m) due to the installation of the LNG tanks and vaporisers on the main car deck.
6.2.1 Main engines

Due to the limited availability of light and high performance duel fuel piston engines, it would be necessary to use gas turbines as the main propulsion power if converting the T&T Spirit. The main benefit of gas turbines is a significantly higher power to weight and size ratio as well as low maintenance and lube oil costs. They are well proven in maritime installations, and in general have a higher reliability than normal piston engines. The main drawbacks are high procurements costs and low fuel efficiency.

Since gas turbines are operated in a completely different rpm range the gear boxes also have to be replaced. Today the T&T Spirit has two diesel engines in each hull with a MCR of approximately 7 000 kW. For efficiency and cost, it has been decided to replace the two present diesel engines in each hull with one large gas turbine of approximately 14 000kW. A new gearbox with one input shaft and two output shafts connected to the present water jets is also a necessary investment.

Air inlets, exhaust outlets as well as engine room ventilations will also require updates due to the installation of gas turbines.

6.2.2 Fuel system

To be able to do one roundtrip fuelled with LNG the T&T Spirit requires an LNG capacity of approximately 75 m³ corresponding to the demand of 30 tonnes of LNG per round trip. To fit the fuel tanks in the ceiling of the main car deck the volume will be divided into three tanks of approximately 25 m³ capacity each.

6.2.3 Total cost

The following table indicates the main cost components of a conversion of T&T Spirit.

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimated cost</th>
<th>Source of info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel system</td>
<td>2 500 000 USD</td>
<td>Patel. S, 2013</td>
</tr>
<tr>
<td>Gas turbines</td>
<td>24 700 000 USD</td>
<td>Lundgren. S-I, 2013</td>
</tr>
<tr>
<td>Gear box</td>
<td>1 800 000 USD</td>
<td>Lundgren. S-I, 2013</td>
</tr>
<tr>
<td>Ventilation and exhaust</td>
<td>500 000 USD</td>
<td></td>
</tr>
<tr>
<td>Design and classification</td>
<td>600 000 USD</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1 900 000 USD</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>32 000 000 USD</td>
<td></td>
</tr>
</tbody>
</table>
6.3 Operational costs for LNG fuelled high speed vessels

6.3.1 Crew and education

As described in section 4.2.5, there is no international regulation in force concerning the crew on gas fuelled vessels. It is up to the flag state to approve an adequate scope of education and training for all crew on board an LNG fuelled vessel. If the recommendation in section 4.2.5 is followed it is estimated that the educational cost related to the usage of LNG as fuel would be approximately 6 000 USD per deck and machinery related crew members and about 2 500 USD for all other crew members (Nylund, J, 2013).

6.3.2 Maintenance

Due to the limited number of comparative type of vessels in operation it is difficult to establish a clear picture of the maintenance costs of LNG fuelled high speed vessel in relation to diesel fuelled, especially as a change from piston engines to gas turbines is also considered.

A general conclusion based on vessels used in Scandinavia is that even if the number of necessary measures in relation to maintenance and repairs are usually less, each measure is usually more expensive due to more specialised service staff and more expensive spare parts. It is, therefore, generally assumed that the overall cost for maintenance and repairs is similar to conventional vessels.
Maintenance of gas turbine machinery is performed strictly according to a schedule of preventive maintenance actions, based on equivalent operating hours accumulated on the particular gas turbine unit (Sörensson, I, 2013). The lowest level of such a maintenance program is performed by the crew on a daily or weekly basis, and include activities such as:

- Check for leaks
- Check for proper operation and instrument readings
- Log and verify important readings
- Check for filter differential pressure
- Inspection of air intake filter condition
- Lubrication oil tank level

When the preventive maintenance program is observed, experience from similar operations has proven that breakdowns or unscheduled disturbances are extremely rare, resulting in very high reliability and availability of gas turbines.

In order to simplify and make the cost for maintenance fully predictable for the ship owner, it is recommended to enter into a service agreement with the gas turbine supplier. The annual cost for such an agreement shall cover full maintenance schedule including all necessary labour and materials.

### 6.4 LNG bunkering infrastructure

Each of the supply chains described in section 3.5 to 3.7 is designed to deliver 30 tonnes of LNG two times per day to the two high speed vessels in operation between Trinidad and Tobago. For each supply chain an estimated supply cost per tonne is presented below. When comparing the figures it is important to note that the actual price of LNG or natural gas is not included in any of the price calculations since that is highly unpredictable, dependent on political decisions and therefore not included in the scope of this study. To create true comparative figures, such prices have to be established and added.

It is also important to understand that the utilization rate of some of the equipage in the supply chains is low, indicating that there are possibilities for significant expansion in capacity if other LNG users and customers contribute to an increasing demand.

#### 6.4.1 Supply chain 1; Direct truck supply

As described in section 3.5, the supply chain requires investments in a truck loading facility as well as in two LNG semi-trailers. In addition to the investments the supply chain two towing trucks are required to be chartered
when needed. The bunkering will be performed by the truck driver with assistance from the ship crew.

*Table 17 Estimated daily cost for a truck loading facility*

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>650 000 USD</td>
<td>Price from ref (DMA, 2011)</td>
</tr>
<tr>
<td>Truck loading facility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated CAPEX</td>
<td>260 USD/Day</td>
<td>8 % interest rate. 10 years depreciation time.</td>
</tr>
<tr>
<td>Estimated OPEX</td>
<td>180 USD/day</td>
<td>3 USD/tonnes LNG</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>440 USD/day</strong></td>
<td></td>
</tr>
</tbody>
</table>

In relation to supply chain 1, the truck loading facility will be used only 2 hours per day.

*Table 18 Estimated daily cost for LNG trucking in supply chain 1*

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price 2 pc of LNG Semi-trailers</td>
<td>720 000 USD</td>
<td>Price from Cryo AB (Hörndahl. H, 2013)</td>
</tr>
<tr>
<td>Estimated CAPEX</td>
<td>480 USD/Day</td>
<td>8 % interest rate. 5 years depreciation time.</td>
</tr>
<tr>
<td>Estimated OPEX</td>
<td>50 USD/day</td>
<td>Maintenance+ misc.</td>
</tr>
<tr>
<td>Estimated rental cost</td>
<td>1 980 USD/day</td>
<td>55 USD/h and truck 18 hours per day</td>
</tr>
<tr>
<td>2 towing trucks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated fuel cost</td>
<td>136 USD/day</td>
<td>0,2 USD/km, 85 km from POS to Atlantic, 2 trucks, 2 return trips/day</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>2 650 USD/day</strong></td>
<td></td>
</tr>
</tbody>
</table>

In relation to supply chain 1 the semi-trailers will be used approximately 18 hours per day implying a high utilization rate.

*Table 19 Estimated costs related to supply chain 1*

<table>
<thead>
<tr>
<th></th>
<th>Per day</th>
<th>Per year</th>
<th>Per tonnes LNG delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total cost</strong></td>
<td>3 090 USD</td>
<td>1 130 000 USD</td>
<td>51 USD</td>
</tr>
</tbody>
</table>

In the table above the total cost is summarised indicating a supply and bunkering cost of 51 USD per tonne delivered to the vessel by supply chain 1. To get a real LNG fuel price, the cost of LNG/tonne at the source has to be added to the 51 USD/tonne.
6.4.2 Supply chain 2; Local production

As described in section 3.6 there are two versions 2a and 2b of supply chain 2. Both are based on local production of LNG but the difference between the two is the location of the production plant. For version “a” the production plant is located in direct proximity of the ferry terminal, and bunkering is conducted by ITPS. For version “b” the local production and storage facility is located close to an already existing pipeline, and the LNG is transported by truck from the production plant to the ferry terminal. The bunkering is done by TTS.

The cost of the local production is deemed similar for both versions of the supply chain.

Table 20 Estimated cost of a local storage and production facility for supply chain 2

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>26 500 000 USD</td>
<td>Price based on information from Galileo (Gandulfo, 2013) and Cryostar (Bertrand, D, 2013)</td>
</tr>
<tr>
<td>Estimated CAPEX</td>
<td>7 300 USD/day</td>
<td>8 % interest rate. 20 years depreciation time.</td>
</tr>
<tr>
<td>Estimated OPEX</td>
<td>4 000 USD/day</td>
<td>Maintenance + electricity + staff + miscellaneous.</td>
</tr>
<tr>
<td>Total Cost</td>
<td>11 200 USD/day</td>
<td></td>
</tr>
</tbody>
</table>

Additional cost supply chain 2a

Supply chain 2a also requires a bunkering station at the ferry terminal. The cost of such facility is described in the table below.

Table 21 Estimated cost of the bunkering station used in supply chain 2a

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>650 000 USD</td>
<td>Price from DMA (DMA, 2011).</td>
</tr>
<tr>
<td>Estimated CAPEX</td>
<td>260 USD/day</td>
<td>8 % interest rate. 10 years depreciation time.</td>
</tr>
<tr>
<td>Estimated OPEX</td>
<td>180 USD/day</td>
<td>3 USD/tonnes LNG</td>
</tr>
<tr>
<td>Total Cost</td>
<td>440 USD/day</td>
<td></td>
</tr>
</tbody>
</table>

Since the local production and storage facility is not located directly at a natural gas pipeline an additional small feeder pipeline is necessary.
The cost of such pipeline is estimated according to the following formula:

\[
price\ USD = (length\ i\ m) \times 800\ USD + 500\ 000\ USD
\]

The formula is based on information from Skangass (Bjørndal. T, 2013), Swedgas (Engstrand. D, 2013) and NGC (Hosein, 2013).

As described in section 3.6, the distance in Tobago is estimated at 7 500 m.

### Table 22 Estimated cost of the required pipeline for supply chain 2a in Tobago

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price Pipeline in Tobago</td>
<td>6 500 000 USD</td>
<td>See formula above</td>
</tr>
<tr>
<td>Estimated CAPEX</td>
<td>1 790 USD/day</td>
<td>8 % interest rate. 20 years depreciation time.</td>
</tr>
<tr>
<td>Estimated OPEX</td>
<td>30 USD/day</td>
<td></td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>1 820 USD/day</strong></td>
<td></td>
</tr>
</tbody>
</table>

In section 3.6 the distance in Port of Spain is estimated to 1 200 m.

### Table 23 Estimated cost of the required pipeline for supply chain 2a in Port of Spain

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price Pipeline in Port of Spain</td>
<td>1 460 000 USD</td>
<td>See above</td>
</tr>
<tr>
<td>Estimated CAPEX</td>
<td>400 USD/day</td>
<td>8 % interest rate. 10 years depreciation time.</td>
</tr>
<tr>
<td>Estimated OPEX</td>
<td>25 USD/day</td>
<td>3 USD/ tonnes LNG</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>425 USD/day</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Additional costs 2b**

The cost of the truck loading facility is expected to be similar to supply chain 1 with a daily cost of 440 USD.

The cost for the trucking part is estimated according to the table below:
### Table 24 Estimated daily cost for LNG trucking in supply chain 2b

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price 1 pc of LNG Semi-trailer Trailer</td>
<td>360 000 USD</td>
<td>Price from Cryo AB (Hörndahl. H, 2013)</td>
</tr>
<tr>
<td>Estimated CAPEX</td>
<td>240 USD/day</td>
<td>8 % interest rate. 5 years depreciation time.</td>
</tr>
<tr>
<td>Estimated OPEX trailers</td>
<td>25 USD/day</td>
<td>Maintenance+ misc.</td>
</tr>
<tr>
<td>Estimated Rental cost towing trucks</td>
<td>550 USD/day</td>
<td>55 USD/h and truck 10 hours per day</td>
</tr>
<tr>
<td>Estimated fuel cost</td>
<td>50 USD/day</td>
<td></td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>865 USD/day</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Total cost supply chain 2**

The following table summarises all costs for the different versions of supply chain 2.

### Table 25 Estimated costs related to supply chain 2

<table>
<thead>
<tr>
<th>Total cost</th>
<th>Per day</th>
<th>Per year</th>
<th>Per tonne LNG delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a Tobago</td>
<td>13 430 USD</td>
<td>4 900 000 USD</td>
<td>224 USD</td>
</tr>
<tr>
<td>2a Port of Spain</td>
<td>12 000 USD</td>
<td>4 400 000 USD</td>
<td>201 USD</td>
</tr>
<tr>
<td>2b</td>
<td>12 500 USD</td>
<td>4 540 000 USD</td>
<td>207 USD</td>
</tr>
</tbody>
</table>

The total production and delivery cost is described in Table 25 and indicates a supply and bunkering cost between 201 to 224 USD per tonne delivered to the vessel through supply chain 2. To get a real LNG fuel price/tonne the cost of approximately 1 400 m$^3$ or 49 500 cft of natural gas delivered to the local production facility has to be added to the above estimated production and supply cost.

#### 6.4.3 Supply chain 3; Bunker barge

As described in section 3.7 the supply chain requires investments in a small-scale jetty and an un-propelled LNG bunker barge. In addition to the investments, the supply chain also requires a tug boat to be chartered when needed.
Table 26 Estimated daily cost for a small-scale Jetty at the LNG source

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price Small-scale jetty</td>
<td>45 000 000 USD</td>
<td>(DMA, 2011)</td>
</tr>
<tr>
<td>Estimated CAPEX</td>
<td>10 860 USD/day</td>
<td>8 % interest rate. 30 years depreciation time.</td>
</tr>
<tr>
<td>Estimated OPEX</td>
<td>180 USD/day</td>
<td>3 USD/tonnes LNG (DMA, 2011)</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>11 000 USD/day</strong></td>
<td></td>
</tr>
</tbody>
</table>

Based on the outlined needs for supply chain No. 3, the small-scale jetty will only be used for 5 hours every 10th day.

Table 27 Estimated daily cost for an un-propelled LNG bunker barge

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price LNG barge</td>
<td>9 000 000 USD</td>
<td>Price of LNG systems from Inox India (Patel, S, 2013)</td>
</tr>
<tr>
<td>Estimated CAPEX</td>
<td>2 475 USD/day</td>
<td>8 % interest rate. 20 years depreciation time.</td>
</tr>
<tr>
<td>OPEX</td>
<td>1 000 USD/day</td>
<td>Cargo master + maintenance + miscellaneous.</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>3 475 USD/day</strong></td>
<td></td>
</tr>
</tbody>
</table>

Based on prices given by NEC (Scipio-Hosang, M, 2013), an estimated price of the required tug hire is 5 500 USD/day including one trip to the source every 10th day. The prices include fuel.

Table 28 Estimated costs related to supply chain 3

<table>
<thead>
<tr>
<th></th>
<th>Per day</th>
<th>Per year</th>
<th>Per tonnes LNG delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost</td>
<td>19 975 USD</td>
<td>7 290 000 USD</td>
<td>333 USD</td>
</tr>
</tbody>
</table>

In the table above the total cost is concluded indicating a supply and bunkering cost of 333 USD per tonne delivered to the vessel through supply chain 3. To get a real LNG as fuel price the cost of LNG/tonne at the source has to be added to the 333 USD.
6.5 Fuel cost estimations and comparison of identified supply chains

Today TTIT operates on MDO subsidised by the government of Trinidad and Tobago. The price is 1.5 TTD/litre equal to a price of 263 USD/tonne. A typical market price for MDO in the WCR is estimated to be about 950 USD/tonne.

The annual-fuel cost for the two high speed vessels today is approximately 4.5 million USD based on the subsidised price. If related to the estimated WCR market price the annual cost would be almost 16.8 million USD, implying an annual fuel subsidy of approximately 12.3 million USD.

It has not been possible to receive an accurate price for natural gas or LNG supplied domestically in Trinidad and Tobago. However, with regard to the proximity of the US market, the Henry Hub prices may be considered as a plausible market price for natural gas in Trinidad and Tobago. At present natural gas is traded at the Henry Hub in the parity of 3.7 USD/MMbtu (RS. Platou, 2013), which corresponds to an approximate price/tonne of 173 USD/tonnes. It is also assumed that a 20% mark-up is necessary to cover the cost of liquefaction, and, consequently, a reasonable price estimation for LNG would be about 208 USD/tonnes.

Table 29 Estimated cost of LNG delivered as fuel to the high speed vessels

<table>
<thead>
<tr>
<th>Supply chain</th>
<th>Supply chain cost USD/tonne LNG</th>
<th>LNG or NG source price USD/tonnes</th>
<th>LNG price delivered USD/tonnes</th>
<th>Corresponding MDO price USD/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51</td>
<td>(LNG) 208</td>
<td>259</td>
<td>306</td>
</tr>
<tr>
<td>2a POS</td>
<td>201</td>
<td>(NG) 173</td>
<td>374</td>
<td>442</td>
</tr>
<tr>
<td>2a TOB</td>
<td>224</td>
<td>(NG) 173</td>
<td>397</td>
<td>469</td>
</tr>
<tr>
<td>2b</td>
<td>207</td>
<td>(NG) 173</td>
<td>380</td>
<td>449</td>
</tr>
<tr>
<td>3</td>
<td>333</td>
<td>(LNG) 208</td>
<td>541</td>
<td>639</td>
</tr>
</tbody>
</table>

Table 29 indicates an estimated cost per tonnes of delivered LNG of 259 USD/tonne LNG, if supply chain 1 is selected. Based on the annual estimated consumption for two vessel of 22 000 tonnes as described in section 3.4, the annual fuel cost would then be 5.7 million USD without any governmental fuel price subsidies.

Compared with the present situation, the introduction of LNG as fuel for the high speed ferry service would increase the annual fuel cost by 1.2 million USD per year if related to the subsidised price. If related to the market price of MDO, the annual fuel cost would be reduced by about 11 million USD per year.
7 Results and recommendations

The TTIT high speed ferry services between Port of Spain and Scarborough are considered a national interest and the cost is subject to financial support from the government of Trinidad and Tobago. The numbers of travellers and vehicles are increasing and the government, PATT and TTIT are eager to develop and modernise the services in a way in which improved environmental performance and reduced emissions can be combined with low fares and low operational costs.

7.1 Cost for reconstruction or newbuilding

The transition from traditional bunker fuel oil to LNG as fuel for the high speed ferries will reduce harmful exhaust emissions significantly and may, in the long run also implicate reduced total governmental cost for the ferry services. The report shows that such a transition to LNG fuel is associated with high investment costs for reconstruction of existing high speed ferries or for design and procurement of new LNG fuelled vessels. Reconstruction of the 11-year-old T&T Spirit is estimated to approximately 32 million USD and an LNG fuelled newbuilding of corresponding capacity may be purchased at a cost of about 100-110 million USD. The 16-year-old T&T Express is anticipated to be in need of replacement within about five years, and is, therefore, not considered to be of interest with respect to modification for LNG fuel.

Today there are no applicable regulations in force for the conversion of the existing high speed vessels or for new construction of high speed vessels. Consequently it is formally up to the competent authority of the flag state to decide which rules, regulations, guidelines and standards should be applied for any conversion or newbuilding project as long the vessels operate domestically. Fortunately, the lack of rules and regulation is not considered a show-stopper since there are already a number of internationally recognised guidelines and codes that may be applied. It is important to understand that the situation calls for particularly close cooperation and dialogue among the developer, the competent authority and the classification society to ensure a smooth process and an efficient and safe vessel.

7.2 Supply chain cost and fuel price comparison

If the investments indicated above will be profitable and how long the payback time will be, is of course dependent of operational costs and if the improved environmental performances are evaluated in monetary terms and taken into account in the cost calculations. With regard to the operational cost and specifically the fuel cost, it is noted in the study that due to governmental subsidies of the MDO price the government in fact may save money if the oil
consumption of the ferries is reduced and the corresponding amount of oil is exported to world market prices. Regarding the cost for the alternative LNG fuel, the price and operational costs are basically determined by the following three components: the price of natural gas or LNG at the source, the cost of the LNG supply chain and the specific energy consumption and efficiency of the new or reconstructed ship.

The gas price or LNG price at the source is not subject to detailed analyses or estimation in this study. The fact that the hub market price in this region is low and that the government, via state owned gas and pipeline companies, has access to natural gas resources and co-ownership in LNG plants, however, implicate favourable pricing conditions.

Regarding the supply cost chain component, three basic options for feasible LNG supply chains have been identified and analysed, including transportation of LNG by truck from source to the bunkering site at the ferry terminal (No. 1), dedicated small-scale liquefaction plant near the ferry terminal (No. 2a and 2b) and a supply by LNG bunker barge from the source to the receiving high speed ferry (No. 3).

The three analysed options represent different capacities and different levels of investment costs in facilities and equipment. If the total supply chain costs are distributed over the potential capacities for the respective options, the large scale systems may offer a more attractive cost per tonne of supplied LNG. If the total supply chain costs have to be distributed over the predicted LNG fuel consumption of the TTIT fleet of high speed ferries only, the cost per tonne of supplied LNG will, however, be very high for the large scale bunker barge based option (No. 3). In this option the cost for a new small-scale export jetty at Atlantic LNG in Point Fortin is the dominating component, and if the TTIT ferry services is the only user of such a facility, it means that it is underutilised.

For the small-scale option (No. 1) based on TTS bunkering the analysis shows that the cost per tonne of supplied LNG may be attractive and possibly even competitive with today’s low subsidised MDO price even if the total supply cost is distributed over TTIT’s predicted LNG consumption only.

If today’s subsidies of the fuel oil are considered and the potential for reducing the governmental oil subsidy expenditures by transition to LNG fuel is taken into account in the cost comparison by instead comparing the estimated LNG price for the respective supply chain options with today’s world market MDO price, all of the three options turn out favourable compared with MDO.

The range of estimated total LNG price delivered to the ferry terminal for the three supply chain options differs a factor 2 when the costs are distributed over TTIT’s predicted consumption only. Capacity wise, the bunker barge option (No. 3) offers possibilities for the supply of LNG fuel to more ships in Port of Spain and the jetty may also generate new export potentials for LNG by small and medium size LNG feeder carriers to other countries within the WCR for
electricity production and fuel. Such a market development and increasing demand was described and predicted in the Feasibility study conducted in 2012 (SSPA, 2012) and may reduce the supply chain cost component of the LNG delivered to the ferry terminal significantly. If an investment partner willing to cover the initial investment cost of a small-scale export facility from Atlantic LNG in Point Fortin can be identified, this supply chain option (No. 3) is considered to combine favourable supply chain costs, safe bunkering solutions and high flexibility for TTIT’s LNG demand and it may also contribute making Trinidad and Tobago a pioneer for small-scale exportation of LNG in the WCR.

The supply chain options with local small-scale liquefaction plants (No. 2a and 2b) may also be designed preferably for a capacity larger than the actual estimated LNG demand of the TTIT high speed ferries. Such an overcapacity is not expected to increase the cost proportionally but will instead offer possibilities for development of new domestic LNG utilisation for local industrial purposes, ship fuel or vehicle fuel. Complementary production and distribution of LNG from the small plants will thus contribute to a reduction of the supply chain costs of ferry fuel and also contribute to environmental improvements if the surplus LNG production is replacing fuel oil of other energy consumers.

Local small-scale production facilities in both the sister islands Trinidad and Tobago, may contribute developing new business in Tobago and if LNG bunkering services are offered in both Port of Spain and in Tobago this means increased flexibility and a potential for less bulky LNG tanks in the ships.

The TTS bunkering concept and supply chain (No. 1) also offers high flexibility, but solutions based on only one LNG tank truck will become sensitive in terms of traffic problems or technical failures.

### 7.3 Safety considerations

All three LNG bunkering and supply chain options have been initially analysed and compared but additional detailed quantitative analysis will be required during the detailed design phase when hose dimensions, flow rate, pressure of the LNG bunkering system etc. are specified.

Due to the complicated traffic situation, limited space and adjacent activities and buildings in the Port of Spain ferry terminal, it is not recommended to arrange ITPS facilities for LNG bunkering given the present terminal layout.

TTS LNG bunkering may be possible without passenger on board and without cargo or passenger handling in the berth area but TTS LNG bunkering with passengers on board or simultaneous cargo handling is not recommended with the present terminal layout.

In Scarborough the ferry terminal is larger, with the passenger and vehicle flows separated from quay areas amidships port side where LNG bunkering
operations TTS or ITPS are considered to be possible with or without passengers on board.

STS LNG bunkering options may involve larger flow rates than TTS, but it is generally considered less difficult because mooring a bunker barge alongside the ship may often ensure safe separation distances from the bunkering safety zone and passenger and cargo handling areas.

7.4 Further studies and other pilot applications

The presented pilot study provides important background data for further elaboration of detailed business case studies for future high speed ferry services of TTIT. The study shows that there are good prospects for finding solutions that combine the reduction of harmful exhaust emissions, high safety and reliability with reduction of the overall operational costs seen from a national perspective by transition to LNG as fuel.

Initial costs are relatively high and investment strategies must include considerations on long term potential of an expanding market for small-scale domestic demand and medium scale regional export of LNG for energy production. The LNG fuel cost depends on the selected supply chain and is thereby also highly influenced by the long term strategies and market prospects for future LNG demand.

As a possible alternative to conversion of TTIS’s existing high speed ferries for LNG by replacement of the diesel engines to gas turbines, procurement of a second hand gas turbine propelled diesel fuelled high speed ferry, may offer a cheaper solution. Conversion of gas turbine machinery from diesel to LNG is expected to be less complicated than replacement of engines and there are diesel fuelled gas turbine propelled high speed ferries laid up and for sale.

This pilot study may also provide guidance for other stakeholders and member states investigating how to adapt to future stricter emission and how to assess the technical and economic prospects for transition to LNG as ship fuel. The initial assumption of this pilot study that the large existing liquefaction plant would provide the obvious source of LNG fuel supply, turned out to be somewhat unexpected. Both technical and business related issues were identified and other sources and local small-scale liquefaction were also identified as feasible options. This experience and the width of the presented fuel cost dependency on source and choice of supply chain, highlight the importance of careful supply chain assessment and securing of long term LNG delivery services. For existing LNG fuelled ferry pilot projects, cf. Appendix 3, well-established cooperation between the ferry operator, the ship designer, the LNG supplier, the port and the regulating authorities at an early project stage have proven to be key factors for success.
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Site visits and project meetings conducted by the consultant team

Project inception phase
The contract between IMO and SSPA Sweden was signed 26 June 2013. White Smoke Consulting and Light Craft Design Group LDG were contracted as sub-consultants to SSPA. The ToR of the contract stipulate a draft report to be delivered by 22 November and a final report by 20 December 2013. Information was initially collected and communicated by correspondence with local counterparts and stakeholders.

On September 5 a teleconference call was held with two representatives from TTIT, two representatives from the consultant team, one IMO Consultant, Liaison/facilitator and one Regional IMO Maritime Adviser in Trinidad and Tobago. At the teleconference, important contact persons and organisations were identified and a preliminary schedule for visits was outlined.

Meetings and workshop in Trinidad and Tobago in September 2013
On September 16 Björn Forsman, SSPA and Johan Algell, White Smoke from the consultant team had a preparatory meeting with Mr Leon Grant, CEO TTIT and Ms Josanne Phillips, Executive Secretary to CEO, TTIT.

On September 17 a meeting was arranged with Mr Colin Young, IMO Regional Maritime Adviser, the TTIT representatives and a tour in the terminal area was arranged. The tour showed that the ferry terminal area has limited space for waiting vehicles and cargo. An on board visit and presentation of the T&T Spirit was also arranged and guided by expertise from the technical management operator, Bay Ferries Ltd. The purpose was to survey the possibilities to convert the vessel for the use of LNG as fuel including LNG tank location and engine room reconstruction. The T&T Express was temporarily out of service but considered too old to be subject for detailed LNG reconstruction considerations.

On September 18 a workshop for presentation of the study and identification of key issues was arranged and hosted by TTIT and PATT. The workshop attracted 29 attendees representing different stakeholders as, TTIT, Maritime Service Division, NIDCO, Atlantic LNG, DNV, Min. of Energy, Min. of Transport, National Energy Corporation, National Gas Company etc.

The workshop focussed on various options for the LNG supply chain and associated safety issues. Regarding possible use of tank trucks for LNG supply and bunkering, safety and reliability concerns were pointed out regarding the traffic situation both locally in Port of Spain and along the existing road from Atlantic LNG in Point Fortin. Atlantic does not have facilities for truck loading nor for loading of small LNG barges and there are presently no plans for development of such facilities. NIDCO reported
that an on-going road development programme includes upgrading of the road between Port of Spain and Point Fortin scheduled for completion in March 2015. After the workshop, the project partners summarised the meeting and agreed on additional meetings with dedicated organisations and a time table for the next site visit in Trinidad and Tobago. A progress report was submitted to IMO, London.

On September 19 an on board visit and demonstration was conducted in one of NIDCO’s Water taxi vessels. Available space for possible placing of LNG tanks was found limited and the engine rooms also have limited space to accommodate modified or replacement engines for LNG fuel.

On September 20 two meetings were arranged with the National Energy Corporation (NEC) and the National Gas Company (NGC) in Couva. NEC described ongoing discussion on the possibilities to establish a small/mid-scale LNG production facility in the La Brea area with a capacity of approximately 0.4 MMpta. If established, such a facility could also include a small scale export jetty and facilities for LNG loading of trucks and containers. NGC owns TTLNG who owns 11% of Atlantic LNG train IV and in two years the contracts may be renegotiated and possibly allow domestic utilisation of a minor portion of the LNG production.

Analysis phase - Compilation and analysis of information

Collected information was compiled and analysed according to the outlined project structure and a draft report was prepared. Additional information was retrieved from various local contact persons and stakeholders.

Meetings in Trinidad and Tobago in November 2013

On November 14 the consultants arrived in Port of Spain and took the T&T Express to Tobago for a presentation and meeting in the ferry terminal in Scarborough. A courtesy call to the Chief Secretary of Tobago house of assembly was also conducted with a short presentation and discussion. The Chief Secretary supported the project for further consideration and appreciated being informed at an early stage of the project.

On November 17 SSPA’s consultants made a presentation for group of 19 stakeholders and representatives from PATT, TTIT, POSINCO, IMO, Maritime Services Division, Min. of Energy, Min. of Transport and NEC. The meeting was followed by productive discussions. The presented output of the study was considered relevant and useful and it was confirmed that a draft report would be delivered to IMO and TTIT on November 22. A short progress update was submitted to IMO, London.

Delivery of draft report

A draft report was submitted on November 22 to IMO, London, and to TTIT and the project representatives including IMO’s regional advisor and project liaison facilitator. Comments on the draft were received on November 29 and have been taken into account in the final version of the pilot study report.

Delivery of final report

The final report was submitted on December 20.
Appendix: 2

Pilot study on the use of LNG as a fuel for a high speed passenger ship from the Port of Spain ferry terminal in Trinidad and Tobago

General LNG supply chain options, box chart
Examples and experience of LNG bunkering of ferries

Outside Norway there are presently only a few LNG fuelled passenger ferries in operation. Between Sweden and Finland a large LNG fuelled roro/passenger-ferry entered in to operation in January 2013 and the first large scale LNG fuelled high speed ferry is about to enter in operation between Argentina and Uruguay. The ferries have different types of engines, dual fuel, pure gas engines and dual fuel gas turbines and all three basic bunkering concepts are represented; ship to ship, truck to ship, intermediate tank via pipeline to ship. For most of the ferries LNG bunkering is conducted night time without passengers on board but some ferries are regularly bunkering with passengers on board. Some examples of LNG fuelled ferries are briefly described below.

GLUTRA, Norway

![Image of GLUTRA ferry]

Figure 1: The first LNG fuelled ferry, the Norwegian ferry Glutra. Profile and section of Glutra, engine room top left and refueling bridge (Stokholm & Roaldsøy, 2000)

Table 1 Data on Norwegian LNG fuelled ferry GLUTRA

<table>
<thead>
<tr>
<th>GLUTRA particulars</th>
<th>LNG bunkering data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of operation</td>
<td>2000</td>
</tr>
<tr>
<td>Route</td>
<td>Flakk–Rørvik, Trondheim</td>
</tr>
<tr>
<td>Length, L</td>
<td>95 m</td>
</tr>
<tr>
<td>Passengers</td>
<td>300</td>
</tr>
<tr>
<td>Cars</td>
<td>96 or (42 + 8 trailers)</td>
</tr>
<tr>
<td></td>
<td>LNG tank type/capacity</td>
</tr>
<tr>
<td></td>
<td>LNG bunkering concept</td>
</tr>
<tr>
<td></td>
<td>LNG Bunkering rate/time</td>
</tr>
<tr>
<td></td>
<td>Ref</td>
</tr>
</tbody>
</table>

SSPA SWEDEN AB – YOUR MARITIME SOLUTION PARTNER
**FJORD1, Norway**

The Norwegian ship owner Fjord 1 operates a large number of road ferries in Norway and started operating LNG fuelled vessels in 2007. The vessels are Stavangerfjord, Fanafjord, Mastrafjord, Bergensfjord and Raunefjord designed with gas only engines and ESD engine room concept. They are bunkered without passengers from landbased intermediate storage tanks supplied LNG by trucks.

**Figure 2:** Fjord1 LNG fuelled ferries - LNG equipment onboard and inherently safe engine rooms (Petrov, 2013)

Fjord1’s Boknafjord is one of three sister ships representing a newer larger generation of LNG fuelled road ferries that has been in service since 2011.

**Figure 3:** Boknafjord layout (Hoel, 2013) engine control system (Rolls Royce, 2012), photo by Karl Otto Kristiansen
Table 2 Data on Boknafjord

<table>
<thead>
<tr>
<th><strong>BOKNAFJORD particulars</strong></th>
<th><strong>LNG bunkering data</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of operation</td>
<td>2011</td>
</tr>
<tr>
<td>LNG tank type/capacity</td>
<td>2 x 125 m³ vacuum/perlite C-tanks</td>
</tr>
<tr>
<td>Route</td>
<td>Fjord crossings</td>
</tr>
<tr>
<td>LNG bunkering concept</td>
<td>Pipeline from land based intermediate storage tank supplied by tank truck</td>
</tr>
<tr>
<td>Length, L</td>
<td>130 m</td>
</tr>
<tr>
<td>LNG Bunkering rate/time</td>
<td>3 hours, once a week</td>
</tr>
<tr>
<td>Passengers</td>
<td>589</td>
</tr>
<tr>
<td>Ref</td>
<td>nighttime, no passengers</td>
</tr>
<tr>
<td>Cars</td>
<td>242</td>
</tr>
</tbody>
</table>

**TIDEKONGEN, Norway**

Tidekongen is one of three sister ferries with dual fuel engines operating in the capital Oslo.

![Tidekongen](image)

*Figure 4 Tidekongen, tank and engine arrangement (Grimstad Osberg, 2013)*

Table 3 Data on Tidekongen – one of three LNG fuelled passenger vessels operating in Oslo

<table>
<thead>
<tr>
<th><strong>TIDEKONGEN particulars</strong></th>
<th><strong>LNG bunkering data</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of operation</td>
<td>2009</td>
</tr>
<tr>
<td>LNG tank type/capacity</td>
<td>50 m³</td>
</tr>
<tr>
<td>Route</td>
<td>Oslo - Nesodden</td>
</tr>
<tr>
<td>LNG bunkering concept</td>
<td>by truck and 7 m hose</td>
</tr>
<tr>
<td>Length, L</td>
<td>50 m</td>
</tr>
<tr>
<td>LNG Bunkering rate/time</td>
<td>Twice a week, 1-2 h, 40 m³/h</td>
</tr>
<tr>
<td>Passengers</td>
<td>628</td>
</tr>
<tr>
<td>Ref</td>
<td>Nighttime, no passengers on board</td>
</tr>
<tr>
<td>Cars</td>
<td>-</td>
</tr>
</tbody>
</table>
Vestfjorden ferries, Torghatten Nord

Torghatten Nord represents the first of the five LNG fuelled sister vessels LNG, Landegode, Værøy, Barøy and Lødingen.

![Torghatten Nord ferries](image)

**Figure 5: Torghatten, Nord ferries**

<table>
<thead>
<tr>
<th>TORGHATTEN Nord particulars</th>
<th>LNG bunkering data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of operation</td>
<td>2012</td>
</tr>
<tr>
<td>LNG tank type/capacity</td>
<td>150 m³</td>
</tr>
<tr>
<td>Route</td>
<td>Lödingen, N Norway</td>
</tr>
<tr>
<td>LNG bunkering concept</td>
<td>ITPS from land based tank (250 m³) supplied by LNG truck</td>
</tr>
<tr>
<td>Length, L</td>
<td>93 m</td>
</tr>
<tr>
<td>LNG Bunkering rate/time</td>
<td>150 m³/h / 1½ h</td>
</tr>
<tr>
<td>Passengers</td>
<td>390</td>
</tr>
<tr>
<td>Bunkering conditions</td>
<td>Nighttime, no passengers on board</td>
</tr>
<tr>
<td>Cars</td>
<td>120 + 12 trailers</td>
</tr>
</tbody>
</table>
FJORDLINE, Norway

FjordLine took delivery of the LNG fuelled RoPax vessel Stavangerfjord in 2013 and the sister ship Bergensfjord will be delivered later this year for operation between Norway and Denmark. The Norwegian authorities initially did not allow LNG bunkering from truck with passengers on board awaiting the finalization of a permanent quay based fixed loading arm at the berth in Norway. The long term bunkering solution includes bunkering via a loading arm supplied from a 600 m long 6 inch vacuum insulated LNG pipeline from a FBT LNG storage tank located near the ferry terminal. The engines are not dual fuel type, operates with LNG only.

![FjordLine's Stavangerfjord](image)

**Figure 6: Terminal with LNG pipeline for bunkering of Fjordline’s Stavangerfjord and engine room and LNG tank arrangement, (Blomberg, 2013), Foto: Espen Gees (Fjordline)**

<table>
<thead>
<tr>
<th>STAVANGERFJORD particulars</th>
<th>LNG bunkering data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of operation</td>
<td>2013</td>
</tr>
<tr>
<td>LNG tank type/capacity</td>
<td>2 x 296 m³ tanks</td>
</tr>
<tr>
<td>Route</td>
<td>Bergen-Stavanger NO - Hirtshals DK</td>
</tr>
<tr>
<td>LNG bunkering concept</td>
<td>Pipeline from land based FBT, to loading arm at berth, no hoses, no vapour return</td>
</tr>
<tr>
<td>Length, L</td>
<td>170 m</td>
</tr>
<tr>
<td>LNG Bunkering rate/time</td>
<td>Max 330 m³/h at 8-10 bar</td>
</tr>
<tr>
<td>Passengers</td>
<td>1500</td>
</tr>
<tr>
<td>Bunkering conditions</td>
<td>Temporarily by LNG trucks. Long term by dedicated fixed loading arm at the berth.</td>
</tr>
<tr>
<td>Cars</td>
<td>600</td>
</tr>
<tr>
<td>Ref</td>
<td>(Rolls Royce, 2012)</td>
</tr>
</tbody>
</table>

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VIKING GRACE, Finland

Viking Grace was the first LNG fuelled large ropax ferry and the first to bunker ship-to-ship. It operates between Sweden and Finland and has dual fuel engines with the LNG tanks located in the aft deck. The LNG bunker is supplied by a dedicated self-propelled bunker barge in Stockholm, mooring alongside the vessel. The LNG is transferred by pressure difference without pumping. The bunker barge is filled from tank trucks at another berth in the port of Stockholm.

![Viking Grace and the LNG bunker barge moored alongside at the ferry's bunker station. Engine and propulsion arrangement (Granberg, 2013)](image)

**Figure 7** Viking Grace and the LNG bunker barge moored alongside at the ferry’s bunker station. Engine and propulsion arrangement (Granberg, 2013)

**Table 6 Data on Viking Grace**

<table>
<thead>
<tr>
<th>VIKING GRACE particulars</th>
<th>LNG bunkering data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of operation</td>
<td>2013</td>
</tr>
<tr>
<td>Route</td>
<td>Stockholm SE – Turku FI</td>
</tr>
<tr>
<td>Length, L</td>
<td>218 m</td>
</tr>
<tr>
<td>Passengers</td>
<td>880 + 200 crew</td>
</tr>
<tr>
<td>Roro Lanemeters</td>
<td>1275 + 550 +550</td>
</tr>
<tr>
<td>LNG tank type/capacity</td>
<td>2 x 200 m³ vacuum insulated type C</td>
</tr>
<tr>
<td>LNG bunkering concept</td>
<td>Ship to ship, 6 inch hose, no vapour return</td>
</tr>
<tr>
<td>LNG Bunkering rate/time</td>
<td>Max 180 m³/h, 55 minutes, 5 times/week</td>
</tr>
<tr>
<td>Bunkering conditions</td>
<td>With passengers on board</td>
</tr>
</tbody>
</table>

![Ship-to-ship LNG bunkering from the LNG bunker barge Seagas to Viking Grace.](image)

**Figure 8** Ship-to-ship LNG bunkering from the LNG bunker barge Seagas to Viking Grace.

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HSC Francisco, Uruguay

The 99 m long HSC Francisco is the first LNG fuelled high speed ferry. The operator Buquebus in Argentina took delivery from InCat Australia in July 2013 and intends to start operate it with LNG fuel produced by own small scale liquefaction plant from December 2013. Two dual fuel 22 MW GE LM2500 gas turbines driving Wartsila LJX 1720 SR waterjets allow an operating speed of 50 knots and maximum speed 58 knots. Six Cryobox nano LNG units will ensure production to meet the daily demand of 84 m$^3$.

![Image of HSC Francisco](image_url)

**Figure 9: HSC Francisco (Incat, 2013), General Arrangement, first fueling in Australia and LNG tank**

<table>
<thead>
<tr>
<th>FRANCISCO particulars</th>
<th>LNG bunkering data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of operation</td>
<td>2013</td>
</tr>
<tr>
<td>Route</td>
<td>Buenos Aires – Montevideo</td>
</tr>
<tr>
<td>Length, L</td>
<td>99 m</td>
</tr>
<tr>
<td>Passengers / cars</td>
<td>1000 /150</td>
</tr>
<tr>
<td>LNG tank type/capacity</td>
<td>2 x 40 m$^3$ LNG, 2 x 70 m$^3$ fuel oil</td>
</tr>
<tr>
<td>LNG bunkering concept</td>
<td>By truck at the ferry berth. LNG from local small scale liquefaction units.</td>
</tr>
<tr>
<td>Bunkering conditions</td>
<td>Nighttime, no passengers on board</td>
</tr>
</tbody>
</table>

**Table 7 Data on InCat No 069 Francisco**

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7(7)