Liquefied Natural Gas:  
A Marine Fuel for Canada’s Great Lakes and East Coast

May 2017
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A Marine Fuel for Canada’s Great Lakes and East Coast

Project Participants

- American Bureau of Shipping
- Babcock Canada
- BC Ferries
- British Columbia Institute of Technology
- British Columbia Ministry of Transportation
- Canada Steamship Lines
- Canadian Natural Gas Initiative
- Canadian Natural Gas Vehicle Alliance
- Canadian Standards Association
- Class NK
- DNV-GL
- Enbridge Gas Distribution
- Encana
- Environment and Climate Change Canada
- Ferus
- FortisBC
- Gaz Métro
- Lloyd’s Register
- Natural Resources Canada
- Ontario Ministry of Environment and Climate Change
- Port of Metro Vancouver
- Port of Montreal
- Rolls-Royce
- Société des traversiers du Québec
- Seaspan
- Shell
- STX / VARD Marine
- S & T2 Consultants
- Teekay
- Transport Canada
- Union Gas
- Wartsila
- Westport Inc.

NOTE: Italics indicate participants in the "Liquefied Natural Gas: A Marine Fuel for Canada’s Great Lakes and East Coast" study. Non-italics indicate participants in both the "Liquefied Natural Gas: A Marine Fuel for Canada’s Great Lakes and East Coast" study and the earlier "Liquefied Natural Gas: A Marine Fuel for Canada’s West Coast" study.
Foreword

With the arrival of liquefied natural gas (LNG) powered ferries in eastern and western Canada, this promising marine fuel has begun to gain a toe hold in Canada. More stringent North American emissions standards now in-force, and aggressive greenhouse gas (GHG) commitments on the part of the Government of Canada, are increasing interest in natural gas as a marine fuel. Coupled with Canada’s abundant supply of natural gas, vessel owners are interested in this fuel as an affordable option to accomplish a variety of emissions reductions.

Unlike many other emissions reductions alternatives which can reduce criteria air contaminants such as sulphur oxide, nitrogen oxide and particulate matter, natural gas can also reduce GHG emissions. According to Environment and Climate Change Canada, transportation related emissions account for 28 per cent of GHGs – finding the reductions to meet international commitments will require action in the transportation industry. The use of natural gas as a marine fuel is one opportunity that can contribute to those reductions.

The challenge for natural gas lies in gaining greater market access. Canadian regulations need to be adapted to better accommodate the use of natural gas as a marine fuel, while codes, standards and regulations, personnel training, operating practices and procedures, and fuel supply infrastructure are all at various stages of development. There is a need to leverage early experience with Canadian operated LNG vessels to identify what has worked and to begin the process of updating these regulations.

Liquefied Natural Gas: A Marine Fuel for Canada’s Great Lakes and East Coast is a condensed version of the Transport Canada report, TP 15347 E, Canadian Marine Liquefied Natural Gas (LNG) Supply Chain Project, Phase 2 & 3 – Great Lakes and East Coast. The East Coast and Great Lakes-focused joint industry project builds on the work of the previous West Coast project and has included additional industry participants. The work of this group has provided an important opportunity for a broad range of stakeholders to collaborate and to advance our collective understanding of the barriers to marine LNG use, including how best to address these barriers. Ongoing collaboration remains essential to clearing the regulatory path and to ensuring Canada’s abundant natural gas resources can be more widely used in the marine sector.

On behalf of the steering committee, I would like to thank the project participants for their many contributions to this work.

Bruce Winchester
Chair, Great Lakes and East Coast Marine LNG Joint Industry Project Steering Committee
Executive Director, Canadian Natural Gas Vehicle Alliance
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Executive Summary

*Liquefied Natural Gas: A Marine Fuel for the Great Lakes and Canada’s East Coast* is a condensed version of the Transport Canada report TP 15347 E, Canadian Marine Liquefied Natural Gas (LNG) Supply Chain Project, Phase 2/3 - Great Lakes and East Coast.

Of the work carried out in Phase 1 – West Coast, many of the findings and related aspects of the work were transferrable to the Great Lakes and East Coast regions of Canada. New work was required to update regulatory and policy changes since the first report and also for aspects that were found to be unique to these new regions (economic modelling, implementation scenario options based on local infrastructure, and aggregate regional environmental and economic benefit analysis). While following the same layout as the original Phase 1 – West Coast report and retaining much of the same information, this report reflects the distinct differences between the regions and the revised scope of the project (Phase 2/3 considers compressed natural gas (CNG) as an additional option for some applications).

**Key Project Findings**

- All of the technologies needed to use natural gas as a marine fuel for Canada’s Great Lakes and East Coast are proven and commercially available. Development of engine and onboard fuel storage is ongoing. In marine applications, natural gas provides significant benefits.

- Natural gas is a clean energy option that offers a means of reducing emissions to meet current and pending environmental regulations and this is potentially a major factor which could drive the growth of natural gas use as a marine fuel. Depending on the engine and after-treatment technologies, natural gas use will result in environmental benefits including reduction in:

  - life cycle carbon dioxide (CO$_2$) equivalent emissions by 22-32 per cent (based on the hydro-powered LNG source);
  - sulphur oxides (SOx) 99 per cent;
  - nitrogen oxides (NOx) by 23 per cent or more; and
  - particulate matter (PM) by 86 per cent or more.

In addition, the potential for environmental damage due to spills or shipping accidents is much reduced using natural gas compared with marine oils, as natural gas dissipates rapidly rather than leaving slicks and residues.

- Natural gas use as a marine fuel will provide significant economic benefits to the owners and operators of vessels, especially coastal vessels. Of the nine case study vessels considered, five had a payback on initial investment of approximately four years or less. The high end of the spectrum had paybacks in the nine to 12 year range.
Executive Summary

Natural gas is abundantly available throughout Canada and the United States, resulting in low feedstock costs to produce LNG and CNG. The current price and long-term supply outlook in North America make it a highly attractive energy source for the marine sector, which will have to comply with more stringent emissions regulations going forward.

While the Great Lakes and East Coast have limited LNG and CNG production and distribution capacity, as marine natural gas demand increases, new infrastructure investments will need to be made.

Realistic adoption rate scenarios indicate that marine use of LNG could lead to significant demand creation for LNG on the Great Lakes and East Coast within the next decade. Under a “medium” adoption scenario, there would be 148 LNG vessels operating on the Great Lakes and East Coast by 2025, requiring 783,000 metric tonnes of LNG annually.

The early demand for LNG will come from ferries and other coastal traffic, but this will build quite rapidly to encompass other vessel types and a significant demand volume.

LNG can be used safely as a marine fuel. Addressing human resources remains a crucial need for safely operating LNG-fuelled vessels. Operations on these ships will differ from those of traditionally powered vessels in several important respects, including vessel layout, fuel properties, fuel handling requirements, and emergency response.

The biggest barriers for the use of natural gas as a marine fuel are its unfamiliarity, and the need to create some or all aspects of the fuel supply chain on Canada’s Great Lakes and East Coast as well as in other areas of the world.

Using LNG as a marine fuel offers benefits such as: reduced emissions from ship engine exhaust, as described above; direct economic benefits in the form of lower operating costs for owners and operators, local infrastructure investments and increased sales of natural gas; indirect economic benefits; and the establishment of an LNG supply chain that can be used in other applications such as trucking, rail and off-grid power generation.

The recommendations noted on the following page have been identified to help drive adoption of natural gas as a marine fuel.
Executive Summary

Recommendations to Encourage the Use of Natural Gas as Marine Fuel on Canada’s Great Lakes and East Coast

1. It is recommended that stakeholders continue to collaborate and build on the findings of this project and the compendium West Coast project to support current marine LNG deployments as well as proposed initiatives. There are potentially significant environmental benefits as well as economic opportunities if Canada can build on the success of early adopters and take a lead in global marine discussions.

2. It is recommended that the Government of Canada with the support of the relevant provincial governments develop a comprehensive Regulatory Approval process for LNG-fuelled operations. The International Marine Organization (IMO) IGF Code provides a firm basis for the approval of the ships themselves, but many aspects of bunkering, operations, and fuelling facilities design and not yet covered by clear policies, standard or regulations. This represents a risk that many potential LNG adopters are unwilling to accept. As a result, it is critical that an updated regulatory framework be established in order to support the widespread adoption of marine LNG.

3. It is recommended the Government of Canada actively support the development and adoption of model international training courses for seafarers and for other operational personnel, with inputs from the Canadian Association of Marine Training Institutes (CAMTI) and from Canadian early adopters. As LNG expands from short sea into deep sea operations, it will become increasingly important to have consistent baselines for safe operations.

4. It is recommended, to encourage efficient review of proposed projects, that the federal and provincial governments review and formalize policies for LNG ships and facilities. To support this, it is recommended that each level of government designate a lead agency to coordinate all processes for marine project approvals.

5. It is recommended that CSA Group and international marine standards organizations continue to work in concert to ensure there are no gaps or differences in North American standards for handling natural gas as a transportation fuel. In particular seamless application of ship side and dock side standards for fuel handling will have a direct and positive impact on bunkering operations.

6. It is recommended that relevant safety related information, such as the results of risk assessments for LNG applications, be easily accessible to the general public in order to increase public understanding and address potential concerns related to LNG safety.

7. It is recommended that the federal government considers designating a small fraction of its planned infrastructure investments to assist leading port facilities in developing LNG fuel handling capabilities to support bunkering activities. This could help Canada to establish a presence in the North American and global LNG bunkering market.
Introduction

This report, *Liquefied Natural Gas: A Marine Fuel for Canada’s Great Lakes and East Coast*, is the result of a multi-participant, joint industry/government study into the implementation of a natural gas marine fuel supply chain in the Great Lakes, including the St. Lawrence, and on the East Coast of Canada. The project has been coordinated by the Canadian Natural Gas Vehicle Alliance (CNGVA), Transport Canada’s (TC) Transportation Development Centre (TDC), and VARD Marine (STX). This report is the continuation of similar work completed on the same subject dealing with Canada’s West Coast, its outline similar to that report, *Liquefied Natural Gas: A Marine Fuel for Canada’s West Coast*, and its observations are in line with those found in the previous report (2014).

Natural gas has traditionally been used for power generation, space and water heating, as well as a process feedstock. Its use as a marine transportation fuel has been limited by a number of barriers, including its much lower energy density compared to that of liquid hydrocarbons; a challenge that can be addressed by storage of gas in its liquefied or compressed forms. Recent trends in international emission regulations, technology development and shipping economics make natural gas increasingly attractive in comparison to more traditional fuels; particularly for voyages within, to, and from North America.

The objective of this project has been to develop a comprehensive understanding of all issues relating to the introduction of natural gas as a marine fuel in the Great Lakes and on the East Coast of Canada, and to use this understanding to formulate a strategy to address barriers and support greater use of natural gas as a marine fuel. The main focus has been on liquefied natural gas (LNG), but many of the findings are applicable to compressed natural gas (CNG) and “hybrid” gas containment systems.

**Project Participants**

The project successfully engaged a diverse set of stakeholders, covering all stages of a potential supply chain and the industry and government sectors which are most likely to be involved. Participants came from:

› fuel suppliers;
› vessel operators;
› vessel designers;
› building and repair companies;
› engine and equipment suppliers;
› ports;
› training organizations;
› regulators and classification societies; and
governments.

Participation by the Federal Government has been led by Transport Canada (TC) with the involvement of Environment and Climate Change Canada, and Natural Resources Canada. Participation by provincial government has involved British Columbia (BC), Ontario (ON) and Quebec (QC). The BC provincial government representation continues to be led by their Pacific Gateway group, and has drawn in additional resources and expertise as required. Representation from the Government of Ontario has been through the Ministry of Environment and Climate Change. The Government of Quebec was represented through Société des traversiers du Québec (STQ) – the government run ferry service. As this report adds to the work completed in the West Coast project, new participants were added to the original participants.

### Project Participants

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*Italics indicate participants in the phase 2/3 project.
Project Scope

The work was undertaken as a set of tasks, with task team membership drawn from the project participants, addressing the following aspects of the use of natural gas as a marine fuel:

1. Technology readiness for the use of natural gas as a marine fuel.

2. Infrastructure options for marine natural gas refueling with reference to existing pipelines, liquefaction, distribution hubs, local transportation and storage, and other significant marine-related components.

3. The economic benefits associated with natural gas fuel for a range of vessel types operating on the Great Lakes and East Coast of Canada.

4. The environmental benefits of adopting natural gas in various sectors of the shipping fleet.

5. Regulatory impediments to the introduction of natural gas at the federal, provincial, municipal, and community levels, and formulating policies and procedures to address these impediments.

6. Human resource challenges for the installation, operation, and maintenance of natural gas vessels and refueling systems. Developing strategies to meet these challenges.

7. Implementation scenarios for the introduction of natural gas-powered vessels, including quantification and scheduling of investment requirements.

8. The potential benefits to Canada of a natural gas marine strategy including environmental benefits, economic gains associated with the fuel and technology supply chain, North American harmonization and competitiveness advantages that could have a positive impact on trade routes.

9. Suggestions that could assist in the implementation of a natural gas fuel strategy.
This chapter reviews the characteristics of natural gas and the technology readiness for the marine application of liquefied natural gas (LNG) and compressed natural gas (CNG), covering:

› the inherent characteristics of natural gas;
› liquefaction and bulk storage systems;
› distribution systems such as feeder vessels, rail and road vehicles, local tanks, and bulk cargo;
› bunkering systems;
› onboard storage and fuel distribution technologies;
› engine technologies for various types of dual fuel and pure natural gas engines;
› the integration of natural gas engines into mechanical and electrical drive systems;
› safety technologies associated with natural gas;
› technical standards available for the certification of equipment using natural gas; and
› ongoing research and development (R&D) activities associated with all of the above.
Natural Gas and Its Use as a Marine Fuel

Natural gas is a mixture of gaseous hydrocarbons and associated compounds found in underground deposits with methane forming the main part of natural gas. Other hydrocarbons, such as butane and propane, as well as contaminants, must be removed via processing before the natural gas is delivered to markets for end use. “Pipeline natural gas” is predominantly methane.

Methane has a low energy density at ambient pressure, so that one cubic metre ($m^3$) of natural gas has the same energy as one litre of diesel fuel. As a result, natural gas must be liquefied or compressed so it can store enough energy to be used as a transportation fuel.

1.1.1 LNG

In liquid form, LNG is lighter than water, and is odourless, colourless, non-corrosive and non-toxic. LNG has a density of about 600 times that of natural gas. The energy density of LNG makes it suitable for all vessels, but especially so for larger vessels or vessels operating long journeys.

1.1.2 CNG

CNG is natural gas that is brought to high pressure (typically around 235 bar) at ambient temperature. CNG has a density of about 200 times that of natural gas. The energy density of CNG makes it more suitable for a short sea ferries or workboats.

LNG Use

Natural gas has been used globally as a marine fuel on a limited basis for several decades. LNG carriers first used LNG boil-off gas to supplement onboard fuel storage 50 years ago and the first non-carrier LNG-fuelled vessel began operations in 2000. There are now over 150 LNG-fuelled vessels (excluding gas carriers) in operation or under development globally, including ferry, cargo, platform supply and tanker vessels. The technology needed to implement LNG as a marine fuel is proven and commercially available.

There are a number of LNG-fuelled vessels operating in North America with more projects at various stages of implementation:

› Harvey Gulf operated the first United States (U.S.) flagged LNG-fuelled vessel. They currently have three vessels delivered with three more at various stages of development;

› The Société des traversiers du Québec (STQ) ordered three new LNG-fuelled ferries, one constructed by Fincantieri of Italy, in service since mid-2015 and another two being constructed by Davie Shipyards in Quebec with expected completion in 2017;

› Desgagnés Group have begun construction on two dual-fuel 15,000 deadweight tonnage asphalt carriers and have committed to building two dual-fuel chemical/product carriers in the near future;

› BC Ferries plans to have five vessels using dual-fuel engines by 2018; and

› Seaspan Ferries Corporation ordered two dual-fuelled/hybrid ferries – the first was delivered in December 2016 and the second is expected to arrive in British Columbia in early 2017.

In the U.S., companies have begun transitioning to LNG for container and product carriers. TOTE has new LNG-fuelled containerships in use from Jacksonville, Florida to San Juan, Puerto Rico. TOTE is also converting two of its Orca class roll on/roll off containerships into LNG for operation between Alaska and Washington State. Crowley Maritime Corporation has two dual-fuelled 2400 Twenty-foot Equipment Unit (TEU) containerships under construction with expected completion in 2017. Another trend in the new-build industry is creating LNG ready vessels, which Crowley and American Petroleum Tankers have done. These companies each have at various stages of development four dual-fuelled 50,000 deadweight tonnage product tankers from Philly Shipyards.
1.3 CNG Use

CNG has been used as a transportation fuel for many years with the main consumers being on-road vehicles both heavy and light duty. In Canada, the Fort Langley ferry that crossed the Fraser River operated on CNG for more than ten years until the ferry was rendered obsolete due to the construction of a new bridge.

Canada currently has 94 CNG vehicle refueling stations which are both public and private access. While these refueling stations currently service on-road vehicles, similar stations could be installed at a port to service marine vessels or a mix of traffic.

1.4 LNG Safety Record

The LNG carrier industry has an excellent safety track record. After over 50 years of operating experience there have been no fatalities onboard vessels related to LNG. Although, there have been some incidents related to loading and unloading resulting in damage to vessels and injury to personnel. Several factors have a role in the safe and secure use and movement of LNG including:

› an industry committed to risk management;
› the risks and hazards due to the chemical and physical properties of LNG are known and appreciated in LNG related technology and operations;
› international standards and codes have been developed by not only regulators, but also the LNG industry, providing a framework for safe LNG operations;
› operational integrity and protocols, operator knowledge, training and experience; and
› technological advances in the LNG industry.

The industry continues to work collectively to develop and evolve best practices and standards.

1.5 Liquefaction Process, Technology Options, and Bulk Storage

The liquefaction of natural gas reduces the volume of the gas by a factor of 619 which results in a proportional increase in the energy density of the fuel. Before it can be liquefied, pipeline quality natural gas must be further conditioned by having any minor contaminants removed. Following pre-treatment the gas is liquefied using refrigerants. A LNG plant’s liquefaction and purification facilities are commonly called a LNG train, and such trains can be built on large, medium and small scales. The output of a large world scale LNG train is typically measured in million metric tonne per annum (MMTPA) while small scale trains are measured in tonne per annum (TPA). Constructing a plant requires both a significant investment and considerable time before it can be brought online. A medium-scale plant, capable of producing 0.25 MMTPA can take approximately 24 months and an investment of over $100 million to build.

Advances in liquefaction technologies are continuously increasing the efficiencies of smaller scale plants which can offer a scalable solution to match the demand for LNG in the marine transportation sector. Compression technologies are also available for small-scale projects with CNG filling stations being able to be located at the source of the transportation fuel demand.

1.5.1 Liquefaction Technologies

There are five distinct natural gas liquefaction processes in use today. Ranging from the most to the least used, they are: the propane pre-cooled mixed refrigerant process (C3MR); the
AP-X large train cycle; the optimized cascade; the Shell double-mixed refrigerant process (DMR); and the mixed fluid cascade. Current world liquefaction capacity for these processes is shown in Figure 1.

1.5.2 Bulk Storage Systems

LNG needs to be stored at approximately -161°C to keep the fuel in liquid form. Most of today’s bulk storage tanks are either full containment tanks or full containment membrane tanks, the latter being used mainly in Japan and Korea. The former type has a cylindrical, inner primary tank and a pre-stressed concrete, outer secondary containment tank. The membrane type uses a thin metal membrane as a primary container, which is structurally supported by an outer, pre-stressed concrete containment tank.

The CSA Group Z276 Standard on LNG has included membrane tanks in its current 2015 edition. This standard establishes essential requirements and minimum standards for the design, installation, and safe operation of LNG facilities. As noted, in the Liquefied Natural Gas: A Marine Fuel for Canada’s West Coast report produced in 2014, previous editions had not included membrane tanks. As a result, the CSA Group technical committee formed a work group representing a range of stakeholders to develop the current standard.

LNG storage tanks are widely used and can be readily incorporated into an LNG marine fuel supply chain. Figure 2 shows typical bulk storage tanks.

1.6 Distribution and Bunkering

There is limited infrastructure in the Great Lakes and on the East Coast. The use of gas in Canada’s Great Lakes and East Coast marine sector will require investment in LNG and CNG production and distribution systems.

1.6.1 Distribution Systems

Globally, distribution options in place for LNG-fuelled vessels include fixed shore storage and bunkering facilities, tanker trucks, and LNG barges/small carriers.

The preferred LNG distribution system for marine vessels depends on fuel demands and the type of berth provided for bunkering. For new, dedicated bunker berths isolated from port traffic, bunkering by tanker trucks might initially be the most feasible in terms of capital investment and flexibility. This form of distribution is already in place in Canada and can be scaled according to demand.

For existing busy cargo/passenger ports, the adoption of large scale bunkering by trucks has limited potential should vessels require bunker volumes greater than 200m³. Dedicated fueling stations are also a viable option, however these require increased capital expenditures and vessels must regularly bunker in the same location.

Railcars are available which can be used for the distribution of LNG, but this is focussed on the bulk transportation of the fuel rather than acting as a direct link between LNG-fuelled vessels and the required fuel source. Several concepts have been developed for LNG distribution via barges and bunker vessels, however few vessels are currently in operation.
Existing LNG distribution options on the Great Lakes and East Coast are tanker trucks which can support the potential initial demands from coastal vessels using LNG supply from Union Gas’s Hagar plant in Hagar, Ontario or Gaz Metro’s LNG plant in Montreal, Quebec. There are also LNG supply points in the U.S. near the Great Lakes with the CenterPoint Energy Facility in Burnsville, Minnesota and the Kinetrex’ Indianapolis Facility.

1.6.2 Bunkering Systems

The extremely low temperature of LNG creates challenges that differ from those of oil-based fuels. The LNG bulk carrier industry has developed reliable systems for the efficient and safe transfer of LNG to vessels. While LNG bunkering is new to the non-carrier market, the lessons learned and approaches can be adapted for fueling LNG vessels.

The bunkering requirements of a vessel are dictated by its design, propulsion system and fuel storage configuration. All vessels, however, have the same system components, such as valves, sensors, control stations, supply hoses, hose couplings and onboard piping.

Shoreside LNG bunkering stations incorporate equipment and safety features similar to those on LNG-fuelled vessels. In the case of tanker trucks, transfer pumps may be fitted to the trucks or pump trailer units, or placed on shore or on the receiving vessel. For example, the fuel supply trucks of some West Coast vessel operators drive aboard the vessel to bunker oil-based fuels. An onboard LNG tanker truck bunkering is shown in Figure 4.

The Society of International Gas Tanker and Terminal Operators (SIGTTO) has introduced guidelines for bunkering from tanker vessels or barges. These cover the LNG transfers between carriers at anchor, alongside a jetty or while under way. There are numerous existing and proposed systems that can be adapted for bunkering operations of these types.

An example of available LNG bunkering operations appear in Figure 3.

Onboard Storage and Distribution

Unlike conventional liquid fuel tanks, which are integrated into a vessel’s structure, the tanks used on LNG-fuelled vessels are expected to be independent of that structure. A tank room is required if the LNG storage tank is located within the vessel rather than on deck. Tank rooms must have fuel containment provisions and secondary barriers to mitigate the effects of natural gas or liquid release. Most LNG-fuelled vessels, (other than LNG carriers, which use membrane tanks) are designed to use Type C tanks.

Although LNG tanks are highly insulated, a gradual boil-off of the gas is inevitable as the fuel warms up over a period of days. For vessels with Type C tanks, the boil-off can be managed up to a point by allowing the pressure to increase. Boil-off gas can also be used as fuel for the engines or in auxiliary systems such as boilers.

LNG tank size and location onboard a vessel are key considerations when converting a diesel-powered vessel to LNG. The size depends on the range required for the vessel between refueling
stops, but the conversion must also allow for the fact that the LNG tank footprint will be larger than the oil tank footprint if the vessel is to retain its original, diesel-powered range. This is because LNG requires 70 per cent more volume than an oil-based fuel to hold the same amount of energy.

CNG Technology and Storage

The entire system to use CNG as a transportation fuel - compressing natural gas, refueling station infrastructure and storage - is fairly simple. The system requires well understood technology and equipment including a natural gas service line, a dryer/filter, a compressor, storage, a temperature compensator, and dispensing equipment. Figure 5 is a schematic of the system for the processes of compressing and dispensing natural gas.

At this time, priorities for research and development are being directed toward reducing the cost of CNG vehicle applications and their weight impact.

CNG is easier to provide wherever there is a convenient source of natural gas, but the limitations of CNG storage options restrict the potential market. With respect to vessel engine technology, CNG can be used with any of the natural gas-fuelled engines as described below.

Natural Gas Engine Technologies

Natural gas-fuelled internal combustion engines have been used for many years both in land based applications and aboard vessels. There are now numerous options for the higher horse power engines for larger types of vessels, using both pure gas and dual fuel (natural gas plus diesel) options and a variety of thermodynamic cycles. There are more limited number of marine natural gas engines available with power ratings below 1,000 kW that are used for auxiliary engines of larger vessels and main propulsion on smaller vessels, but these are also becoming available. There are three basic types of engines:

› Lean burn, spark-ignition, pure natural gas types operate on the Otto cycle and use a spark plug to ignite the natural gas/air mixture in the combustion chamber. Manufactured by companies such as Rolls-Royce Marine/Bergen, Mitsubishi and Hyundai, they range in power from 316 kW to 9,700 kW. Figure 6 shows an example.

› Dual fuel with diesel pilot engines operate on the Otto cycle and use natural gas together with a second fuel source, which may be distillate or heavy fuel oil. They allow the operator flexibility in deciding which fuel to use, based on price and availability. Manufacturers include Wartsila, MAN, Caterpillar/MAK, ABC Diesel and Electro Motive Diesel. They range in power from 720 kW to 17,550 kW.

› Direct injection with diesel pilot engines operate on a diesel cycle, with natural gas injected directly into the cylinder near the top of the compression stroke. Conversion of an existing diesel engine requires limited modification to the engine itself, so this type of engine offers a higher potential for retrofitting existing units for direct injection operation. At present, no medium - or high-speed marine engines are available in this category, but slow-speed
The relative economic and environmental performance on different options is covered in other chapters.

### Engine Propulsion Systems

Marine propulsion systems are the means by which the engine’s power moves the vessel, usually via propellers. On LNG-fuelled vessels, these systems incorporate subsystems not typically found on those conventionally fuelled. LNG engines also have unique operating characteristics that must be considered when designing a vessel’s propulsion system. Developing these systems, however, does not present any insurmountable technological barriers.

There are two major propulsion options for LNG engines; direct drive and electric drive. With direct drive, the engines drive the propeller shaft directly or through a gearbox, depending on the engine speed. Direct drive can usually offer better fuel efficiency than electric drive when the engine is operating at partial power.

Electric drive systems consist of engine-powered generators connected to electric motors, which drive propellers, thrusters, or a combination of the two. Their advantages include increased flexibility in optimizing engine load. They also permit greater design flexibility because the engines do not need to be mechanically connected to the propulsion equipment. Electric propulsion requires fairly sophisticated power management systems and these systems are readily available for LNG vessels. Figure 7 shows the Seaspan LNG ferry which uses LNG propulsion.

### Safety Technologies

The technologies for marine LNG use are not unique. However, their application in LNG-fuelled vessels and support systems is still relatively new. International regulations have been developed for the use of LNG, but national regulatory regimes are still under development. At this time, guidelines, codes and standards for equipment, LNG systems, and installations are all available and are being applied to new projects in generally similar ways. All LNG-fuelled vessels have placed great emphasis on safety in both design and operation, and their safety record is excellent.

### Future Developments

Recent technological developments related to liquefaction technologies are significant and are leading to the emergence of small-scale, efficient liquefaction plants with a reduced capital cost and an ability to be located close to markets.

The cost of the on-board components of LNG remain a barrier to adoption. Most of the available LNG engines are more expensive than their non-LNG equivalents, partly because of their greater complexity and their relatively small production runs.

On the standards and regulations side there are a large and growing number of standards, regulations, guidelines and other materials that can be used to implement LNG marine fuel projects. Some key aspects remain in draft form in Canada, the U.S. and internationally.

The biggest challenge for LNG as a marine fuel is system integration. While the components exist, there is little experience in the marine sector in pulling them together. As global demand for LNG vessels increases, it can be expected that this systems integration issue will be addressed.

### Conclusions

There are technologies available for all aspects of a marine gas (LNG and CNG) installation. While no gaps in the availability of technology have been found, there are several areas in which new products are under development to improve effectiveness and reduce cost. The biggest barriers for the use of natural gas as a marine fuel are its unfamiliarity, and the need to create some or all aspects of the fuel supply chain on Canada’s Great Lakes and East Coast as well as in other areas of the world.
This chapter presents the outcome of the economic aspects of adopting natural gas as a marine fuel, focusing on the owner/operator’s investment decision-making.

There is a general appreciation in the marine industry that, in comparison with other fuels, natural gas is an option that can facilitate compliance with current and future emission regulations, and may also offer economic benefits. To determine the potential economic benefits, a model was developed and nine case studies of vessels operating within or visiting Canada’s Great Lakes and East Coast were analyzed. In addition to the individual case studies, three fleet wide scenarios were forecasted to provide an indication of possible natural gas demand for fleets in these jurisdictions in future years.

Note that the results presented are the product of data and assumptions provided by the study participants. Actual economic benefits will depend on the in-service operating profile of a vessel, its engine performance and the delivered cost of natural gas.

Chapter findings confirm that the adoption of natural gas can be economically attractive for owners and operators, depending on the nature of their operations and the price of natural gas and other fuels. Realistic potential adoption rate scenarios indicate that marine use of natural gas could lead to significant demand creation for natural gas on Canada’s Great Lakes and East Coast within the next decade.
Model Methodology

The model uses a range of variables affecting the economic feasibility of natural gas. These variables cover both investment and life cycle operational costs, as described below.

2.1 Ship Side Investment

On the ship side, the model analyzes capital investments for a new build or for converting an existing vessel to natural gas, which involves changes to the engines, auxiliary systems and fuel supply systems. The major variables are as follows:

› that the type of propulsion system used can impact costs, for example diesel electric installations are more expensive than mechanical drive;
› that fuel systems must be redundant, for instance pure LNG engine installations require redundancy in the fuel supply, covering the tanks and other equipment;
› that early LNG and CNG adopters will need to bear increased costs for regulatory approval;
› that the operator may have additional costs for shore side bunker infrastructure; and
› that labour rates for the installation of both conversions and new builds may result in additional costs.

2.1.2 Life Cycle Operational Costs

The model includes a life cycle analysis to determine the operating cost differentials of the various ship types when using fuel oils versus using LNG or CNG. The variables include:

› the cost of fuel;
› fuel price inflation rates;
› diesel and LNG engine fuel consumption and performance information;
› load conditions;
› vessel specifics such as power requirements, route particulars, endurance requirements, expected vessel life, and bunkering profile; and
› crew training costs.

Fuel pricing is an important factor in determining economic payback. The price for natural gas in Canada is one of the lowest in the world. By comparison, the price for marine fuel oil is one of the highest globally. The low pricing for natural gas applies even when the additional costs of natural gas liquefaction, compression and distribution to generate LNG are taken into account, as is explored in detail in chapter 4. As the tax regimes for fuels in different regions is quite complex, the costing was completed without taxes.

Figure 8 shows the price differential of the different fuel types included in the analyses. Due to the current instability of energy prices, the energy costs used in Phase 1 “Liquefied Natural Gas: A Marine Fuel for Canada’s West Coast” study were also used in the analysis for comparison. Note as Phase 1 studied only one region (British Columbia) taxes were included in the costing for domestic operations.

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Phase 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULSD</td>
<td>$787.00/MT</td>
<td>$1,190.00/MT</td>
</tr>
<tr>
<td>MGO</td>
<td>$679.37/MT</td>
<td>$1,080.00/MT</td>
</tr>
<tr>
<td>IFO 380</td>
<td>$373.00/MT</td>
<td>$600.00/MT</td>
</tr>
<tr>
<td>LNG Domestic – Avg</td>
<td>$517.50/MT</td>
<td>$649.50/MT</td>
</tr>
<tr>
<td>LNG – Deep Sea</td>
<td>$457.24/MT</td>
<td>$765.00/MT</td>
</tr>
<tr>
<td>CNG</td>
<td>$175.74/MT</td>
<td>$217.44/MT</td>
</tr>
</tbody>
</table>

Figure 8: Fuel Prices by Type
It should be noted that the cost of CNG was calculated using the equivalent commodity, delivery and tax cost as LNG without the liquefaction cost component. Compression of CNG will incur a smaller cost, which has been set nominally at $1 per GJ.

### 2.1.3 Exclusions From The Model

The model does not account for variables including the cost of capital, and others such as:

- the costs associated with reduced cargo capacity resulting from the increased space required by LNG systems;
- the costs associated with taking a vessel out of service while converting to LNG;
- project-specific variables affecting capital costs; and
- additional operating costs caused by limited LNG bunkering facilities.

### Emissions Control Area

A key consideration in the current model is the amount of time a ship spends in an Emission Control Area (ECA). ECAs are described in detail in Chapter 3. Most deep sea ships operate on inexpensive heavy fuel. In the North American and other ECAs, ships must meet strict emission standards, requiring them to use expensive low-sulphur distillate fuels, or to install exhaust treatment systems. LNG offers an alternative. In 2020, new global sulphur limits for marine fuels will come into effect. While the cost implications are still unclear, this is likely to help drive LNG adoption.

### Case Study Vessels

Nine vessel case studies were examined with economic modelling used to compare the costs of LNG/CNG operation to the use of traditional fuel oils.

#### 2.2.1 Case Study Vessel Types

The nine cases cover a range of vessel types used on the Great Lakes and East Coast, and include a mix of new-builds and conversions, as shown in Figure 9. The natural gas-fuelled engine types shown in the table have been selected to be representative of the vessel type and the nature of the operation. Fuel consumption data for both the natural gas-fuelled engines and the alternative diesels uses data provided by engine suppliers.

<table>
<thead>
<tr>
<th>Vessel</th>
<th>% ECA</th>
<th>Power (kW)</th>
<th>New build / Conversion</th>
<th>NG Engine Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Lakes Self-Unloader</td>
<td>100</td>
<td>8,750</td>
<td>New build</td>
<td>Slow Speed Dual-Fuel</td>
</tr>
<tr>
<td>Offshore Supply Vessel</td>
<td>100</td>
<td>12,000</td>
<td>New build</td>
<td>High Speed SI Gas</td>
</tr>
<tr>
<td>Handysize Bulk Carrier</td>
<td>72</td>
<td>10,000</td>
<td>New build</td>
<td>Slow Speed Dual-Fuel</td>
</tr>
<tr>
<td>Coastal Tanker</td>
<td>100</td>
<td>7,000</td>
<td>New build</td>
<td>Medium Speed Dual-Fuel</td>
</tr>
<tr>
<td>Toronto Island Ferry</td>
<td>100</td>
<td>500</td>
<td>New build</td>
<td>High Speed SI Gas</td>
</tr>
<tr>
<td>Vehicle Ferry</td>
<td>100</td>
<td>20,880</td>
<td>New build</td>
<td>Medium Speed Dual-Fuel</td>
</tr>
<tr>
<td>Shuttle Tanker</td>
<td>100</td>
<td>18,000</td>
<td>Conversion</td>
<td>Slow Speed Dual-Fuel</td>
</tr>
<tr>
<td>Great Lakes Self-Unloader</td>
<td>100</td>
<td>6,700</td>
<td>Conversion</td>
<td>Slow Speed Dual-Fuel</td>
</tr>
<tr>
<td>2,200 TEU Container Ship</td>
<td>65</td>
<td>12,250</td>
<td>Conversion</td>
<td>Slow Speed Dual-Fuel</td>
</tr>
</tbody>
</table>
The case study involving the Toronto Island Ferry is the only case study that involves the use of CNG with a high speed pure natural gas engine. This is given that the ferry operates 15 hours per day year round with each transit taking 15 minutes and the vessel operates entirely within the ECA zone. This use pattern makes it suitable for a CNG application.

### Life Cycle Analysis Results

The following is an overview of the capital costs of LNG propulsion systems, together with the payback period for LNG use, over the life of the case study vessels.

#### 2.3.1 Propulsions System Capital Costs

An analysis of the propulsion system capital costs indicates that, in all cases, these costs are greater for LNG propulsion systems than for conventional systems. For conversions, the results reflect the assumption that there would be no additional capital costs if the vessel continued to operate without the conversion.

Figure 10 details the fuel oil propulsion system costs, LNG propulsion system costs, and the differential for all nine case study vessels.

#### 2.3.2 Payback Period

Economic analysis of each case study established the payback period over which the initial investment in the LNG system can be repaid by savings in fuel cost.

For deep sea (Trans-Atlantic) vessels, it has been assumed that bunkering will occur at both ends of the route, and a representative European LNG price has been used for 50 per cent of the fuel cost. The European LNG price has been indexed based on the cost of Brent crude, this oil-based pricing has historically been the basis for European LNG pricing. It was also assumed that these ships will use fuel switching from Intermediate Fuel Oil (IFO) to diesel to comply with requirements when they enter an ECA. The alternative of using scrubbers has not been analyzed, as this is itself a complex subject.

Figure 11 provides detailed results on a case-by-case basis with two LNG pricing options factored in for the analyses; using Phase 1 (2013) and current (2016) cost data. In general, the greater the fuel consumption and the less the additional capital costs, the more feasible a project becomes, particularly for vessels that spend most of their time in the ECA.

The economic modelling showed that there was a payback on initial capital investment based on fuel savings, although the payback timing varied considerably depending on the application and assumptions. At the low end of the spectrum with a payback of approximately four years or less for six of the cases modelled – the Great Lakes Self Unloader, the Offshore Supply Vessel, the Coastal Tanker, the
Toronto Island Ferry, the Vehicle Ferry, and the conversion of a Shuttle Tanker. At the high end of the spectrum with paybacks in the nine to twelve year range were the Handysize Bulk Carrier, and the conversion of a 2,200 TEU Container Ship.

› Fuel Cost Effects on the Payback Period

A number of payback period sensitivity analyses were completed in order to determine what key variables influence the viability of LNG as a marine fuel.

Figure 12 shows the payback period sensitivity to LNG prices ranging from $8 - $20/GJ, against a fixed cost of $18.39/GJ for ULSD for eight of the cases. The Toronto Island Ferry was not included as it will use CNG instead of LNG.

Figure 12: Payback Period Sensitivity to LNG Price

› ECA Effects on the Payback Period

Figure 13 analyzes the impact of the percentage of time a vessel spends in an ECA on the payback period. It was determined that the time spent in an ECA directly affects the payback period for an LNG system when fuel switching is used for emission compliance.

Figure 13: Payback Period Sensitivity to LNG Price

2.4 Fleet Analysis and LNG Demand

Low, medium and high adoption rates for LNG were considered in this part of the modelling. The medium adoption rate was calculated after reviewing several forecasts, including from Lloyd’s Register, Germanischer Lloyd, and the IMO Feasibility Study on LNG Fuelled Short Sea and Coastal Shipping in the Wider Caribbean Region. The medium adoption rate assumes one LNG vessel in 2016,
2.5 Conclusions

An economic model has been developed and used to analyze the economics of LNG propulsion systems for eight different vessels and CNG propulsion for one vessel. The model incorporates the capital costs associated with natural gas propulsion plants, the vessel operational profiles, and the vessel fuel consumption. A variety of engine types are considered in the model including medium speed dual-fuel engines, spark ignited gas engines, and slow speed dual-fuel engines. The model indicates the variables that have the greatest effect on the payback period and the life cycle costs of using LNG as a marine fuel alternative. They are:

› the price differential between fuel oils and LNG/CNG;
› the percentage of time a vessel spends in an ECA; and
› the capital costs for LNG/CNG systems.

The model shows that:

› LNG use can offer significant economic benefits to the owners and operators of vessels, especially coastal vessels;
› Of the nine case study vessels considered, six had a payback on initial investment of approximately four years or less. The high end of the spectrum had paybacks in the nine to twelve year range.
› Realistic adoption rate scenarios indicate that marine use of LNG could lead to significant demand creation for LNG on the Great Lakes and East Coast within the next decade.
› Under a “medium” adoption scenario, there would be 148 LNG vessels operating on the Great Lakes and East Coast by 2025, requiring 623,000 metric tonnes of LNG annually.
This chapter examines the environmental aspects of adopting natural gas as a marine fuel and the potential reductions in sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM) as well as greenhouse gas (GHG) emissions. The work evaluates not only emissions generated at the ship level but also the lifecycle emissions from well to propeller. Also included are comparisons of natural gas marine propulsion systems with other alternatives for meeting future regulatory requirements. Accident scenarios are also reviewed, highlighting the differences in potential impacts from the liquid fuels now in general use compared to the impacts with LNG use as a marine fuel.

Note that the results presented in this chapter are the product of data and assumptions provided by the study participants. Actual environmental benefits will depend on the in-service operating profile of a vessel, its engine performance and the nature of the supply chain providing the natural gas.
3.1 Marine Fuels and Propulsion Options

Natural gas is a clean burning energy choice. Once it is refined to pipeline standards, using natural gas creates few by-products except for carbon dioxide (CO\textsubscript{2}), NO\textsubscript{x} and water. In contrast, oil-fuelled engines produce many gaseous emissions and particulate matter (PM), which have undesirable effects on human health and the environment. The environmental benefits of using natural gas over other fuels include reductions in CO\textsubscript{2}, SO\textsubscript{x}, NO\textsubscript{x}, and PM.

Most deep-sea shipping, and a significant percentage of coastal shipping, has traditionally operated on heavy fuel oil (HFO). Marine propulsion has, therefore, been characterized by high emissions since the HFO, often referred to as “bunker” or “residual” fuel oil, burned by these large ocean-going vessels is usually the residue of other refining processes and contains even higher concentrations of harmful compounds than the original crude oil.

The combustion processes in marine diesel engines also create environmental challenges. These engines are very fuel-efficient, but the diesel cycle on which most marine engines operate requires high combustion temperatures. This promotes the formation and emission of NO\textsubscript{x}, which forms acidic precipitates that can damage natural ecosystems. By comparison, Natural gas engines have lower combustion temperatures, and consequently emit less NO\textsubscript{x}.

In recent years, national and international standards have focused more attention on the contribution of marine transportation to local and global levels of pollution. As a result, new standards are coming into effect, which lead to fundamental changes in both marine fuels and marine engines. Natural gas offers a means of reducing emissions to meet current and pending environmental regulations from the International Maritime Organization (IMO) and related domestic legislation. Regulatory changes are a major factor that could drive the use of LNG as a marine fuel. In fact, the GHG emissions benefit of LNG is recognized in IMO’s Energy Efficiency Design Index (EEDI) which is being applied progressively to reduce overall GHG emissions from the global shipping industry. Using LNG fuel will help ships to meet future EEDI requirements.

3.1.1 Oils, Distillates and LNG

Marine transport has traditionally used heavy oils and marine distillates as fuels. LNG use is currently much less common.

› Heavy Fuel Oils

The most common fuel for marine operations has traditionally been HFO. HFO is considered a residual product since it remains after the more valuable components of crude oil have been extracted through refining. It contains a wide range of contaminants such as ash, sulphur and sodium which makes its post-combustion exhaust a danger to the environment and to human health.

› Marine Distillates

These are marine diesel oil (MDO) and marine gas oil (MGO). While MDO has traditionally contained lower concentrations of sulphur than HFO, permissible sulphur content levels have remained quite high until the recent advent of new national and international standards. The new emissions standards have imposed a limit of 0.10 per cent by weight (1,000 parts per million (ppm)) on the sulphur content of fuels within the North American ECA as of January 2015.

For domestic vessels, as of June 2012, the fuel used in marine applications by small and medium-sized vessels must be ultra-low sulphur diesel (ULSD). Larger engines may use fuels compliant with international regulations such as sulphur content compliant MGOs. Compared with MDO, MGO and ULSD are more highly refined products, with lower viscosities and with various additives to improve the combustion processes. Figure 15 shows the sulphur content of Great Lakes and East Coast LNG and common marine fuel oils.

<table>
<thead>
<tr>
<th></th>
<th>LNG – East Coast Supply</th>
<th>ULSD</th>
<th>DMA (MGO)</th>
<th>RMG 180 (HFO)</th>
<th>RMG 380 (HFO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur content (max) % m/m</td>
<td>0.0</td>
<td>0.0015</td>
<td>0.1</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Figure 15: Sulphur Content: Great Lakes and East Coast LNG Compared to ISO 8217 Marine Fuel Limits
Natural Gas

The natural gas used to make CNG and LNG in North America has a relatively narrow range of constituents and properties, making it a cleaner-burning fuel compared to oil-based fuels. Pre-treatment of natural gas eliminates CO$_2$, H$_2$S, water, odorant, and mercury from the natural gas.

3.1.2 Propulsion Systems

The following covers the major marine engine types and their characteristics.

Diesels

Diesel engines are the mainstay of the marine propulsion market. Modern diesel engines are sophisticated machines and incorporate a range of auxiliary equipment to boost power and efficiency. Slow speed engines will work with any grade of diesel fuel, as will most medium speed engines. High speed engines tend to require the more refined diesel. The high temperatures and pressures in modern diesels mean that the exhaust streams contain oxide forms of fuel and contaminants, most notably SOx. The combustion process also generates NOx from the nitrogen in the air which are also considered pollutants. Changes in fuel standards and engine emission regulations have typically focused on reducing SOx, NOx and PM emissions.

Gas Turbines

Gas turbines can run on natural gas fuel, but the marine industry normally uses some grade of distillate. Gas turbines are used predominantly in military vessels, where the need for high power and rapid response outweighs their higher cost and higher fuel consumption. Some cruise ships, icebreakers and other commercial vessels have been designed with gas turbine plants, but most were converted to diesel or removed from service when the price of fuel increased over the last decade.

Steam

The last major market sector for steam reciprocating engines was with LNG tankers. These propulsion plants were able to use LNG boil-off gas from the cargo in the boilers. Even in this sector, diesels or dual-fuel gas engines are now the most common type of prime mover due to their significant advantages in efficiency. With shrinking market shares, steam plants are increasingly expensive to buy, operate and maintain.

Natural Gas Engines

As mentioned in chapter 1, marine natural gas engines use three basic technologies: spark-ignition, pure gas-dual fuel with diesel pilot, and direct injection with diesel pilot. Most current natural gas-fuelled marine engines are dual fuel, medium-speed engines.

Emissions

The main emissions from marine engines are GHGs, SOx, NOx and PM.

Greenhouse Gases (CO$_2$, methane)

Two of the main GHGs – carbon dioxide (CO$_2$) and methane – are contained in marine engine exhaust. CO$_2$ emissions are related to the carbon content of the fuel and the amount of fuel consumed. They can be reduced by creating more efficient engines, transitioning to fuels containing less carbon per unit of energy or by reducing energy demand such as by reducing the speed, or by improving ship hull forms.

Regardless of the type of engine or its operating speed, using natural gas rather than oil reduces the amount of CO$_2$ produced by the engine. This is a result of the estimated 25-30 per cent lower carbon content of natural gas compared with oil-based fuels.

While natural gas produces less CO$_2$ per unit of energy than fuel oils, this potential benefit...
can be compromised by “methane slip”. Natural gas is primarily methane. As LNG-fuelled engines can release small amounts of unburned methane, for LNG to offer a net environmental benefit in terms of GHG reduction, methane slip must be minimized. Manufacturers believe there is the potential to reduce methane emissions by up to 80 per cent as a result of enhanced engine design, integration of methane-related controls and the use of other innovative control technology.

› **SOx**

SOx engine emissions vary with the sulphur content of the fuel. There is very little sulphur in LNG, so it generates very little SOx when compared with oil-based fuels. There are next to no SOx emissions from spark-ignited gas engines operating on the Otto cycle, while SOx emissions from dual fuel engines come only from small amounts of pilot fuel.

› **NOx**

NOx engine emissions vary with the combustion temperature. The higher the cylinder temperature during combustion, the more NOx is produced. Diesel engines, operating at higher temperatures regardless of the fuel type, have higher NOx emissions than equivalent Otto cycle engines.

› **PM**

PM result from the incomplete combustion of fuels and include carbon particles, sulphates and nitrate aerosols. Fuels with a higher Sulphur content generate more PM because some of the fuel converts to sulphates in the exhaust. Figure 16 below shows the PM of common marine fuel oils and LNG.

<table>
<thead>
<tr>
<th>PM (g/kWh)</th>
<th>LNG</th>
<th>ULSD 0.0015% S</th>
<th>DMA (MGO) 0.1% S</th>
<th>RMG 180 &amp; 380 (HFO) 3.5% S</th>
<th>RMG 380 (HFO)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.04</td>
<td>0.25</td>
<td>0.30</td>
<td>1.88</td>
<td>3.5</td>
</tr>
</tbody>
</table>

**Emissions Compliance**

Ship emissions are controlled under the International Convention for Prevention of Pollution from Ships (MARPOL), with air emissions forming Annex VI. This Annex is applying progressive reductions in the amount of SOx and NOx that can be accepted globally. It also allows for the creation of Emission Control Areas (ECA), in which reductions have to be deeper and faster. Figure 17 shows the North American ECA, which took effect in 2012. In 2014 a U.S. Caribbean ECA also came into effect, and a North Sea and Baltic ECA cover the other end of many shipping routes from Eastern Canada. In 2020 more stringent sulphur limits will come into effect globally, but will still be above those for ECAs. All ECAs limit SOx emissions, but the American ECAs are currently the only ones to also address NOx. IMO “Tier III” NOx limits apply only to new ships constructed after January 1, 2016 and operating in these ECAs.

Another recent development under MARPOL is the Energy Efficiency Design Index (EEDI). The objective of the EEDI is to reduce the environmental impacts of shipping through the adoption of enhanced energy efficiency measures that reduce GHG emissions. The EEDI is now mandatory for new builds of various ship types including bulk carriers, tankers and container ships and is intended to be a requirement for a wider range of ships in the future.

Meeting EEDI targets will be challenging for many vessel operators. Switching to cleaner crude oil-based fuels will make it more difficult to meet EEDI targets as distillate fuels have higher...
calculated carbon values. The use of LNG rather than crude oil-based fuels simplifies the compliance challenge as LNG has lower carbon factors than alternatives.

### Compliance Options

The major options for complying with MARPOL Annex VI include strategies to reduce emissions, ship design improvements and legislative alternatives. The opportunities are described below.

- With respect to emission reduction strategies, the alternatives include fuel switching where vessels use less expensive, higher emission residual fuels outside of ECAs and switch to cleaner distillates or natural gas inside ECAs. In either case, additional space is needed for the second set of fuel tanks and related fuel supply systems. Another option is SOx content of the exhaust being reduced by using scrubbers. These systems also require space aboard the ship and increased power requirements.
- Ship design improvements and operational measures, such as slow steaming, can reduce fuel consumption and as result reduce emissions.
- Legislative measures may permit fleet averaging which considers the total inventory of emitting vessels under one owner, rather than the emissions of individual vessels.

### Accidental Pollution

If LNG is spilled on water, it remains on the surface and immediately begins to vaporize and disperse into the air. If an ignition source is available, the edge of the vapour cloud could ignite, and a pool fire or an explosion could occur. However, without the right ratio of air to gas, LNG will not burn. As the gas itself is not toxic, a spill poses little direct risk to marine or airborne organisms unless it is present in high enough concentrations, and for long enough, to cause asphyxiation. No post-spill clean-up is needed. In general, while accidental releases of LNG are highly undesirable and do represent a safety risk, from an environmental standpoint, they are far more benign than oil spills. Likewise CNG if spilled, will disperse into the air.

### Emissions Benefits Modelling: Case Studies

Two separate analyses were undertaken to determine the emissions benefits associated with natural gas use compared with oil-based fuels. The first analysis was carried out on a full "well-to-vessel" basis using the Government of Canada’s GHGenius model. This analysis compared the emissions impact of LNG/CNG use against that of conventional marine fuel (marine diesel and ULSD) for four sample vessels, with three engine technology options and three LNG supply scenarios.

#### 3.6.1 Lifecycle GHG Emission Reductions

The potential lifecycle emissions benefit of using LNG as a marine fuel, based on modelling nine vessel cases, ranged from 22-32 per cent CO2-equivalent. Figure 18 shows the potential reduction of GHG emissions for the cases modeled, taking into account energy inputs for all aspects of natural gas production, liquefaction and combustion.

As mentioned earlier, while natural gas can provide emissions benefits which support regulatory compliance, “methane slip” is the term used to describe the release of methane in the exhaust due to incomplete combustion. The amount of methane slip depends on many factors, and manufacturers are working to improve performance. Medium speed Otto cycle engines are more prone to methane slip compared to Diesel cycle engines. In all cases, manufacturers are working to improve this performance. Figure 18 incorporates current methane slip engine data.
3.6.2 SOx Emission Reductions

The amount of SOx produced is a direct function of the sulphur content of the fuel. There is very little sulphur in natural gas or in LNG. As a result, SOx emissions are significantly below those from vessels consuming fuel oils even at the lower sulphur levels now mandated by IMO. Figure 19 shows the reduction in SOx emissions for four of the cases modeled.

3.6.3 NOx Emission Reductions

The reduction in NOx emissions depends on the type of natural gas engine used. Current natural gas fuelled medium speed engines operate on the Otto combustion cycle, resulting in significant NOx reduction and compliance with IMO Tier III requirements. By contrast, the direct injection slow speed engine used in the analysis operates on the Diesel cycle and the reduction in NOx emissions is less pronounced. Figure 20 shows the reduction in NOx emissions for four of the cases modeled. Engines that do not comply directly with NOx limits will need to utilize supplementary emission control technologies, which are now becoming available for conventionally-fuelled engines.
3.6.4 PM Emission Reductions

PM results from various impurities and incomplete combustion. Most PM emissions are harmful to humans, and there is increasing international focus on reducing them. Switching to natural gas has significant PM benefits. Figure 21 shows the reduction in PM emissions for four of the cases modeled.

![Figure 21: PM Emission Reductions](image)

East Coast Emissions Reduction

Most marine fuel is consumed by deep sea shipping, which can still use relatively high sulphur content fuel oils outside the North American coastal ECA. Until LNG availability, relative cost and emission requirements lead to widespread adoption by the deep sea fleet, the use of natural gas will have modest though positive effects on total emissions. These will, however, be concentrated in the coastal areas where they have the greatest impact on human health and on public perception. Figure 22 shows potential emission reductions, assuming the medium adoption rate for LNG vessels derived in other chapters.

<table>
<thead>
<tr>
<th></th>
<th>Emissions Avoided (tonnes/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2015</td>
</tr>
<tr>
<td>SOx</td>
<td>2,450</td>
</tr>
<tr>
<td>PM</td>
<td>390</td>
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<td>CO₂</td>
<td>81,700</td>
</tr>
<tr>
<td>CO₂-eq</td>
<td>48,100</td>
</tr>
</tbody>
</table>

![Figure 22: Medium Adoption Rate - Fleet Wide Emission Reductions Using LNG](image)
Conclusions

Natural gas is a clean energy option that offers a means of reducing emissions to meet current and pending environmental regulations and this is potentially a major factor which could drive the growth of natural gas use as a marine fuel. Depending on the engine and after-treatment technologies, natural gas use will result in environmental benefits including reduction in:

- Life cycle CO₂ equivalent emissions by 22-32 per cent (based on the hydro-powered LNG source);
- SOx by 99 per cent, nitrogen oxides;
- NOx by 23 per cent or more; and
- PM by 86 per cent or more.

Until natural gas availability, relative cost and emission requirements lead to widespread adoption by the deep sea fleet, natural gas use will have modest though positive effects on total emissions given that the majority of marine fuel is used for deep sea shipping. Natural gas emission reduction benefits can, however, be concentrated in coastal areas where it will most benefit local communities and human health. In addition, the potential for environmental damage due to spills or shipping accidents is much reduced using natural gas compared with marine oils, as natural gas dissipates rapidly rather than leaving oil slicks and residues.
This chapter provides information on infrastructure availability and requirements for the supply and distribution of natural gas for marine applications on the Great Lakes and East Coast.

Canada has long been a producer of natural gas for domestic purposes. Recent advances in drilling technology which allow for the cost effective production of unconventional natural gas have increased supply and reserves available from both Canadian and U.S. sources. In parallel with this change, increased world demand for energy combined with stringent environmental regulations is creating opportunities for non-traditional uses of natural gas in the transportation sector including for marine applications. Potential new marine demand may be supplied from existing infrastructure or may stimulate new investments in natural gas supply and distribution infrastructure. This chapter examines:

› LNG supply and demand on the Great Lakes and East Coast;
› existing and planned natural gas and LNG infrastructure;
› pricing of natural gas in Canada’s Great Lakes and East Coast markets; and
› marine LNG delivery infrastructure options and costs.

With respect to CNG and infrastructure requirements, the use of CNG as a marine transportation fuel requires that natural gas be compressed. This is assumed to take place at the point of use.
4.1 Supply and Demand on the Great Lakes and East Coast

Canada has an abundant supply of natural gas. According to Natural Resources Canada, Canada is the world’s fourth largest producer of natural gas. In 2015, Western Canada and Nova Scotia, on the east coast, contributed 98.6 per cent and 1.3 per cent respectively to Canada’s total natural gas production.

4.1.1 Supply

Nova Scotia currently has two offshore natural gas production facilities located on the Scotian Shelf called the Sable Offshore Energy Project and the Deep Panuke Project that produced 3.5 trillion m$^3$ of natural gas in 2014. With minimal production of natural gas, the Great Lakes and East Coast regions import natural gas from the Western Canadian Sedimentary Basin (WCSB) and the U.S. by way of an extensive pipeline network.

Figure 23 shows the multiple unconventional natural gas deposits onshore in Eastern Canada in Nova Scotia, New Brunswick, and Quebec. In addition, the province of Newfoundland and Labrador has vast natural gas potential with various offshore oil and natural gas projects. While there are no plans for the utilization of natural gas from these fields in the near future, on the potential alone they should all be monitored.

Historically Canada’s Great Lakes and East Coast regions have imported natural gas from Western Canada, but they are turning now to the U.S. and the Marcellus Shale development. As illustrated in Figure 24, the Marcellus field is a major natural gas producer located in the Appalachian states and it is expected that the East Coast will rely heavily on this development in the coming years.

4.1.2 Demand

The traditional customers for natural gas in the downstream sector are the residential, commercial, and industrial sectors as well as the power generation sector. Potential new markets for natural gas in the Great Lakes and East Coast regions are on-road transportation, off-road marine, rail, mining trucks, and export markets.

Although natural gas will play a greater role as a transportation fuel in the future, estimates show it will still constitute only 5 per cent of the global transportation fuel mix by 2040. In the marine and rail sectors this number rises to 10 per cent (Exxon Mobil, 2016). The relatively low cost of natural gas in Canada may, however, mean that adoption rates in the country are higher than any global average. Transportation demand is at its highest in the Great Lakes area. This is a major centre for marine and rail commerce, encompassing 15 large international marine ports and 50 regional marine ports across the U.S. and Canadian shorelines. With this level of demand, once proper infrastructure is in place, natural gas fueling is likely to increase rapidly.
Existing and Planned Infrastructure

The infrastructure required for establishing CNG and LNG as a marine fuel includes pipelines, CNG stations at the point of use, liquefaction plants, bulk storage facilities, and LNG distribution.

4.2.1 Pipeline

Major natural gas transmission pipeline systems connect the East Coast and Great Lakes with Western Canada and the U.S. as shown in Figure 25. The TransCanada Mainline is the principal pipeline coming from the Western Canada Sedimentary Basin east. A number of pipelines connect with the Mainline to service eastern markets.

The Dawn Hub is a natural gas storage facility in southern Ontario well connected to receive natural gas from both Western Canada and the U.S. to service markets in Eastern Canada and the Northeast U.S. This significant connectivity makes the Dawn Hub a major trading point for natural gas in the Great Lakes and East Coast region. With the rise of U.S. production, more natural gas is now coming from the U.S. into the Dawn Hub than historically from Western Canada.

There are pipeline projects proposed throughout the Great Lakes and East Coast region to service domestic markets as well as projects proposed to bring U.S. natural gas from the Marcellus region to Canada.

4.2.2 LNG Production Capacity

There are a number of potential sources of LNG for marine and other transportation demands, including existing domestic facilities, new predominantly export-oriented projects, and supplies from adjacent areas of the United States. Currently there are two LNG production facilities in eastern Canada, Union Gas’ Hagar facility in Ontario and Gaz Metro’s Montreal LNG facility in Quebec. The Hagar facility has a storage capacity of 17,000,103 m$^3$. The Montreal facility has a production capacity of 145,000 m$^3$/year and is being upgraded to increase capacity to 436,000 m$^3$/year to meet its growing demand for LNG for road and maritime transportation markets and power supply in regions remote from the natural gas network. There are currently two more planned small scale liquefaction facilities on Canada’s East Coast. Northeast Midstream in Thorold, Ontario is due to start in 2017 and Stolt LNGaz which is located in Becancour, Quebec will be used to meet domestic needs on the North Shore of Quebec and for export markets in Europe, U.S., Caribbean and South America.

There are currently 26 LNG export facilities that have been proposed for Canada and are at various stages of regulatory and financial approval. All projects must undergo regulatory reviews and final decisions to proceed will depend on approvals and on securing contracts with prospective buyers. The potential to access LNG from any of the proposed export facilities for marine use has yet to be determined.

In addition to the current and proposed facilities on the East Coast of Canada, there are existing small scale plants in the Northeastern United States. Along with these small scale facilities, there are currently two East Coast proposed export facilities with liquefaction capacity in Maryland and Georgia.

4.2.3 Compression Capacity

Compressed natural gas capacity can be provided more easily wherever a source of natural gas is available. Almost all CNG stations are small scale and used for localized transportation demand. These facilities require a natural gas source which is then compressed, stored and dispensed on site. Due to the lower capital cost and demand for CNG in the transportation industry these facilities are spreading on major roadways throughout Canada and the United States.
Natural Gas, LNG and CNG Pricing Forecasts

The growing supply of unconventional natural gas in Canada and the United States (U.S.) mean that North America now has the world's lowest natural gas prices. Many forecasts suggest that the North American cost of natural gas will increase quite gradually over the next several decades based on extensive continental natural gas reserves and probable increases in domestic and export demand. The cost of the natural gas feedstock for producing LNG and CNG is currently approximately $3/GJ and is expected to remain at an attractive level over the time horizon for most marine fuel projects. Figure 26 shows forecast pricing by trading hub out to 2035 with "Dawn Hub" representing Ontario gas price.

![Figure 26: Forecast North American Natural Gas Prices At Various Delivery Hubs](image)

4.3.1 Delivery Infrastructure Development and Costs

In order to be useful as a transportation fuel, gas must either be liquefied (LNG) or compressed (CNG). For LNG in particular, the fuel must then be delivered to a fuel bunkering location. Combining the cost of natural gas, liquefaction and distribution to estimate the price at which LNG could be delivered to a ship provides a fairly wide range of results, depending on the nature of the project and the infrastructure which is assumed to support it.

Liquefaction technologies exist for very small to very large scale plants, and these may be co-located with a bunkering location or at some distance from it. Although, in general, there are economies of scale in liquefaction plants, the price of LNG from export plants may not be as attractive as that from smaller facilities devoted to transportation fuel needs, as all of the export plant production may be committed to overseas clients using different pricing models and long term contracts. For any size of plant, the liquefaction cost has two major components – amortization of the large capital costs of the plant, and the cost of energy to operate the facility.

Supply of LNG to a ship can be direct from the liquefaction plant, or can use trucks, rail and feeder ships with or without a local storage and distribution system at the dockside. An analysis of the capital and operating costs of a variety of alternatives, and their sensitivity to key variables such as level of utilization and transportation distances was completed. Tanker trucks offer a relatively inexpensive delivery method for local supply, particularly in smaller volumes. Feeder ships or barges have high levels of capacity. Feeder ships and rail may both be viable options for delivery of LNG over longer distances.
Figure 27 illustrates the overall price breakdown for two scenarios described in detail in the report. Simply put, the utilization rate influences costs – higher utilization lowers the unit cost of fuel.

Estimated LNG cost structure results have been fed back into this work where the economic benefits for the ship owner have been analyzed using assumed costs for LNG. A “low end” cost of $8/GJ and a “high end” cost of $14/GJ have been used for the bulk of this work, with additional sensitivity studies for costs outside this range.

The use of CNG as a marine transportation fuel requires natural gas to be compressed, which is assumed to take place at the point of use. Analysis of a 1,700 terms per annum (tpa) CNG station at 55 per cent utilization gives a compression cost of $2.74/GJ, and a total CNG cost in the range of $6/GJ. Figure 28, illustrates total compression costs of a 1,700 tpa facility as a function of utilization.
Conclusions

This chapter has examined the existing and planned natural gas infrastructure in the Great Lakes and East Coast areas and both the supply and demand factors that may influence how this develops in the future. It was assessed that:

› natural gas is plentiful throughout Canada and the United States, resulting in low feedstock costs to produce LNG and CNG;

› the Great Lakes and East Coast have limited LNG and CNG production and distribution capacity, but as marine natural gas demand increases, new infrastructure investments will be made;

› the potential to access LNG from export facilities for marine use is yet to be determined; and;

› it should be possible to supply LNG and CNG at attractive prices in comparison with fuel oil alternatives.
The report titled “The Liquefied Natural Gas: A Marine Fuel for Canada’s West Coast” outlined proposed competencies and potential training approaches required for the full range of personnel who are responsible for the safe use of natural gas in marine applications. Since the production of that report, there have been significant developments (domestic and international), notably for seafarers and bunkering personnel, in advance of the implementation of the International Maritime Organization’s (IMO) International Code of Safety for Ships using Gas or Other Low-Flashpoint Fuels (IGF Code) in January 2017.

This chapter provides a summary of these developments, updates previous recommendations for other disciplines where appropriate, and provides information on new sources of support and expertise for organizations planning natural gas projects.
5.1 Human Resource Categories and Required Competencies

Several types of human resources are needed, with various kinds of specialized skills, training and knowledge. These include:

› **Vessel designers**
  The use of natural gas as a marine fuel is becoming more familiar to ship designers as new projects are developed and reported in technical papers and journals. Training courses and seminars have helped to extend knowledge of the design approaches required, and also of the resources available to assist in the work. However, the work from the previous report remains valid and the competency requirements remain unchanged.

› **Seafarers**
  There has been agreement to develop model courses to provide necessary training. Transport Canada has developed draft policies in order to allow pilot projects to proceed on both East and West Coasts. A continuing challenge for early adopters is to acquire sea time on LNG-fuelled ships and hands-on experience with LNG handling during transfer operations, both of which are preferred elements of certification programs. LNG carrier operators, overseas natural gas fuelled vessel operators and equipment suppliers have provided assistance in these areas for a number of Canadian organizations.

› **Certification and inspection authorities**
  Most classification societies have experience in the LNG carrier industry and are rapidly building the capability to address natural gas fuel projects.

› **Shipyard personnel**
  Training is required to ensure that shipyard workers are aware of the hazards of CNG/LNG and of the requirements for constructing or repairing a CNG/LNG-fuelled vessel.

› **Bunkering personnel**
  Safely bunkering an LNG-fuelled vessel will require skills and knowledge that are not normally provided by the training programs for bunkering fuel oils. The IMO has extensive training requirements for LNG bunker vessels, but currently no LNG carrier training is available in Canada. LNG training facilities do exist throughout the world and these training centres could potentially provide training to Canadian seafarers in accordance with the regulations. LNG tanker trucks already deliver bulk LNG to consumers in Quebec and Ontario and the truck operators have been trained by a certified trainer for the LNG bunkering.

› **Emergency responders**
  Firefighters and other responders will need specialized training to ensure that they can respond safely and effectively to emergencies involving LNG vessels or bunkering facilities.

› **Original Equipment Manufacturers personnel (OEMs)**
  LNG-fuelled vessels require engines, tanks, and fuel distribution systems that differ from those used on oil-fuelled ships. OEMs must provide employees with training that deals with these differences and that also meets the health and safety requirements mandated by regulators. Such training is currently done in-house by the OEMs.

It is worth noting that several Canadian early adopters and other stakeholders have implemented wide-ranging training programs that incorporate the IMO’s principles and which address their own operational requirements. The model being used by BC Ferries is probably the most comprehensive approach developed to date in Canada.
5.2 Sources of Knowledge

As the use of LNG-fuelled vessels increases, the experience of existing LNG industries will be invaluable to the marine sector. Listed below are several useful sources of information.

› **LNG carrier industry**
  
  The mandate of the Society of International Gas Tanker and Terminal Operations (SIGTTO) is to develop criteria for best practices and acceptable standards. SIGTTO recently announced the launch of the Society for Gas as a Marine Fuel, which will encourage the safe operation of vessels using LNG and help develop guidance for best practices among its members.

› **Operators of LNG-fuelled vessels**
  
  A number of vessel operators, primarily in northern Europe, have decades of experience with LNG-fuelled vessels such as ferries, recognized organizations and patrol vessels. These operators may be a valuable source of knowledge for East Coast ship operators who are considering their first use of LNG.

› **Classification societies**
  
  All major classification societies have decades of experience in surveying LNG carriers. They have developed rules for these carriers and most have developed guidelines for LNG-fuelled vessels as well. Several societies offer training for operators and designers of both types of ships.

› **Shore-based LNG facility operators**
  
  These operators have decades of experience in handling and processing LNG. Furthermore, they possess intimate knowledge of the skills and training required to ensure safe and reliable operations.

› **OEMs**
  
  OEMs have training programs for their own personnel and provide training to operators of ships that use their equipment.

5.3 Training Sources

Transport Canada recognizes a number of Canadian colleges and other institutions which provide training for mariners including:

› Canadian Coast Guard College;
› L’Institute maritime du Quebec (IMQ);
› Georgian College, Owen Sound Campus;
› Marine Institute in St. John’s, NL;
› Nova Scotia Community College, 2003;
› British Columbia Institute of Technology (BCIT) Marine Campus;
› Holland College Marine Centre of PEI; and
› Camosun College.

While there is no IMO or Transport Canada approved course for natural gas competency, IMQ in Rimouski has worked with STQ to develop training programs for the crews of its LNG-fuelled vessels in line with IMO’s competency requirements and STQ’s supplementary needs.

As well, several other organizations are working to develop courses that meet the IMO requirements.
5.4 Training Costs

Estimated costs for training at three levels were developed for the West Coast LNG study and have been updated for this study. The two higher levels are similar in scope to the “basic” and “advanced” levels in the current IMO approach. Figure 29 below provides the estimated cost per student and hours of training for each level. These costs, which are relatively small considering the full costs of adopting natural gas for marine fueling, do not include any costs for OEM training.

<table>
<thead>
<tr>
<th>Training Course</th>
<th>Estimated Hours</th>
<th>Price Per Student¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level A (familiarization)</td>
<td>30</td>
<td>$650 - $990</td>
</tr>
<tr>
<td>Level B (basic)</td>
<td>90</td>
<td>$1,950 - $2,970</td>
</tr>
<tr>
<td>Level C (advanced)</td>
<td>150</td>
<td>$3,350 - $4,950</td>
</tr>
</tbody>
</table>

Figure 29: Estimated Training Costs

5.5 Conclusions

Addressing human resources remains a crucial need for safely operating LNG-fuelled vessels. Operations on these ships will differ from those of traditionally powered vessels in several important respects, including vessel layout, fuel properties, fuel handling requirements, and emergency response. In addition to seafarers, a range of other stakeholders require training. This training is a relatively small component of the overall cost differential in moving from a conventionally-fuelled vessel to one that uses natural gas.

It is vital to continue to leverage the lessons learned from the existing LNG industry to ensure that LNG’s safety record is maintained.
This chapter defines proposed changes to Canada’s regulatory framework in order to accommodate the use of natural gas as a marine fuel. The recommended actions will support marine natural gas projects in Canada while ensuring safety, reducing risk and guiding the work of designers, suppliers and operators. The recommendations are related to:

› ongoing dialogue with Canadian stakeholders;
› vessel design and construction;
› operations in Canadian waterways and ports; and
› bunkering and terminal facilities.
Approach for Canada

Since the production of the report “Liquefied Natural Gas: A Marine Fuel for Canada’s West Coast”, the international regulatory framework for the use of natural gas as a marine fuel is becoming clearer. However, it is also clear that the international framework will leave significant issues to the discretion of national administrations such as Transport Canada. This chapter discusses these and other issues of interest to regulators.

The International Regulatory Framework

At the international level, interest in LNG as a marine fuel has developed more quickly than has a regulatory framework to govern it. Nonetheless, a review of the literature reveals a substantial body of existing regulations and guidelines related to LNG-fuelled shipping. Sources include the following:

6.2.1 The International Maritime Organization (IMO)

The IMO is a specialized United Nations agency responsible for the safety and security of shipping and for the prevention of marine pollution by ships. The IMO’s International Convention for the Safety of Life at Sea (SOLAS) is the most important of all treaties dealing with maritime safety. It references many other documents, such as the codes described in this section. The domestic maritime regulations of many nations reflect the terms and provisions of SOLAS. The main IMO pollution convention is the previously described MARPOL, covering oils, chemicals, packaged goods, sewage and garbage, as well as air pollution. Other codes and regulations include:

- *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (IGC Code). The volume of liquefied gases transported by ship increased rapidly in the 1980s, and the IMO introduced the IGC Code to regulate such carriers. Its purpose is to minimize the potential risks to the vessel and the environment that result from the very low temperatures and high pressures involved in natural gas transport.

- *International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels* (IGF Code). A key development since the report “Liquefied Natural Gas: A Marine Fuel for Canada’s West Coast” has been the finalization and ratification of this code, which came into effect in January 2017. This will be implemented in Canada under Transport Canada’s Canada Shipping Act, with what are expected to be relatively minor additions and interpretations of the IGF Code, as identified in this report.

- *Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Convention*. The STCW Convention addresses the minimum standards of competence for seafarers. It does not reference gas handling, but an IMO subcommittee is discussing the introduction of qualifications for LNG-fuelled vessel personnel, based on the IGF Code’s personnel requirements for operating LNG fuelled vessels.

- *International Safety Management Code* (ISM Code). The ISM Code establishes safety-management objectives. It requires the entity responsible for operating the vessel to establish and implement a safety management system that will meet these objectives.

6.2.2 ISO Guidelines

ISO/TC 18683, Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships, is a significant ISO document. Although not yet an international standard, these draft guidelines provide guidance on bunkering facilities, vessel/facility interfaces, procedures for connection and disconnection, emergency shutdown and bunkering process control.

The ISO has other technical standards relevant to LNG. Many can be applied to the systems installed on LNG-fuelled vessels and to the systems supplying LNG to such vessels.

6.2.3 Classification Societies

Classification Societies are non-government organizations that set and maintain technical standards for the design, construction and operation of ships. They develop their own rules and adopt,
adapt, and apply international standards (primarily IMO ship standards). Many classification societies have modified their rules to cover LNG-fuelled vessels.

National Regulatory Frameworks

Canada and several other nations have developed regulations and codes that, although not designed specifically to govern the use of LNG as a marine fuel, can provide a basis for regulatory development. These include:

6.3.1 Canada

The *Canada Shipping Act, 2001* is administered by Transport Canada and applies to all Canadian flagged vessels and all vessels in Canadian waters, except those belonging to the Canadian Forces or to foreign governments. While Transport Canada does not currently have specific rules and codes for natural gas fuelled vessels, it has a number of regulations that could provide a basis for developing them. These include:

- Marine machinery regulations that deal with all aspects of fuel oil systems for fixed installations. These regulations currently do not allow the use of natural gas as a fuel for Canadian-registered ships either domestically or abroad.
- Marine personnel regulations that are based on the current IMO and International Labour Organization standards. These regulations currently do not specifically address competency and training on vessels using natural gas.
- The TP 743E TERMPOL Code that includes deals with the handling of bulk shipments of LNG, liquefied petroleum gas and chemicals.
- Marine transportation security regulations that came into force in 2004 and provide a framework for detecting security threats and preventing incidents that could affect marine vessels and their facilities.

Over the last two years, Transport Canada has developed several draft policy documents and guidance and has also made a number of decisions related to natural gas-fuelled vessels. This includes pending policy that will require vessels to follow international standards and codes including the IMO Guidelines, the IGF Code and other Canadian draft supplementary requirements and guidance on training for engineers onboard vessels using gases or low-flashpoint fuels.

6.3.2 United States

The U.S. Coast Guard (USCG) *Policy Letter CG-521 No. 01-12 Equivalency Determination – Design Criteria for Natural Gas Fuel Systems* establishes criteria for achieving safety levels at least equivalent to those of...
traditional fuel systems. The policy contains modifications and additions in three main areas: the use of United States standards for Type Approval products; fire protection, including monitoring systems; and electrical systems, particularly the designation of hazardous areas.

This policy letter remains in place, but many of its provisions are now in effect replaced by the IGF Code and current classification society rules. A revised policy letter is believed to be under development.

Several other policy letters were developed in 2015 and 2016. These deal with a range of issues including personnel qualifications, safety and security requirements and LNG bunkering operations.

6.3.3 Norway

Norway has been an early adopter of LNG-fuelled ships, particularly ferries, offshore supply vessels and short-sea cargo vessels. Norwegian regulations address ship design, operation, training and bunkering.

6.3.4 European Union

The EU has been promoting the adoption of LNG as a fuel through studies and grants to ports and operators. Several dozen projects have been undertaken, including a number which focused on regulatory reviews and recommendations.

Risk Identification and Assessment

An effective regulatory framework is essential to the success of any project involving the use of LNG as a marine fuel. It is needed to assure all stakeholders of the project's safety, reduce risk for the proponents, and inform and guide the work of designers, suppliers, operators and others throughout the project's life. Phase 1 of this project defined such a framework, by considering the risks associated with the use of natural gas in four main areas:

- Vessel design and construction;
- Operations in coastal waters and waterways;
- Bunkering and terminal facilities; and
- Security (in the sense of protection against malevolent or mischievous actions).

As the IGF Code is partly goal-based, and also requires project-specific risk assessments, other standards organizations and regulators have developed supplementary requirements and guidance. This includes all classification societies currently authorized as Recognized Organizations (ROs) in Canada, the ISO, national administrations such as the USCG and others. Their approach and coverage are outlined in the report.

Bunkering operations on LNG have been highlighted as an area with many potential risks in the IGF Code and elsewhere, and are a second area addressed by many supplementary standards.

Coastal and harbour operations were considered to be an area with significant gaps in the regulatory approach in Canada.

Gaps Identified

The earlier West Coast report identified a number of gaps in how Canada was addressing natural gas fuelled ships and operations. Since then, there have been many developments on both the international and the domestic front.

The earlier report recommended that Canada, wherever possible, use existing international regulatory standards and documents as a basis for domestic policy and regulations. This avoids the need for new research and drafting efforts and also ensures a high level of commonality between Canadian requirements and those adopted elsewhere. The policies currently being followed and proposed by Transport Canada are largely in line with this recommendation. However, there are still a number of gaps for some aspects of the system internationally and in other national rules. Also, where other guidelines and standards are performance based rather than prescriptive, there can remain a need to provide better definition of methodologies that will be used to demonstrate compliance.
Conclusions

The full report provides a series of recommendations as to how the gaps and issues noted above could be addressed, and which key stakeholders should be involved in the process. Suggestions are also made as to how future risk and safety assessments could be made more consistent and transparent, given their importance and relative unfamiliarity in the Canadian marine regulatory system.

With respect to the design and construction of LNG-fuelled ships, it is proposed that:

- Draft policies for vessels using LNG as a fuel are a logical starting point for design and construction requirements, aligned with the IGF Code and offering some supplementary guidance on the process to be followed. The USCG model for barges may offer one partial approach; initiatives in the EU and by other administrations should also be reviewed and considered.

- With respect to the operation of LNG-fuelled ships in Canadian waterways and ports, it is proposed that the federal government and port authorities make use of the TERMPOL Review Process to plan and assess the management of LNG-fuelled ships within the waterways under their jurisdiction and control.

- With respect to bunkering of LNG-fuelled ships, there is a growing body of documentation from IMO, ISO and Internation Association of Classification Societies (IACS) that provides goals and standards for the bunkering of natural gas, and which can inform Canadian policies related to the approval of bunkering operations and operators, and to the review, inspection and audit of the conduct of actual operations. The development of such policies and their enforcement mechanism requires further consideration and consultation.

- It is recommended that this all be done within the framework of the Canada Marine Act, and its provisions regarding Port Traffic Control and “Undertakings within a Port”. However, in order to achieve reasonable consistency between requirements in different ports and the safety levels targeted and achieved, Transport Canada should take a lead in defining expectations and approaches. It should also work with early adopters – both ports and user groups – to develop more detailed methodologies and to clarify responsibilities.

Meanwhile, there are some areas of marine regulation in which Canada continues to expect higher standards of safety than those provided by international requirements, and it can be expected that the same principles will be applied to natural gas-fuelled ships, particularly when defining acceptable levels of risk.

Figure 30 outlines strategies for addressing gaps in the current and planned Canadian regulatory regime for natural gas fuelled vessels.

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**Figure 30: Strategies for Addressing**

- Dialogue with Canadian stakeholders, including operators, ports, and NG suppliers;
- Bilateral discussion with U.S. authorities, given the geographical and regulatory overlaps for some issues (e.g. Great Lakes and Seaway);
- Continued review of international approaches, including administrations/ports with the highest potential for LNG-fuelled routes with Canadian ports; and
- Sharing of approaches with the broader international community, through IMO forums.
The overall challenge for the Great Lakes and East Coast supply chain is to ensure that it can meet projected growth in demand. While this chapter does not recommend specific approaches, it does attempt to identify the challenges and suggest ways of addressing them. Items reviewed in this chapter include:

› natural gas marine fuel projects that have been implemented to date, principally in Europe;
› natural gas marine fuel projects that are now in the process of implementation in Canada, the U.S. and elsewhere;
› current initiatives on the Great Lakes and East Coast;
› demand forecasts for Great Lakes and East Coast marine transportation; and
› supply chain options to meet potential demands.
Implementation

7.1 Existing Projects

A selection of projects are described below with many more described in the full report.

**Norway** can be considered to represent an almost ideal environment for the introduction of LNG as a marine fuel. The country has abundant supplies of gas from offshore fields in the North Sea. Due to its rugged topology, while some major centres are served by a pipeline network, others are supplied with gas through local distribution networks supplied with LNG by sea. Therefore, before considering LNG as a marine fuel, there was already extensive local infrastructure including large and small scale liquefaction plants, feeder LNG carriers, LNG tanker trucks and local storage systems.

The *M/S Viking Grace* was the first large scale passenger ferry in **Finland** to be powered by natural gas. The LNG supply chain supporting this vessel’s operation includes a number of firsts; for example, the **Baltic Sea**’s first LNG hub and the first small scale LNG bunker barge, the SeaGas. In 2016 the Arctech Helsinki Shipyards completed construction on the **Polaris**, the first LNG-powered icebreaker for the Finnish Transport Agency.

The Port of Gothenburg in **Sweden** is an infrastructural hub for shipping, industry and transport in the Nordic region. In the summer of 2015 the Port began bunkering LNG with the expected visits from an LNG-fuelled vessel once or twice a week with growth in the future. To encourage growth the port offers a 30 per cent discount on all tariffs for ships using LNG until December 2018.

The **MT Argonon** is the world’s first LNG-fuelled chemical tanker, which operates on the inland waters of **Europe**. A number of challenges were overcome in the implementation of this vessel, primarily on the regulatory front due to the different regulatory regimes applicable across multiple jurisdictions.

7.2 Ongoing Projects

Ongoing projects are taken to include those for which contracts have been signed that will lead to ships with gas or dual-fuelled engines being supplied with LNG through one or more delivery systems. There are a number of such projects in North America, and others elsewhere in the world – some are described below and more are described in the full report.

**Washington State Ferries (WSF)** is looking to convert six of their vessels with gas-fuelled engines. The basic design for the Issaquah class of ferries has been approved by the USCG and WSF is working on the safety and security plan with DNV, and the local USCG district. Currently two liquefaction facilities exist on the Washington/Oregon border in addition to the peak shaving plants operated by FortisBC in Tilbury and Mt. Hayes, BC. LNG may be trucked to the vessels as is now done for diesel-fuelled operations. Puget Sound Energy already has a fleet of trucks that deliver LNG to their Peak Shaving Plant in Gig Harbor, Washington.

The **Port of Rotterdam**, which is the second largest supplier of conventional bunker fuels, is also moving rapidly to implement LNG fueling infrastructure. Rotterdam has an LNG import terminal within the port to act as a source of supply. The Port has supplied early adopters – small vessels in the inland and coasting trades - using tanker truck delivery. Work is underway to augment this with a shore-to-ship facility within the port, and with bunkering vessels. Rotterdam was somewhat unusual in that the legal framework for LNG bunkering was developed fully prior to the first fueling operations, and as of July 2013 it became the first port within the EU to have a full legal framework for bunkering operations.

**Singapore** is currently the largest port for conventional bunkering in the world, with over 45 million tonnes of fuel oils supplied in 2015 (MPA Singapore, 2016). It sees the provision of LNG bunkering as important to maintain its position as the regional hub for various types of trans-shipment activity. Singapore is developing an LNG bunkering capacity for deep-sea shipping to tie in with its LNG import and re-export (trans-shipment) capabilities and initiatives. Singapore also recently opened a large LNG import terminal, and is planning to use this as a regional hub for distribution of smaller packets of LNG as well as to supply local natural gas consumers. Some of this may be done shore-to-ship, and some by ship-to-ship transfer.
7.3 Current Initiatives on the Great Lakes and East Coast

Petro-Nav, a subsidiary of Groupe Desgagnés, was created in 1996. Groupe Desgagnés has signed a contract with the Besiktas Shipyard in Turkey for the construction of two chemical tankers. The two asphalt/oil carriers will be able to carry over 13,350 metric tonnes of asphalt. These vessels will be the first commercial vessels in Canada powered by dual-fuel engines [HFO and LNG]. The first vessel, the Damia Desgagnés, was officially launched on June 11, 2016 with operation beginning in the Great Lakes in the coming months.

Société des traversiers du Québec (STQ) is a Quebec Government corporation with a fleet of 17 vessels, eight of which are ferries that operate along the St. Lawrence. In 2012, STQ announced its plans to construct two 92 m Ro-Pax passenger ferries and one 130 m Ro-Pax passenger ferry, all to be powered by LNG fuel and operate on the St. Lawrence and Saquenay rivers.

Several operators in the Great Lakes have looked at moving towards the use of LNG as a marine fuel. The major considerations for these companies is whether the LNG is economically feasible and if the infrastructure is available.

There are currently three proposed liquefaction facilities for Eastern Canada which include:

- Goldboro, Nova Scotia – Export Capacity: 10.0 MMTPA, Commence operations: 2019

In addition to these facilities, the Canaport LNG facility in New Brunswick currently operates as an LNG import terminal. The Canaport facility is Canada’s first LNG terminal and has a daily import capacity of 34 million m$^3$.

7.4 Demand Forecasts

Projections for the number of vessels operating in the Great Lakes and off Canada’s East Coast that may be expected to use LNG as their primary fuel, were completed using a range of scenarios. Vessels operating exclusively in an ECA zone such as ferries or cruise ships are most likely to be the early adopters and for the earliest projects can be supplied by sources already available on the Great Lakes and East Coast.

Figure 31 describes, in metric tonnes, the forecasted LNG demand in a low, medium and high demand scenario. Figure 32 illustrates how the demand may be distributed between different types of vessels. This is important to consider for determining where and what LNG-fueling infrastructure may be required. Figure 33 outlines how this demand could be expected to be distributed between the three major ports in the regions.
Canada’s Great Lakes and East Coast have a number of current and potential future LNG facilities to service the demand described above. All major ports throughout the region have the potential to become LNG bunkering locations although the proximity to LNG supply is greater for some ports than others.

Pre-existing liquefaction sites in Montreal, Quebec and in Hagar, Ontario are potential bunkering ports. Tanker trucks can deliver LNG in parcels of approximately 50 m³ and represent the optimal delivery solution from local liquefaction plants to nearby bunkering ports for low bunkering volumes. Trucks could make multiple deliveries to several vessels or to local shore-based bunkering facilities. Figure 34 shows the maximum throughput capacity of a single truck when utilized to supply each of the ports noted in the table above. Bunkering vessels becomes cost effective with longer distances and greater volumes of LNG. Figure 35 shows the maximum throughput capacity of a large and small bunkering vessel when supplying LNG varying distances.
### Investment Requirements: LNG Infrastructure

Figure 36 below illustrates the minimum necessary additional infrastructure, assuming that all assets are fully utilized, to cost effectively meet projected total demand at each port in future years.

#### Evolving LNG Infrastructure Requirements

**2020 Infrastructure Requirements**

<table>
<thead>
<tr>
<th>Liquefaction site</th>
<th>Bunkering Port</th>
<th>Annual Capacity ( m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montreal LNG</td>
<td>Montreal</td>
<td>35,000</td>
</tr>
<tr>
<td>Montreal LNG</td>
<td>Quebec City</td>
<td>17,500</td>
</tr>
<tr>
<td>Hagar LNG</td>
<td>Sault Ste. Marie</td>
<td>17,500</td>
</tr>
<tr>
<td>Hagar LNG</td>
<td>Sarnia</td>
<td>8,750</td>
</tr>
<tr>
<td>Hagar LNG</td>
<td>Thunder Bay</td>
<td>5,800</td>
</tr>
</tbody>
</table>

**2025 Additional Infrastructure Requirements**

<table>
<thead>
<tr>
<th>Liquefaction site</th>
<th>Bunkering Port</th>
<th>Distance</th>
<th>Maximum Throughput Capacity (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nautical Miles</td>
<td>Small Bunker Vessel</td>
</tr>
<tr>
<td>Canaport</td>
<td>Port of Halifax</td>
<td>590</td>
<td>100,000</td>
</tr>
<tr>
<td>Boston LNG</td>
<td>Port of Halifax</td>
<td>713</td>
<td>85,000</td>
</tr>
<tr>
<td>Bear Head</td>
<td>Port of Halifax</td>
<td>194</td>
<td>173,000</td>
</tr>
<tr>
<td>Goldboro</td>
<td>Port of Halifax</td>
<td>308</td>
<td>245,000</td>
</tr>
<tr>
<td>Bear Head</td>
<td>Port of Montreal</td>
<td>1,680</td>
<td>38,000</td>
</tr>
</tbody>
</table>

#### Total Infrastructure Requirements by 2025

<table>
<thead>
<tr>
<th>Liquefaction site</th>
<th>Bunkering Port</th>
<th>2020</th>
<th>2025</th>
<th>2025 Additions</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5000 m$^3$ Bunker Vessel</td>
<td>1000 m$^3$ Bunker Vessel</td>
<td>Tanker Trucks</td>
<td>1000 m$^3$ Insulated Tank</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>1000 m$^3$ Insulated Tank</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
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<td></td>
<td></td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>
7.7 Demand and Infrastructure Requirements for Key Ports – Sault Ste. Marie, Montreal, Halifax

7.7.1 Sault Ste. Marie

The port in Sault Ste. Marie is where Lake Superior, Lake Huron and Lake Michigan meet making it a chokepoint for a large amount of both Canadian and U.S. Great Lakes vessel traffic. In recent years the Port of Algoma in Sault Ste. Marie has received funding for planning and design in order to redevelop the Port. The need for many vessels to transit the locks in Sault St. Marie means that there is some potential to adjust vessel schedules to allow for a bunkering operation without major impact on overall voyage durations.

The potential LNG demand and infrastructure requirements for vessels calling at Sault Ste. Marie in 2020 and 2025 is shown in Figure 37, 38 and 39. Modeling shows that in 2020, the LNG will be transported from the Hagar LNG facility. The requirement is one tanker truck for delivery, a 1,000 m³ insulated tank for storage and a short-run pipeline to connect the storage tank to a bunkering station. Post 2020, as the demand increases, it is assumed that a small scale LNG facility capable of producing 136,080 m³ of LNG per year will be built in the port along with a 5,000 m³ storage tank with a short run pipeline.

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>2020</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand (m³)</td>
<td>Vessels</td>
</tr>
<tr>
<td>Tanker</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bulk</td>
<td>27,510</td>
<td>2</td>
</tr>
<tr>
<td>Tug</td>
<td>1,494</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>29,004</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 37: Potential Demand Breakdown, Port of Sault Ste. Marie

Figure 38: Port of Sault Ste. Marie Demand Distribution by Vessel Types, 2020 and 2025
### 7.7.2 Montreal

The port of Montreal is Canada’s second largest container port, moving $41 billion in goods per year. The port has approximately 30 km of berths. The potential LNG demand and infrastructure requirements for vessels calling this port in 2020 and 2025 is shown in Figures 40, 41 and 42.

Modeling shows that in 2020, the demand for LNG comes from a variety of vessels with container ships creating the highest demand. This trend continues to 2025 where demand doubles. In 2025, the port will require an additional three tanker trucks for delivery and bunkering, a 1,000 m³ insulated tank for storage and an additional short run pipeline for the additional tank. The LNG supply from the Montreal LSR facility will reach a saturation point midway through 2023. Demand could be met by building a short-run pipeline from the existing liquefaction facility to the waterfront, a new shore-side LNG plant fed from local supply infrastructure, or the alternative shore-side LNG plant, Stolt LNGaz, that has been proposed in Becancour.

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>2020</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand (m³)</td>
<td>Vessels</td>
</tr>
<tr>
<td>Tanker</td>
<td>16,833</td>
<td>2</td>
</tr>
<tr>
<td>Bulk</td>
<td>13,755</td>
<td>1</td>
</tr>
<tr>
<td>Container</td>
<td>70,786</td>
<td>4</td>
</tr>
<tr>
<td>Cruise</td>
<td>14,945</td>
<td>1</td>
</tr>
<tr>
<td>Ferry</td>
<td>9,184</td>
<td>1</td>
</tr>
<tr>
<td>Tug</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>116,319</td>
<td>9</td>
</tr>
</tbody>
</table>

---

**Figure 40:** Potential Demand Breakdown, Port of Montreal

**Figure 41:** Port of Montreal Demand Distribution by Vessel Types, 2020 and 2025
Evolving LNG Infrastructure Requirements

<table>
<thead>
<tr>
<th>2020 Infrastructure Requirements</th>
<th>Port of Montreal</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanker Trucks</td>
<td>4</td>
<td>Transport LNG from LSR facility to Port</td>
</tr>
<tr>
<td>5,000 m³ Insulated Tank</td>
<td>1</td>
<td>Insulated LNG storage tank at Port</td>
</tr>
<tr>
<td>Short-run Pipeline</td>
<td>1</td>
<td>From storage tank to bunkering station</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Infrastructure Requirements by 2025</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,000 m³ Bunker Vessel</td>
<td>Transport LNG from outside Montreal</td>
</tr>
<tr>
<td>Tanker Trucks</td>
<td>7</td>
</tr>
<tr>
<td>1,000 m³ Insulated Tank</td>
<td>1</td>
</tr>
<tr>
<td>5,000 m³ Insulated Tank</td>
<td>1</td>
</tr>
<tr>
<td>Short-run Pipeline</td>
<td>2</td>
</tr>
</tbody>
</table>

7.7.3 Halifax

Although the Port of Montreal is a larger container port in terms of tonnage, the Port of Halifax has more port calls, due to its positioning on the eastern seaboard. In 2014, the Port of Halifax saw 582 vessels, while the Port of Montreal saw 412 vessels. Halifax also has a high volume of cruise ship traffic.

Figures 43, 44 and 45 below show the potential LNG demand and infrastructure requirements for vessels calling this port in 2020 and 2025. In both 2020 and 2025 the demand for LNG is greatest for container vessels and cruise ships. There is currently no LNG infrastructure to facilitate bunkering at the Port of Halifax, but it is close to both current and potential LNG facilities via bunkering vessel as shown in the table below. It is assumed that the Goldboro LNG facility, which is expected to have production in 2020, would be the best option for supplying LNG to the Port of Halifax. In 2020, this would require a 5,000 m³ bunker vessel, a 5,000 m³ insulated tank and a short-run pipeline to one or more bunkering locations. In 2025, another 5,000 m³ insulated tank and short run pipeline would be installed. Building a small scale LNG facility in the port was deemed economically unfeasible given the high price of natural gas in Eastern Canada. Future changes to the pipeline and supply network may alter this situation.

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>2020</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand (m³)</td>
<td>Vessels</td>
</tr>
<tr>
<td>Bulk</td>
<td>27,510</td>
<td>2</td>
</tr>
<tr>
<td>Container</td>
<td>49,094</td>
<td>4</td>
</tr>
<tr>
<td>Cruise</td>
<td>29,889</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>106,493</td>
<td>7</td>
</tr>
</tbody>
</table>

Per Vessel Type

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>2020</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand (m³)</td>
<td>Vessels</td>
</tr>
<tr>
<td>Bulk</td>
<td>27,510</td>
<td>2</td>
</tr>
<tr>
<td>Container</td>
<td>49,094</td>
<td>4</td>
</tr>
<tr>
<td>Cruise</td>
<td>29,889</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>106,493</td>
<td>7</td>
</tr>
</tbody>
</table>
As the demand for LNG grows in the Great Lakes and on the East Coast, other bunkering locations in the regions could be viable options. Options in the Great Lakes could include the ports of Thunder Bay, Sarnia and Hamilton. In the St. Lawrence region, other ports could include Quebec City, Saguenay and Becancour. On the East Coast, the Port of Saint John, New Brunswick and St. John’s, Newfoundland and Labrador could be other locations.

### Investment Requirements: Vessel Owners

For vessel owners, using LNG requires larger capital investments than remaining with conventional fuels and engines. Using the study’s demand forecasts, Figure 46 summarizes the estimate of ship-side investments needed to meet forecasted levels of demand.
Figure 47 shows estimates of the cumulative supply side investments needed to meet the same forecast levels of demand. Costings are drawn from the capital expenditure (CAPEX) elements of the models derived under Task 4 for liquefaction, distribution and bunkering systems.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5000 m$^3$ Bunker Vessel</td>
<td>$35,000,000</td>
<td>1</td>
<td>$35,000,000</td>
<td>1</td>
<td>$35,000,000</td>
<td>$70,000,000</td>
</tr>
<tr>
<td>1000 m$^3$ Bunker Vessel</td>
<td>$25,000,000</td>
<td>0</td>
<td>$ -</td>
<td>0</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Tanker Trucks</td>
<td>$270,000</td>
<td>5</td>
<td>$1,350,000</td>
<td>3</td>
<td>$810,000</td>
<td>$2,160,000</td>
</tr>
<tr>
<td>1000 m$^3$ Insulated Tank</td>
<td>$2,400,000</td>
<td>1</td>
<td>$2,400,000</td>
<td>1</td>
<td>$2,400,000</td>
<td>$4,800,000</td>
</tr>
<tr>
<td>5000 m$^3$ Insulated Tank</td>
<td>$11,900,000</td>
<td>2</td>
<td>$23,800,000</td>
<td>2</td>
<td>$23,800,000</td>
<td>$47,600,000</td>
</tr>
<tr>
<td>60 KTPA liquefaction plant</td>
<td>$70,000,000</td>
<td>0</td>
<td>$ -</td>
<td>1</td>
<td>$70,000,000</td>
<td>$70,000,000</td>
</tr>
<tr>
<td>Jetty/Pipelines</td>
<td>unknown</td>
<td>3</td>
<td>$ -</td>
<td>3</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>$62,550,000</strong></td>
<td><strong>$132,010,000</strong></td>
<td><strong>$194,560,000</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Approval**

The schedule for many LNG projects is strongly influenced by the need to obtain approvals and permits. This requirement can have unexpected effects on work scope and compliance costs.

The approvals framework for the construction or importation of an LNG-fuelled vessel in Canada’s Great Lakes and East Coast is relatively simple, with almost all aspects being under the jurisdiction of Transport Canada Marine Safety. In contrast, the scope of regulatory approval for land infrastructure is much more complex and depends on factors such as the purpose, location, size and capacity of a proposed facility. Depending on the project, the following authorities may need to be involved.

- Canadian Environmental Assessment Agency
- Provincial Utilities Commission/Energy Boards
- Provincial Oil and Gas Commission
- Provincial Safety Authority
- Port Authority
- Transport Canada
- Department of Fisheries and Oceans
- Environment Canada
- Natural Resources Canada (National Energy Board)

In general, both the federal and provincial governments have been making considerable and reasonable efforts to simplify their systems particularly for smaller-scale projects.

**Conclusions**

The early demand for LNG will come from ferries and other coastal traffic, but this will build quite rapidly to encompass other vessel types and a significant demand volume.

How the natural gas is supplied to ships depends on the nature of the ship and its operations – not all ships have the same priorities and considerations for bunkering operations. Efficient delivery systems might be put in place across the Great Lakes and East Coast incrementally over the period to 2025. Both the ships and the infrastructure will take a number of years to build and commission.
The adoption of LNG and CNG as a marine fuel will have many direct and indirect benefits to a wide range of stakeholders. The chapter discusses both the nature of the benefits and also provides recommendations as to how they may be realized. The benefits include:

- **Environmental Benefits**
  Using LNG to fuel domestic vessels and deep sea ships entering Canadian waters will reduce the engine exhaust emissions that affect public health and the environment.

- **Economic Benefits**
  The marine sector could provide a new market for Canada’s abundant natural gas resources. In addition, ship operators and their customers could benefit from the reduced fuel prices that may result from the adoption of affordable LNG. The availability of LNG at competitive prices could also provide a competitive advantage for the Great Lakes and East Coast ports, encouraging companies to select these areas as their North American import and export hubs.
8.1 Environmental Benefits

8.1.1 Emissions Reduction

Earlier chapters examined how the marine use of traditional fuel oils produces GHGs, SOx NOx and PM, all of which have undesirable effects on the environment. LNG, however, produces fewer emissions than any other fossil fuel, and using it instead of traditional fuels in marine applications would reduce emissions. Figure 48 lists what the annual emission reductions for the ships built or converted to operate on LNG could be in 2020 and 2025.

<table>
<thead>
<tr>
<th>Substance</th>
<th>% Emission reduction (LNG compared to MGO)</th>
<th>Emissions Avoided (tonnes/yr) based on scenario presented in Task 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur oxides (SOx)</td>
<td>98</td>
<td>13,000 32,800</td>
</tr>
<tr>
<td>Particulate matter (PM)</td>
<td>85</td>
<td>2,100 5,400</td>
</tr>
<tr>
<td>Nitrogen oxides (NOx)</td>
<td>60</td>
<td>6,400 15,900</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>25</td>
<td>484,000 1,200,000</td>
</tr>
<tr>
<td>CO₂-Equivalent greenhouse gases (GHG)*</td>
<td>25</td>
<td>284,000 712,000</td>
</tr>
</tbody>
</table>

*It should be noted that the total CO₂ benefits are highly dependent on the source of the LNG, as liquefaction is itself energy intensive. Task 3 describes a number of options with lesser reductions. Also, some types of gas-fuelled engines incur ”methane slip”; i.e. the release of unburned methane into the atmosphere. As methane has a higher global warming potential than CO₂, this can also reduce the GHG benefits of gas as a fuel.

8.1.2 Spills

LNG spills are more environmentally benign than HFO or diesel oil spills. LNG vaporizes after release, becomes lighter than air and thus disperses rapidly. As a result, spills do not require cleanup.

8.2 Economic Benefits

Using LNG as a marine fuel could benefit Canada’s natural gas producers and distributors, ship operators, industrial development, international trade and coastal and inland communities.

8.2.1 Ship Operators

For operators, there are potential fuel savings benefits since LNG can be significantly less expensive than other fuels. An attractive payback can be achieved for certain types of vessels and, after the payback period, LNG-fuelled ships continue to see significantly reduced fuel costs. This provides an ongoing competitive advantage as shown in Figure 49.

After the payback period, an LNG-fuelled ship will continue to save fuel costs, providing an ongoing competitive advantage. As examples, the annual fuel cost savings for a Great Lakes Self-Unloader is approximately $2,000,000 and for a shuttle tanker operating entirely in ECA waters, annual savings are approximately $4,500,000. For a new build vehicle ferry, cost savings are approximately $6,000,000.


**8.2.2 Gas Producers and Distributors**

The abundant supply of natural gas resources in North America means that there is an excess of supply over domestic demand, which is expected to persist for some time. Capacity to export Canadian natural gas is currently limited and the projects to establish export capabilities are subject to implementation uncertainty and will take time to complete. The marine sector represents a new commercial outlet for Canada’s gas. Close to 800,000 tonnes a year of LNG will be sold to ship operators by 2025. This represents in the order of $400 million of annual LNG sales.

**8.2.3 Industrial and Services Development**

The development of an LNG or CNG supply chain can lead to construction, manufacturing and operating activities. Opportunities relate to the:

- creation of natural gas and LNG infrastructure;
- building, conversion and repair/maintenance of ships that operate on natural gas (opportunities for shipyards);
- supply of equipment and services to both of the above (opportunities for suppliers);
- bunkering of natural gas-fuelled ships; and
- developing and delivering training services.

**8.3 Ports and Trading Patterns and Non-Marine LNG Infrastructure**

On the Great Lakes and East Coast, the ability to fuel vessels with LNG could turn their inland locations from a source of disadvantage due to ECA requirements to one of competitive advantage. East Coast ports could also use LNG availability to generate changes in trading patterns and to make them preferred locations for regional distribution networks. Ports are well placed to provide fuel to other transportation modes which distribute goods to their final destinations, such as trucks, locomotives and short-sea shipping.

**8.4 Non-Marine LNG Infrastructure**

There are also extensive opportunities for the use of LNG in non-marine applications throughout the Great Lakes and the East Coast. This applies both to other sectors of the transportation industry and also to power generation, heating and other markets which are currently remote from, or poorly serviced by the gas pipeline network.

**8.4.1 The Trucking Sector**

The trucking sector is seeing increasing use of LNG in a number of regions. Gaz Metro has been a pioneer in the development of the “Blue Road” from Quebec City to southern Ontario, and its provision of LNG to the STQ ferry services in Matane and (soon) Tadoussac will help with the extension of this network. Combining marine, trucking and rail provisions of LNG and CNG in ports is attractive as the same location is a convenient fueling (bunkering) hub for all modes.

**8.4.2 For Communities, Industrial Facilities and Mines**

Below Quebec City throughout the Gulf of St. Lawrence there is very limited availability of natural gas in any form, and a number of potential users including communities, industrial facilities, power generation facilities, mines and other energy-intensive operations could benefit from LNG.
Potential Incentives

Early adopters of marine LNG will incur higher costs than later users, for reasons such as:

› higher equipment costs while R&D investments are being amortized;
› higher infrastructure costs, while utilization levels are still low;
› higher risk premiums; and
› the learning curves associated with design, construction and regulation.

The public and/or private sector could help by offering support and incentives to reduce the costs of adopting LNG. This has happened in Europe, through initiatives such as the EU’s Mobility and Transport Commission, which supports infrastructure projects, and Norway’s NOx fund, which supports LNG-fuelled projects.

There are various ways for both the federal and provincial governments to support early adoption of LNG as a marine fuel. They could, for example, foster links with trans-Pacific trading partners to help build the critical mass of deep sea shipping that will justify new investments by ship operators and LNG suppliers.

Policy as an Enabler

Establishing LNG as a viable alternative to marine oil fuels will be a complex process and would be supported by policy development.

8.6.1 Regulatory Policies

The introduction of more extensive marine LNG infrastructure will require policies for standards and regulations that deal with its construction, operation and maintenance. It is highly desirable that federal and provincial governments formalize their policies towards LNG ships and facilities.

Additionally, all levels of government could have a policy of assigning responsibility for the coordination and approval of projects to a clearly designated lead agency. Industry investment will be encouraged by clarification and simplification of the process for project approvals and certifications.

8.6.2 Economic Policies

The successful and timely introduction of marine LNG infrastructure could be aided by economic policies to address a number of issues. In particular, policies could be considered to support the integration of new LNG infrastructure development with existing industry programs, and to create certainty which will accelerate private sector investments in LNG-related infrastructure and vehicles whether for marine, rail or road use.

Communications

A comprehensive policy covering how the environmental benefits of natural gas are communicated to the public could be implemented to ensure that the public’s perception of the industry is accurate, and that the information being distributed is clear, open and understandable. As well, policies that support balanced, honest and reliable information on the economic impacts, including job creation, to the public could be developed to satisfy taxpayers that the investment being made represents good value. Finally, information on LNG’s safety record should be widely available.
Conclusions

Recommendations to encourage the use of LNG on Canada's East Coast and Great Lakes:

1. It is recommended that stakeholders continue to collaborate and build on the findings of this project and the compendium West Coast project to support current marine LNG deployments as well as proposed initiatives. There are significant potentially environmental benefits as well as economic opportunities if Canada can build on the success of early adopters and take a lead in global marine discussions.

2. It is recommended that the Government of Canada with the support of the relevant provincial governments develop a comprehensive Regulatory Approval process for LNG-fuelled operations. The International Marine Organization (IMO) IGF Code provides a firm basis for the approval of the ships themselves, but many aspects of bunkering, operations, and fuelling facilities design and not yet covered by clear policies, standard or regulations. This represents a risk that many potential LNG adopters are unwilling to accept. As a result, it is critical that an updated regulatory framework be established in order to support the widespread adoption of marine LNG.

3. It is recommended the Government of Canada actively support the development and adoption of model international training courses for seafarers and for other operational personnel, with inputs from the Canadian Association of Marine Training Institutes (CAMTI) and from Canadian early adopters. As LNG expands from short sea into deep sea operations, it will become increasingly important to have consistent baselines for safe operations.

4. It is recommended, to encourage efficient review of proposed projects, that the federal and provincial governments review and formalize policies for LNG ships and facilities. To support this, it is recommended that each level of government designate a lead agency to coordinate all processes for marine project approvals.

5. It is recommended that CSA Group and international marine standards organizations continue to work in concert to ensure there are no gaps or differences in North American standards for handling natural gas as a transportation fuel. In particular seamless application of ship side and dock side standards for fuel handling will have a direct and positive impact on bunkering operations.

6. It is recommended that relevant safety related information, such as the results of risk assessments for LNG applications, be easily accessible to the general public in order to increase public understanding and address potential concerns related to LNG safety.

7. It is recommended that the federal government considers designating a small fraction of its planned infrastructure investments to assist leading port facilities in developing LNG fuel handling capabilities to support bunkering activities. This could help Canada in establishing a presence in the North American and global LNG bunkering market.
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