Liquefied Natural Gas:
A Marine Fuel for Canada's West Coast

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Project Participants

- American Bureau of Shipping
- BC Ferries
- British Columbia Institute of Technology
- Canadian Natural Gas Initiative/Canadian Natural Gas Vehicle Alliance
- Canadian Standards Association
- Encana
- FortisBC
- Government of Canada (Transport Canada, Environment Canada, Natural Resources Canada)
- Lloyd's Register
- Port Metro Vancouver
- Province of British Columbia (Ministry of Transportation and Infrastructure, Pacific Gateway Branch)
- Rolls-Royce
- Seaspan
- Shell
- STX Canada Marine
- Teekay
- Wärtsilä
- Westport Innovations

Foreword

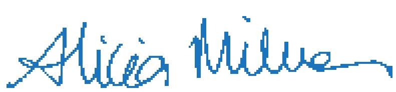
Liquefied natural gas (LNG) holds great promise as a marine fuel in Canada. Its affordability, abundance, and significantly lower emissions profile in marine applications mean that LNG is well positioned to enter the marine sector. With more stringent marine emissions regulations coming into force in North America in 2015, natural gas is of increasing interest as a fuel option for vessel owners.

Unlike many other emissions reduction alternatives, the use of natural gas can offer a favourable return on capital investment for marine vessel owners. The emissions benefits of natural gas include reductions in criteria contaminants such as sulphur oxides, nitrogen oxides and particulate matter, as well lower greenhouse gas emissions.

The challenge for natural gas lies in gaining market access. Current Canadian regulations need to be adapted to accommodate the use of natural gas as a marine fuel, while codes, standards, regulations, personnel training, operating practices and procedures, and fuel supply infrastructure are all at various stages of development. There is a need to identify and apply what will work in Canada, particularly given that early-stage marine LNG projects are now being pursued in both western and eastern Canada.

This West Coast-focused joint industry project 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 will be essential to clearing the regulatory path and to ensuring that Canada's abundant natural gas resources can be 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.



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Executive Summary

Liquefied Natural Gas: A Marine Fuel for Canada's West Coast is a condensed version of the Transport Canada report, TP 15248 E, *Canadian Marine Liquefied Natural Gas (LNG) Supply Chain Project, Phase 1 – West Coast*. The original detailed report was prepared in 2013 by STX Canada Marine for joint industry project participants and the Transportation Development Centre of Transport Canada.

This condensed report summarizes project results related to identifying and addressing barriers to the establishment of a LNG marine fuel supply chain on Canada's West Coast. The project contributed to the development of a thorough understanding of key issues and how to design approaches that will encourage the use of LNG as a marine fuel in Canada.

Key Project Findings

- All of the technologies needed to use LNG as a marine fuel are proven and commercially available, including dual fuel and pure gas engines in power ranges that meet the needs of many types of coastal and deep sea vessels. Development of engine technologies and onboard fuel storage systems is also continuing.
- In marine applications, LNG provides significant benefits in terms of reducing emissions from ship engine exhaust. When compared with modern engines using even "clean" fuel oils, LNG can lower ship exhaust emissions of sulphur oxides (SOx) by over 90%; of nitrogen oxides (NOx) by up to 35% for diesel-cycle engines and up to 85% for Otto cycle engines; of particulate matter (PM) by over 85%; of carbon dioxide (CO2) by up to 29%; and of greenhouse gases (GHGs) by up to 19% on a CO2-equivalent basis. The use of natural gas as a marine fuel allows compliance with all current and known future emission requirements.
- "Methane slip" is associated with natural gas marine engines and refers to the release of unburned methane from the combustion process. As methane is a potent GHG, such slip can significantly reduce the emissions advantage of using LNG. Different engine technologies vary considerably with respect to levels of methane slip.

- LNG use can offer significant economic benefits to owners and operators of certain types of vessels. For the six coastal vessel scenarios modelled, five had a payback of less than six years on initial investment. Annual fuel costs for coastal vessels were reduced by more than 50%, with estimated fuel savings ranging from $500,000 per year to more than $5 million per year, depending on the vessel type. For deep sea vessels, payback improved with the amount of time spent in the North American Emission Control Area, which extends 200 nautical miles off of the West Coast.
- LNG can be used safely as a marine fuel. That said, adequate personnel training is crucial because LNG-fuelled vessels differ from traditionally powered vessels in important respects. These differences include vessel layout, fuel properties and hazards, fuel handling requirements and emergency response.
- There are currently no international or Canadian regulations covering the use of LNG as a marine fuel, although international efforts are under way to develop appropriate codes, standards, and regulations. Fortunately, Canada can draw upon the large amount of existing material that could be adapted to regulate LNG use for the marine sector.
- British Columbia has an opportunity to become a preferred North American destination for LNG bunkering, with Port Metro Vancouver well positioned to be a leader in this regard.
- Under a "medium" LNG adoption scenario, there would be 150 LNG vessels operating on Canada's West Coast by 2025. These vessels would consume approximately 570,000 tonnes of LNG annually, representing 8.5% of British Columbia's total natural gas demand during 2012.
- As LNG use expands on the West Coast, the private sector will invest in infrastructure for natural gas liquefaction, storage, distribution and delivery in order to bring LNG to the marine market.
- The current price and long-term supply outlook for British Columbia's natural gas resources make it a highly attractive energy source for the marine sector, which will have to comply with more stringent emissions regulations going forward.
- Using LNG as a marine fuel offers benefits to British Columbia and Canada, such as:
    - Reduced emissions from ship engine exhaust, as described above
    - Direct economic benefits, in the form of lower operating costs for vessel owners, local infrastructure investments and increased sales of LNG produced from British Columbia's natural gas
    - Indirect economic benefits, such as the development of an industrial base, promotion of British Columbia's ports as preferred trade destinations, and cost savings for the users of shipping services
    - The establishment of an LNG supply chain that can be used in other applications, such as railways, trucking and off-grid community power generation

Recommendations to encourage the use of LNG on Canada's West Coast:

1 Stakeholders need to continue to collaborate and use the findings of this project to support current and proposed marine LNG initiatives. There are major potential environmental and economic benefits to be realized if Canada and British Columbia are early adopters of LNG as a marine fuel.

2 It is recommended that Transport Canada adopt an Alternate Regulatory Approval process for LNG-fuelled ships, based on the International Maritime Organization (IMO) guidelines and draft codes for such ships and their crews. The gaps in existing Canadian marine regulations, in relation to LNG use, represent a risk that many potential LNG supporters 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 Three levels of Canadian training courses are proposed to meet the seafarer training requirements, on an interim basis, until international standards for crew training for LNG-fuelled ships are developed over the next few years. Existing academic institutions, such as the British Columbia Institute of Technology, are well positioned to develop the needed courses and to add LNG training to their existing curricula.

4 To encourage efficient review of proposed projects, it would be helpful if 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 work be undertaken to engage with CSA Group in order to identify gaps and to determine how to address them with respect to the inclusion of LNG technologies in Canada's LNG code (CSA Z276, *Liquefied natural gas (LNG) – Production, storage, and handling*). Many LNG technologies, such as membrane fuel tanks and the ISO containers used for fuel transport, are under development or are commercially available, but are not currently included in the Canadian code. Approaches to address this gap area could include expanding the scope of CSA Z276, adopting ISO or other international standards, or developing new Canadian standards.

6 Safety-related information, such as the results of risk assessments for LNG applications, should 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 consider designating a small fraction of its current investment in rebuilding Canada's shipyard capability to assist shipyards that are interested in LNG vessel conversions and new builds. This could help Canada develop a sustainable niche in the global shipbuilding sector.

Introduction

Natural gas has traditionally been used in Canada for power generation, space and water heating, and as an industrial feedstock. Recently, however, trends in international emission regulations, technology development and shipping economics are making liquefied natural gas (LNG) an increasingly attractive alternative to traditional fuels in the marine sector. This is particularly true for ships that travel to or from North America, or that operate in North American coastal waters, where stringent emissions regulations are coming into effect.

In 2013, a joint industry/government project was initiated to develop an understanding of the opportunities and barriers associated with establishing a marine LNG supply chain on the West Coast of Canada. This report, *Liquefied Natural Gas: A Marine Fuel for Canada's West Coast*, is a condensed version of a longer report on the project. It summarizes the project's results and key findings.

The project scope included the following eight tasks:

- Assess technology readiness for marine-related LNG technologies, including engines, liquefaction technologies, and bulk and onboard fuel storage systems
- Calculate estimated economic benefits associated with using LNG as a fuel for a range of ship types operating on Canada's West Coast
- Identify potential environmental benefits and document potential environmental risks
- Present infrastructure options for West Coast marine LNG refuelling, with reference to existing pipelines, distribution hubs, local transportation and storage, and other significant marine-related components
- Explore regulatory challenges to introducing LNG as a marine fuel, including potential barriers at the federal, provincial, and municipal levels, and recommend ways to overcome these barriers
- Detail human resources requirements and explore ways of ensuring the availability of trained personnel with competencies related to LNG vessels and fuelling systems
- Describe potential implementation scenarios for the introduction of LNG-powered vessels
- Identify the environmental, economic, and competitive advantage benefits to Canada of an LNG marine strategy

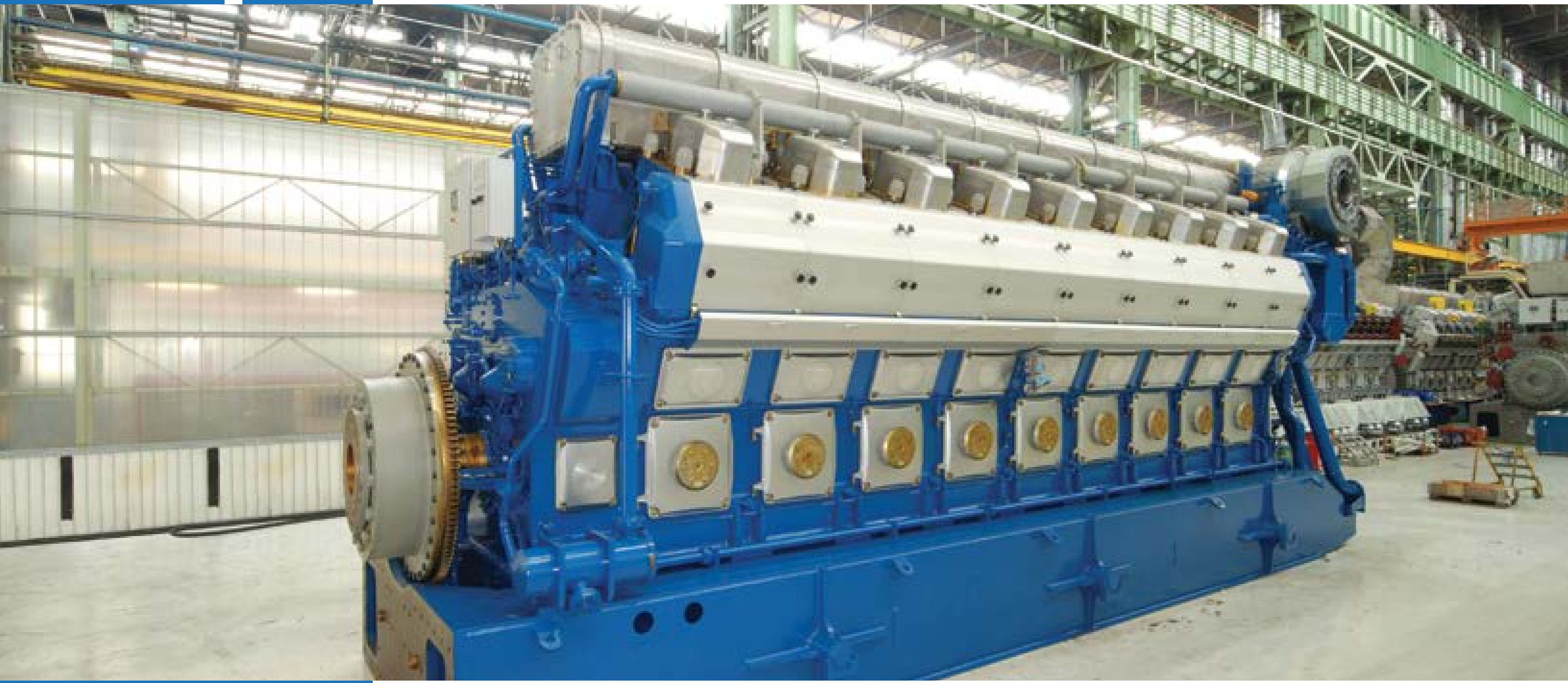
Within the scope of the project, economic and environmental modelling was carried out for 14 case studies representing the types of ships operating on the West Coast or making port calls there. These case study vessels are described in the table below.

	Vessel	New Build or Conversion
1	100 CEU ferry	New build
2	375 CEU ferry	Conversion
3	125 CEU ferry	Conversion
4	Coastal roll-on/roll off	New build
5	Bulk carrier	New build
6	Dry bulk carrier	New build
7	Crude oil tanker	New build
8	Oil/chemical tanker	New build
9	2,200 TEU container ship	Conversion
10	6,500 TEU container ship	New build
11	6,500 CEU car carrier	New build
12	6,500 CEU car carrier	Conversion
13	Passenger ship	New build
14	Escort tug	New build

CEU refers to car-equivalent units and TEU refers to 20-foot equivalent units, which are used to measure the capacity of container ships.

Chapter 1

Technology Readiness



This chapter reviews the characteristics of natural gas and the technologies that are currently available for marine LNG fuelling systems, which include:

- Liquefaction, bulk storage and bunkering systems
- Distribution systems such as rail and road vehicles, local tanks, and bulk cargo and feeder vessels
- Onboard storage and fuel distribution technologies
- Engine technologies for various types of dual fuel and pure LNG engines
- The integration of LNG engines into mechanical and electrical drive systems
- Safety technologies associated with LNG

All of the technologies needed to use LNG as a marine fuel are proven and are commercially available. In addition, development is continuing in order to improve performance or reduce the cost of engine technologies and onboard fuel storage systems.

1.1 Natural gas and its use as a marine fuel

Natural gas is a mixture of gaseous hydrocarbons and associated compounds found in underground deposits. Methane forms 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 (m3) 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. In liquid form, LNG is lighter than water, and is odourless, colourless, non-corrosive and non-toxic.

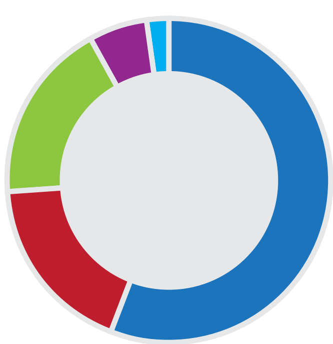
1.1.1 LNG use and safety record

LNG has been in global use as a marine fuel for several decades, although in a very limited way. Bulk LNG carriers, for example, have used the boil-off gas from their cargoes to supplement onboard fuel storage for almost 50 years. Based on this extensive experience, the LNG carrier industry is committed to risk management, thoroughly understands the hazards of LNG use and rigorously maintains operational protocols and operator knowledge. In addition, international standards developed by both regulators and the LNG industry provide a framework for safe operations. As a result, the industry has an excellent safety record and there have been no LNG-related fatalities aboard LNG ships for the estimated 50-year period that they have been in use.

Excluding bulk LNG carriers – about 300 in all, globally – most of the 70 LNG-fuelled vessels now operating or under development worldwide are ferries and offshore supply ships. No LNG-fuelled vessels are currently in service in North America, but several are under construction or are being converted to LNG for organizations including Harvey Gulf International Marine, the Société des traversiers du Québec, Interlake Steamship and TOTE Maritime.

1.2 Liquefaction and bulk storage

Figure 1: Worldwide natural gas liquefaction capacity by technology, 2001-12 (M.N. Usama, 2011)



- 56% C3MR
- 18% AP-X
- 18% Optimized Cascade
- 6% DMR
- 2% Mixed Fluid Cascade

While liquefying natural gas greatly increases the energy density of the fuel, it is capital- and energy-intensive. The cost of liquefaction can account for up to 50% of the cost of bringing LNG to the market (M.N. Usama, 2011).

Before it can be liquefied, pipeline-quality natural gas must be further conditioned by having any minor contaminants removed. An LNG plant's liquefaction and purification facilities are commonly called an LNG train, and such trains can be built on large, medium and small scales. However, 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 million metric tonnes per annum (MMTPA) can take approximately 24 months and an investment of over $100 million to build.

1.2.1 Liquefaction technologies

There are five distinct natural gas liquefaction processes in use today. Ranging from the most to 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.

1.2.2 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.

Membrane tanks are not currently included in Canada's LNG code (CSA Z276, *Liquefied natural gas (LNG) – Production, storage, and handling*). This is a gap that could be addressed by expanding the scope of CSA Z276, adopting ISO or other international standards, or developing new Canadian standards.

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.

Figure 2: Bulk LNG storage tanks (courtesy of Gaztransport & Technigaz (GTT))

1.3 Distribution and bunkering

There is an established infrastructure already in place on the West Coast that could be used as the basis for expanding the production, distribution and bunkering of LNG as a fuel for the marine market.

1.3.1 Distribution systems

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 British Columbia and could be scaled according to demand.

For existing cargo/passenger ports, the adoption of large-scale bunkering by trucks has limited potential. Dedicated shoreside fuelling stations with LNG storage tanks are a viable option in this case, but will require new capital expenditures as well as assurances that vessels will regularly bunker in the same location.

Railcars can be used to distribute LNG, but this approach currently focuses on the bulk transportation of the fuel, rather than on delivering it to a ship. Bunker vessels and short-distance LNG pipelines are other potential options for supplying LNG to ships, but these currently do not exist in Canada and would require greater capital investments compared with truck- or tank-based shoreside bunkering facilities.

1.3.2 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, safe transfer of LNG to ships. While LNG bunkering is new to the non-carrier market, the lessons learned and approaches can be adapted for fuelling 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 ships. 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. At present, the fuel supply trucks of some West Coast vessel operators drive aboard the vessel to bunker oil-based fuels.

The Society of International Gas Tanker and Terminal Operators (SIGTTO) has introduced guidelines for bunkering from tanker ships or barges. These cover the ship-to-ship LNG transfers between LNG 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 ship-to-ship transfer appears in Figure 3.

***Figure 3: Ship-to-ship transfer: MS* Pioneer Knutsen *bunkering MS* Coral Methane**

1.4 Onboard storage and distribution

Unlike conventional liquid fuel tanks, which are integrated into the ship'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 ship rather than on deck. Tank rooms must have fuel containment provisions and secondary barriers to mitigate the effects of gas or liquid release. Most LNG-fuelled vessels, (other than LNG carriers, which use membrane tanks) are designed to use Type C tanks. A Type C installation is shown in Figure 4.

Figure 4:
***Type C tank installation aboard* Viking Grace**

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 is a key consideration when converting a diesel-powered vessel to LNG. The size depends on the range required for the vessel between refuelling 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 ship is to retain its original, diesel-powered range. This is because LNG requires 70% more volume than an oil-based fuel to hold the same amount of energy.

1.5 Engine technologies

Natural gas engines have been used for many years both on land and aboard ships. While there is a limited choice of marine LNG engines with power ratings below 1,000 kilowatts (kW), numerous options exist for engines above this rating, and these are commonly used on merchant vessels. The ready supply of high-powered LNG engines means that the availability of commercial engine technology is not a barrier to the use LNG as a marine fuel.

There are three basic types of LNG engines:

Figure 5:
A Bergen B35:40 pure LNG engine

- Lean burn, spark-ignition, pure gas types operate on the Otto cycle and use a spark plug to ignite the 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 5 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 Wärtsilä, 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 engines now on order can deliver up to 42,700 KW.

Engine availability

The ready supply of high-powered LNG engines means that the availability of commercial engine technology is not a barrier to the use of LNG as a marine fuel.

1.6 LNG engine propulsion systems

Marine propulsion systems are the means by which the engine's power moves the ship, usually via propellers. On LNG-fuelled vessels, these systems incorporate subsystems not typically found on conventionally fuelled vessels. 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.

Figure 6:
The* Viking Grace *uses an electric propulsion plant with dual fuel engines

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 6 shows the *Viking Grace*, which uses electric propulsion.

1.7 Safety technologies

The technologies for marine LNG use are not unique. However, their application in LNG-fuelled ships and support systems is new, and tailoring safety requirements for LNG fuel systems remains a work in progress.

The impact of LNG on materials is one area that must be addressed through vessel design, since there is a risk of materials becoming brittle and fracturing. There is extensive experience with components that can be used for LNG storage and handling; operators use double-walled piping and cryogenic hoses and seals, together with drip trays at potential leak points, to safeguard non-LNG system materials onboard the ship.

The biggest perceived risk with LNG is that gas leaks may catch fire or explode. This can be addressed through isolation measures, the use of inherently safe equipment and the use of sensor and control technologies that automatically shut down equipment if a leak occurs.

One of the most probable sources of a gas leak is over-pressurization of the storage tank. While design and operational measures can reduce this risk, isolation measures and gas dispersion techniques must also be used, including airlocks, gas-safe fans, vent masts and separate ventilation systems for hazardous and non-hazardous spaces.

Personal protection gear is essential when handling LNG. This includes eye protection, face shields, insulated gloves and boots, and respiratory gear for oxygen-deficient environments.

1.8 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 shipboard components of LNG – engines and storage systems, for example – 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. The reduction of methane slip (the release of unburned methane during the combustion process), together with efficiency improvements, would also improve the future performance of LNG marine engines. As methane is a very potent greenhouse gas (GHG), methane slip reduces the GHG emissions advantage of using LNG.

On the standards and regulations side, there are already numerous resources that can be used to implement LNG marine fuel projects in Canada, the United States and internationally. Some key regulatory aspects, however, remain in draft form.

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

1.9 Conclusions

There is a solid foundation of existing technologies available today that can be used to support LNG use in the marine sector.

- LNG has been used safely as a marine fuel for more than 50 years.
- The use of LNG as a marine fuel can employ existing commercial technologies that are well proven in both marine- and land-based applications.
- There are growing numbers of standards and regulations that can be used to implement LNG marine fuel projects.
- The two major barriers to widespread use of LNG as a marine fuel are a lack of familiarity with LNG in this role and the need to expand the supply chain to bring LNG to the marine market.
- A third barrier, for shipboard use, is the cost of LNG engines, storage systems and related components. Most LNG engines are more expensive than their conventional counterparts and there is limited experience with respect to LNG system integration.

Chapter 2

Infrastructure Options

Recent advances in drilling technology have made it cost effective to produce natural gas from "unconventional" sources such as shale formations. While British Columbia has long been a producer of natural gas, the ability to access unconventional resources has significantly increased the province's proven natural gas reserves. This new natural gas abundance could mean inexpensive feedstock for liquefaction plants, allowing them to supply LNG for marine and land transportation as well as for other end uses. A limited amount of new LNG demand from the marine market could be supported from existing infrastructure. Greater projected LNG demand for marine use would stimulate new investments in LNG supply and distribution systems.

This chapter examines West Coast LNG supply and demand, existing and planned infrastructure, natural gas pricing in British Columbia's market, and marine LNG infrastructure options and costs.

2.1 Supply and demand on the West Coast

Canada is the world's third-largest producer of natural gas, and British Columbia accounted for about 20% of the total national production in 2010 (National Energy Board, Nov. 2011). British Columbia has historically supported the development of the province's extensive natural gas resources and is promoting the benefits of a potential LNG export industry.

2.1.1 Supply

British Columbia has abundant conventional and unconventional natural gas resources. The latter include shale gas, "tight" gas in nonporous sand formations, and coal bed methane, which is natural gas associated with coal deposits. According to Statistics Canada's *Energy Statistics Handbook, First Quarter 2012*, British Columbia's annual gross natural gas production rose from over 30 million m3 in 2004 to over 40 million m3 in 2011.

In British Columbia, a long-distance pipeline system connects the natural gas-producing areas in the northeast to the rest of the province, as well as to the United States, which is the destination of a large portion of the province's current natural gas production. If LNG terminals proposed for Kitimat and Prince Rupert come online, exports to Asian markets will follow. This would create a world market for British Columbia natural gas.

2.1.2 Demand

Current natural gas use in British Columbia is primarily in the industrial, residential, and power generation sectors, as shown in Table 1 below. The consumption statistics show a distinct fall in demand across all three sectors since 2007.

While the use of natural gas in the on-road transportation sector has been limited to date, some fleets that operate buses, highway trucks, and refuse trucks are considering switching to natural gas. Rail may also hold promise once LNG-fuelled locomotives are commercially available. In the marine sector, ExxonMobil sees a shift toward natural gas and expects the use of this fuel to account for 8% of total global demand by 2040.

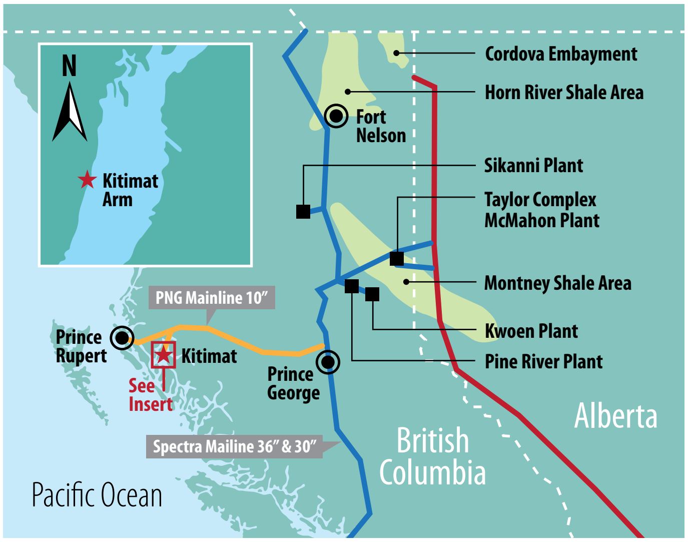
Table 1: Top three sectors for natural gas use in British Columbia

Natural Gas Use in British Columbia - Top Three Sectors			
Sector	2012 Consumption (millions of m^3)	Percentage of Total Consumption - Three Sectors	Consumption Decline Since 2007 (%)
Industrial	2,927	59	16.7
Residential	2,017	40	8.0
Power generation	0.293	<1	4.6

2.2 Existing and planned infrastructure

The infrastructure required for establishing LNG as a marine fuel includes pipelines, liquefaction plants and bulk storage facilities.

Figure 7: Existing natural gas pipelines on the West Coast



2.2.1 Pipelines

Existing pipelines, as shown in Figure 7, provide natural gas to British Columbia's West Coast and support exports to Alberta and the United States. Overall demand for natural gas in British Columbia and for United States export has been decreasing since 2007. As it is desirable to maximize pipeline usage in order to minimize operating costs, this decline is a challenge. Increased use of LNG in the transportation market could help to stimulate increased natural gas demand.

Additional pipelines will be needed to develop LNG export terminals on the West Coast, and several companies are proposing to build new pipelines to supply these new facilities in Kitimat and Prince Rupert. With respect to potential new marine LNG demand, West Coast natural gas distributors such as PNG and FortisBC have noted that existing local capacity could support the development of an LNG marine fuel supply chain, at least in the short term. Over the longer term, new investments in infrastructure will be needed.

2.2.2 LNG production capacity

Currently there are two LNG production facilities in British Columbia. Both are owned and operated by FortisBC. Each facility includes a liquefaction plant, storage tanks and a vaporization system. The Tilbury plant can produce 30,000 tonnes per annum (TPA) and is being upgraded to increase storage and production capacity. The Mt. Hayes plant on Vancouver Island can produce 55,000 TPA. The Tilbury plant has load-out facilities for bulk tanker trucks. Similar facilities are planned for the Mt. Hayes plant.

Nine LNG export projects, which will focus on exporting LNG to Asian markets, are in various stages of development on the West Coast. A summary describing four of these projects at time of writing is shown in Table 2.

All projects must undergo regulatory reviews. 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 current and proposed LNG production facilities in British Columbia, there are three small-scale LNG plants in the northwest United States (one in Washington and two in Oregon), as well as existing and planned facilities in Alberta. All could provide LNG for marine use in British Columbia.

Table 2: Partial listing of West Coast LNG export projects

Project	Partners	First Shipment	Liquefaction Capacity (million m^3/day)	Liquefaction Capacity (tonnes/year)
Douglas Channel LNG	Haisla First Nations, LNG Partners, Golar LNG	2015	2.5	0.7
Kitimat LNG	Chevron, Apache	Unknown	21.2	5.0
LNG Canada	Royal Dutch Shell, Korea Gas, Mitsubishi, PetroChina	Unknown	141.5	37.0
Pacific Northwest LNG	Petronas, Japan Petroleum	Unknown	68.0	18.0

2.3 Pricing of natural gas in the British Columbia market

The feasibility of LNG as a marine fuel depends on its availability and its price relative to other marine fuels. However, there are large differences in the price of natural gas used to produce LNG as well as in the cost of delivered LNG in markets around the world. For example, North American natural gas in mid-2013 was significantly lower in price compared with natural gas in Europe and Japan. The price differential has been increasing due to growing North American production of unconventional natural gas resources.

2.3.1 Marine LNG pricing

For many potential users of LNG as a marine fuel, especially on trans-Pacific and other international routes, the ability to refuel at both ends of a voyage will be essential. LNG's lower energy density compared with oil fuels means reduced range for LNG-fuelled vessels. The cost of LNG in non-Canadian markets is therefore an important factor for its adoption in deep sea shipping.

LNG in overseas ports is likely to be available only at local market prices. This assumption has been made by most of the studies into the global adoption of LNG as a marine fuel, and is one reason why these studies predict a relatively slow rate of uptake for LNG in the global marine market, given the higher price of LNG outside North America.

2.4 Delivery infrastructure development and costs

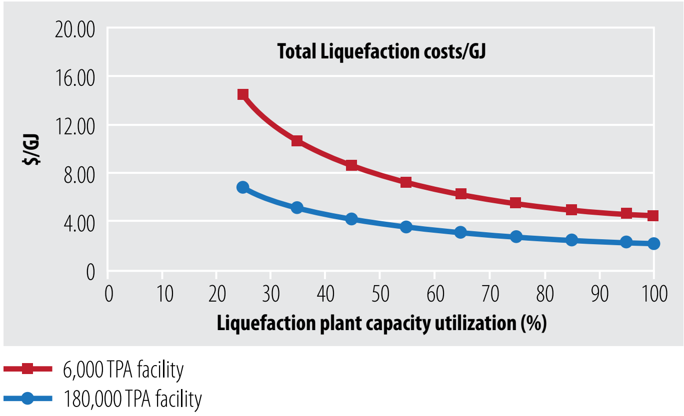
The existing West Coast LNG supply chain can satisfy a limited demand for marine fuel. As demand increases, new investments in supply, liquefaction, distribution and storage will be needed.

2.4.1 Liquefaction

The largest capital investment in new infrastructure will likely be for liquefaction plants. It is assumed that the liquefaction plants producing LNG for transportation will be on a smaller scale than the large-capacity facilities used at LNG export plants, and will be located relatively close to their end users or to the distribution infrastructure. The economics of these small-scale plants depends on their capital and operating costs.

Analysis shows that liquefaction costs are a significant part of the cost of LNG, and that this cost is highly sensitive to plant size and utilization. A plant with an 180,000 TPA capacity will provide significant economies of scale compared with one capable of 6,000 TPA, provided that the former operates at more than about 30% capacity (see Figure 8).

Figure 8: Total liquefaction cost as a function of plant capacity and utilization



2.4.2 Distribution

LNG may be delivered to a ship by means of tanker trucks, shoreside bunkering facilities or bunker/ feeder vessels.

- Tanker trucks, as shown in Figure 9, may be adequate for the small-scale deliveries initially required. Analysis conducted during the project shows that, as needs increase, a dedicated truck fleet may continue to be an economical option if the truck fleet utilization rate can exceed 40 – 50%.
- Shoreside bunkering facilities will require capital expenditures on tanks and other equipment such as piping, manifolds, pumps and possibly wharves. These types of facilities can supply considerably more fuel to a vessel than tanker trucks.
- Bunker/feeder barges have the greatest capital and operating costs, but can deliver the largest volumes of LNG. Analysis shows that they can compete with trucks on shorter routes if their capacity is efficiently used.

Figure 9: LNG bunkering by tanker truck at Elbehafen

2.5 Delivered cost scenarios

There is a wide range of potential delivered LNG costs, depending on natural gas feedstock costs, liquefaction costs, fuel delivery and storage costs, and producer/distributor profit margins. Taking each of these factors into account, low and high domestic LNG prices were calculated for LNG sourced from British Columbia. The range of prices is shown in Table 3. These low/high price scenarios reflect two ends of the spectrum of potential LNG fuel pricing on the West Coast. The profit component adds 20% to both liquefaction and delivery costs, and includes both profit and cost of capital.

The calculated low value for delivered LNG is consistent with recent direction from the Province of British Columbia allowing for a LNG dispensing rate, or liquefaction cost, of $4.35/GJ. Based on this rate, a delivered LNG cost of $9.28/GJ is available from FortisBC.

It is also noteworthy that, at current British Columbia prices, feedstock cost is a relatively small component of delivered LNG cost.

Table 3: Domestic low and high LNG price scenarios

Cost Component	Domestic LNG – Low ($/GJ)	Domestic LNG – High ($/GJ)
Commodity Cost (feed gas)	$3.79	$3.79
Liquefaction Cost	$3.65	$5.50
Delivery Cost	$0.69	$3.01
Profit	$0.87	$1.70
Total Before Taxes	$9.00	$14.00

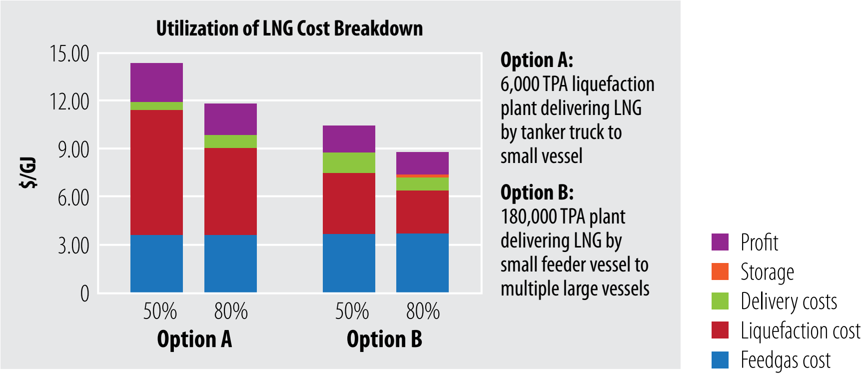
LNG pricing and supply

It should be possible to supply LNG at attractive prices, compared with the fuel oil alternatives, under a range of production and delivery scenarios on the West Coast.

Two other determinants of delivered cost are LNG production facility utilization and scale. Figure 10 provides cost breakdowns in dollars/gigajoule (GJ) at 50% and 80% utilization of each of two differently sized LNG production facilities. In Option A, a small-scale plant (6,000 TPA) is assumed, with LNG delivery via tanker truck to a small vessel. In Option B, a large-scale plant (180,000 TPA) is assumed, with LNG delivery to a feeder vessel supplying several larger ships. Profit and the cost of capital are set at 20% of the total in each case.

By comparison with these LNG cost estimates, the delivered costs of oil-based fuels range from an estimated $12/GJ for intermediate fuel oil (IFO) 380, a commonly used fuel oil for deep sea vessels, to $23.80/GJ for ultra-low-sulphur diesel (ULSD), the main fuel used by coastal vessel operators. With LNG delivered costs ranging from approximately $9/GJ to $14/GJ, depending on the noted assumptions, it is evident that LNG can offer economic benefits to vessel owners operating on the West Coast.

Figure 10: LNG delivered costs at 50% and 80% production plant utilization



2.6 Conclusions

The development of marine LNG infrastructure on the West Coast will be influenced by various supply and demand factors, including the following:

- Natural gas is plentiful in Canada and in British Columbia, resulting in low feedstock costs to produce LNG.
- In the near term, LNG for marine use may be supplied from existing smaller-scale LNG production facilities.
- The West Coast currently has limited LNG production and distribution capacity, and it can be expected that as marine LNG demand increases, new infrastructure investments will be made.
- The potential to access LNG from export facilities for marine use is yet to be determined.
- It should be possible to supply LNG at attractive prices, compared with the fuel oil alternatives, under a range of production and delivery scenarios on the West Coast.

Chapter 3

Economic Benefits

There is a general understanding in the marine industry that, in comparison with other fuels, LNG 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 14 case studies of vessels operating on or visiting the West Coast were analyzed.In addition, three fleet-wide scenarios were considered in order to estimate possible future LNG demand on the West Coast.

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 LNG.

3.1 Model methodology

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

3.1.1 Ship side investment

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

- Type of propulsion system: This strongly affects capital costs. Diesel electric installations, for instance, are inherently more expensive than mechanical drives.
- Fuel systems: Pure LNG engine installations currently require redundancy in the fuel supply, covering the tanks and cold boxes (insulated boxes that house heat exchangers, piping and other cryogenic equipment).
- Regulatory approval: Early LNG adopters will need to bear increased costs for regulatory approval.
- Infrastructure costs: The operator may have to bear additional costs for shoreside bunker infrastructures.
- Labour rates: These will affect the installation costs of both conversions and new builds.

3.1.2 Life cycle operational cost

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. The variables include:

- The cost of fuel
- Fuel price inflation rates
- Engine type and efficiency, ranging from high-speed, 4-stroke diesel to slow-speed, 2-stroke dual fuel
- Load conditions, based on an average load profile
- Ship specifics, such as power and endurance requirements, routes followed, expected vessel life and bunkering profile
- Additional crew training costs

The maintenance cost differential between LNG vessels and fuel oil vessels is assumed to be zero, although this is a simplification given that replacement part costs for an LNG-fuelled vessel are expected to be greater than those for a conventional vessel over its lifetime. Balancing this, LNG vessels may save on operational costs via the decreased consumption of lubricating oil, and longer lubricating oil life due to the clean-burning nature of LNG.

Table 4 shows the energy cost parameters used for the life cycle cost analysis. Fuels include ULSD, which is the primary marine fuel used by coastal operators in British Columbia within the Emissions Control area (ECA); IFO 380, one of the more common fuel oils used by deep sea vessels outside the ECA; and three LNG supply scenarios. The low and high domestic LNG prices reflect the range of delivered cost scenarios, as outlined in the previous chapter, that could apply on the West Coast. The LNG deep sea price reflects the average price of LNG an operator may pay if a vessel is operating on a route between Asia and British Columbia, with bunkering at both ends of the voyage. While some dual fuel engines can use alternative distillate fuels or heavier fuel oils for the pilot fuel, the analysis assumed ULSD for the pilot fuel.

Table 4: West Coast fuel prices by type

Fuel Type	Cost per Tonne	Cost per GJ
ULSD	$1,190.00	$23.80
IFO 380	$600.00	$12.00
LNG domestic price (low)	$524.54	$10.49
LNG domestic price (high)	$774.50	$15.49
LNG deep sea price	$765.00	$15.30
Pilot fuel (ULSD)	$1,190.00	$23.80

Emission Control Areas

ECAs are geographical areas where emission regulations are stricter than in non-ECA areas. The North American ECA will require significant reductions in sulphur emissions. This ECA will extend to within 200 nautical miles of the east and west coasts, but will exclude Arctic waters north of 60° latitude. From 2015 onwards, vessels operating within the North American ECA must use fuel oils not exceeding 0.10% sulphur content. This will replace the current 1.0% limit. LNG offers an alternate compliance option, given that the sulphur content of LNG is effectively zero.

3.1.3 Exclusions from the model

The model does not account for variables 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
- Additional operating costs caused by limited LNG bunkering facilities

3.2 Case study vessels

The 14 vessels used for the case studies fall into the categories below:

3.2.1 Ferries and roll-on/roll-off (RO/RO) vessels

These vessels are assumed to be in service along the West Coast and to operate exclusively within the North American ECA. Capacities are in car-equivalent units (CEUs) except as noted. Table 5 shows details.

Table 5: Case study vessels: ferries and RO/RO ships

Ship type	Capacity (CEU except as noted)	Route Length (nautical miles)	Operates	Bunkering	LNG Engine Type
Ferry (new build)	100	280	Year-round within ECA zone	Once per round trip	Medium-speed, spark-ignited gas
Ferry (conversion)	375	32	330 days/year within ECA zone	Daily	Medium-speed, dual fuel
Ferry (conversion)	125	3.5	330 days/year within ECA zone	Every 3 days	Medium-speed, dual fuel
Coastal RO/RO (new build)	25 trailers	30	Year-round within ECA zone	Every 5 days	Medium-speed, spark ignited

3.2.2 Deep sea cargo vessels

The scenarios consider these to be long-haul vessels plying international waters. All are assumed to operate year round. "Deadweight" is a measure of how much weight a ship can safely carry and is the sum of the weight of cargo, fuel, fresh water, ballast water, provisions, passengers and crew. Table 6 shows details. All deep sea vessels are assumed to have low-speed, dual fuel engines.

Table 6: Case study vessels: Cargo ships on long-distance voyages

Ship type	New Build or Conversion	Deadweight (tonnes)	Route Length (nautical miles)	Time spent in an ECA (%)
Bulk carrier	New Build	175,000	5,200 (Vancouver-Asia)	20
Dry bulk carrier	New Build	55,000	12,500 (Vancouver-South Asia)	20
Crude oil tanker	New Build	105,000	1,250 (Vancouver-Los Angeles)	100
Oil/chemical tanker	New Build	21,000	1,250 (Vancouver-Los Angeles)	100
Container ship	Conversion	30,000	7,200 (Vancouver-Asia)	20
Container ship	New Build	85,000	6,300 (Vancouver-Asia)	20
Car carrier	New Build	22,500	4,200 (Vancouver-Asia)	20
Car carrier	Conversion	22,500	4,200 (Vancouver-Asia)	20

3.2.3 Other vessels

These two ships represent vessels other than ferries and cargo carriers that were included in the modelling. Table 7 shows details. The cruise ship is assumed to have a medium-speed, dual fuel engine. The escort tug is assumed to have a spark-ignited, pure gas engine.

Table 7: Case study vessels: Cruise ships and tugs

Ship type	Deadweight (tonnes)	Route Length (nautical miles)	Operates	Bunkering
2,700-passenger cruise ship (new build)	7,200	1,890 (Vancouver-Anchorage)	4 months/year on West Coast within ECA zone	Once in Vancouver, once in Anchorage for each round trip
Escort tug (new build)	60	Not applicable	Year-round within ECA zone	Every 4 days

3.3 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. Note that all the modelled fuel oil results incorporate fuel switching, rather than the use of scrubbers for achieving emissions compliance.

3.3.1 Propulsion system capital costs

An analysis of 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 (that is, with its conventional power plant instead of the LNG system).

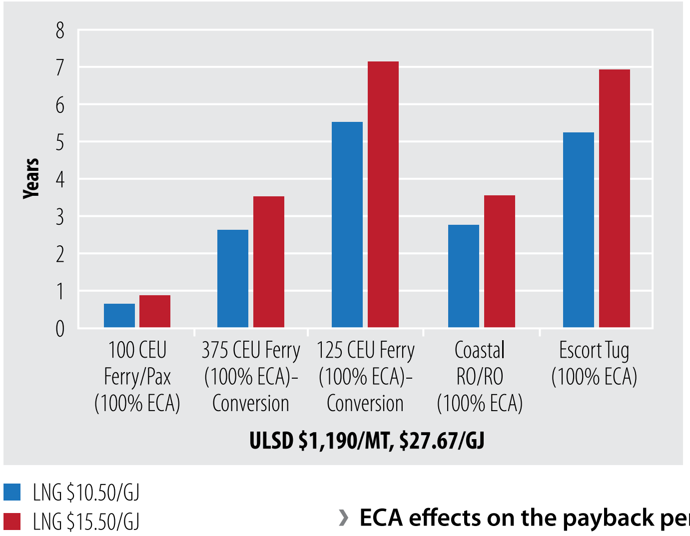
On the new builds side, a fuel oil propulsion system for a 100-CEU ferry would cost about $12 million, while an LNG propulsion system for the same ship would be about $18 million. For a 6,500-TEU container ship, the costs would be $19 million for fuel oil and around $55 million for LNG. For converted vessels, the LNG propulsion system for a 375-CEU ferry would cost about $19 million, and for a 2,200-TEU container ship, around $14 million.

3.3.2 Payback period

LNG use was found to offer significant economic benefits to owners and operators of certain types of vessels. For the six coastal vessel scenarios modelled, five had a payback of less than six years on initial investment (see Figure 11). Annual fuel costs for these vessels were reduced by more than 50%, with estimated fuel savings ranging from $500,000 per year to more than $5 million per year, depending on the vessel type. These findings suggest that, for coastal domestic vessels, LNG may be viable depending on fuel costs, the cost of alternative emission compliance options and vessel usage patterns.

For deep sea vessels, the payback period improved with the amount of time spent in the ECA. For example, there was a 12-year payback period for a dry bulk carrier that spent 20% of its time in the ECA. In contrast, a deep sea cruise ship that spent 100% of its time in the ECA would have a payback period of about one year, which indicates that the ECA effect is quite marked for deep sea vessels. Typically, however, the payback period for these ships is longer than it is for coastal vessels.

Figure 11:
LNG payback period in years for coastal domestic vessels

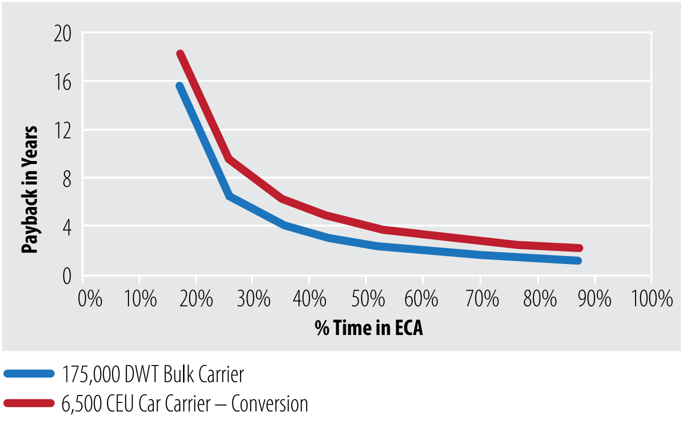


› ECA effects on the payback period

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. For coastal domestic vessels (100% of time spent in ECA), it was demonstrated that LNG may be viable depending on fuel costs and vessel usage patterns. Payback periods are the longest for vessels operating largely outside an ECA and for the converted vessels. In fact, the payback periods for converted vessels that operate primarily outside an ECA can exceed the vessel's expected lifespan and are not viable given the current pricing of intermediate fuel oils.

Figure 12 shows an example of how the time spent in an ECA affects the payback period. The example assumes fuel switching for emission compliance within the ECA; scrubber use, as mentioned earlier, is not modelled. The fuel costs used for this analysis were $600/tonne for IFO 380 (outside the ECA) and $1,190/tonne for ULSD (inside the ECA). The deep sea LNG cost was used and was assumed to be $765/tonne or $15.30/GJ.

Figure 12:
Sensitivity of payback period to amount of time spent in an ECA



Fuel cost effects on the payback period

Figure 13 shows how the payback period for coastal vessels operating exclusively in an ECA varies as LNG prices range from $8 – $20/GJ, against an assumed fixed cost of $1,190/tonne or $23.80 for ULSD.

Figure 13: Coastal vessels: payback period sensitivity to LNG price

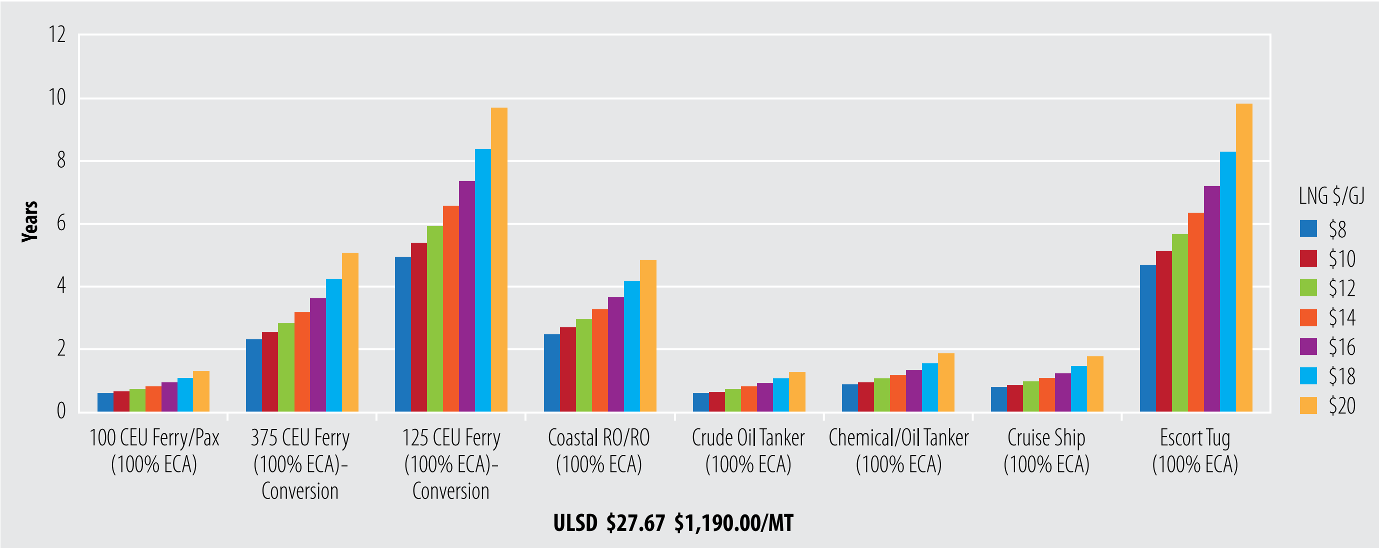
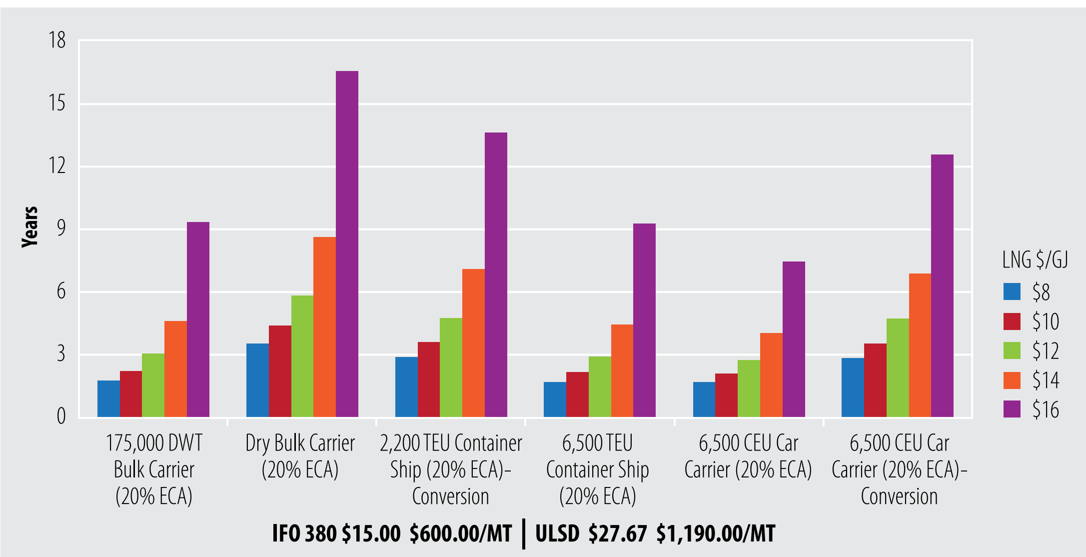


Figure 14 shows how the payback period for deep sea vessels varies as LNG prices range from $8 – $16/GJ, against assumed fixed costs of $600/tonne or $12/GJ for IFO 380, and $1,190/tonne or $23.80/GJ for ULSD. Again, it was assumed that these vessels will operate on IFO while outside an ECA and switch to ULSD inside an ECA.

Figure 14: Deep sea vessels: payback period sensitivity to LNG price



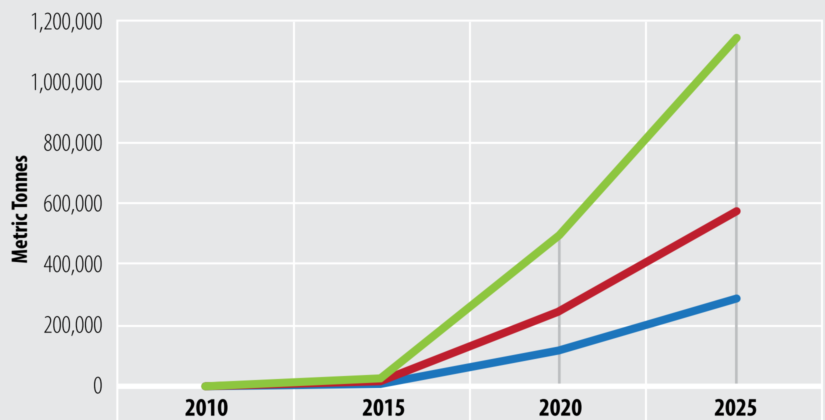
3.4 Fleet analysis and LNG demand

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 one from Lloyd's Register. The medium adoption rate assumes five LNG vessels in 2015, 60 in 2020 and 150 in 2025. The low adoption rate is half the medium rate. The high rate is twice the medium rate.

Figure 15 shows projected demand for all three adoption scenarios, based on actual data for vessels visiting the West Coast in 2011 combined with predicted adoption rates for LNG. The analysis assumed that domestic vessels such as ferries and tugs bunker exclusively on the West Coast, while deep sea vessels bunker 50% of the time on the West Coast of Canada and 50% somewhere else.

The early adopters are most likely to be vessels operating exclusively in ECAs, such as ferries, cruise ships or tankers. This is consistent with what has occurred in Europe, where ferry and short-sea operators have been the first to use LNG as a marine fuel. Container ships and bulk carriers operating on fixed routes within an ECA may also become early adopters.

Figure 15: West Coast LNG demand forecast by adoption rates, 2010–25



	2010	2015	2020	2025
Low Case Demand (MT)	0	2,000	123,000	286,000
Medium Case Demand (MT)	0	4,000	246,000	571,000
High Case Demand (MT)	0	8,000	492,000	1,140,000

Early adopters

The early adopters of LNG are most likely to be vessels operating exclusively in ECAs, such as ferries, tugs, and barges as well as coastal cruise ships and tankers.

3.5 Conclusions

The model used in this chapter indicates that four variables have the greatest effect on the payback period and the life cycle costs of using LNG. They are:

- The price differential between fuel oils and LNG
- The percentage of time a vessel spends in an ECA
- The capital costs of LNG systems
- The amount of fuel to be consumed

In more detail, the model also shows that:

- LNG use can offer significant economic benefits to the owners and operators of certain types of vessels, especially coastal vessels.
- Depending on the size and type of coastal vessel, annual fuel savings with LNG could range from $500,000 per year to more than $5 million per year.
- Of the six coastal vessel scenarios considered, five had a payback on initial investment of less than six years. For deep sea vessels, the payback improved with time spent in the West Coast ECA.
- Realistic adoption rate scenarios indicate that marine use of LNG could lead to significant demand creation for LNG on the West Coast within the next decade.
- Under a “medium” adoption scenario, there would be 150 LNG vessels operating on the West Coast by 2025, requiring approximately 571,000 tonnes of LNG annually. This demand outlook assumes that coastal vessels bunker on the West Coast, while deep sea vessels get half of their fuel supply at the other end of their route, outside Canada.

Chapter 4

Environmental Benefits

This chapter examines the potential reductions in pollutants such as sulphur oxides (SO_X), nitrogen oxides (NO_X), and particulate matter (PM) as well as in GHG emissions that could result from using LNG as a marine fuel. It also includes comparisons of LNG marine propulsion systems with other alternatives for meeting future regulatory requirements. In addition, it examines the potential environmental risks associated with accidents involving LNG.

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 LNG.

4.1 Marine fuels and propulsion options

Natural gas is considered the cleanest of the fossil fuels. Once it is refined to pipeline standards, burning it creates few by-products except for carbon dioxide (CO_2), NO_X and water. In contrast, oil-fuelled engines produce many gaseous emissions and PM, which have undesirable effects on human health and on the environment.

Marine propulsion has been characterized by high emissions, since marine fuels have traditionally consisted of oils of poor to very poor quality. The heavy or "bunker" oil burned by most large ocean-going vessels is often 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_X, which forms acidic precipitates that can damage natural ecosystems. By comparison, marine Otto cycle engines have lower combustion temperatures than diesels, and consequently emit much less NO_X.

In recent years, national and international regulations have focused on the impact of marine transportation on local and global emissions. New ECA regulations require significant reductions in SO_X emissions, with reductions in NO_X emissions also proposed. The impact of the ECA regulations in North America will include fundamental changes in the choice of marine fuels and marine engines. LNG, because it can help reduce many types of emissions, is also a viable choice for new and existing vessels operating in ECA zones.

Traditional marine fuels

Marine propulsion has been characterized by high emissions, since marine fuels have traditionally consisted of oils of poor to very poor quality. The heavy or "bunker" oil burned by most large ocean-going vessels today is often the residue of refining processes and contains even higher concentrations of harmful compounds than the original crude oil.

4.1.1 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 heavy fuel oil (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 by weight has remained quite high, at 1.0%. New standards, however, will limit this to 0.1% by weight within the North American ECA as of January 2015.

The usual diesel fuel for marine use in Canada is known as MGO. In the past, MGO was allowed to have a sulphur content of 1.5% which was higher than the sulphur content of ULSD used for on-road vehicles. Now, however, MGO must meet ULSD standards of 0.0015% sulphur.

Natural gas

The natural gas used to make LNG in North America has a relatively narrow range of chemical constituents, making it a cleaner-burning fuel compared with oil-based fuels. Table 8 shows the sulphur content of West Coast LNG compared with that of commonly used marine fuels. It should be noted that the table shows sulphur limits based on an ISO standard and that these limits are, in some cases, higher than current or future North American ECA sulphur limits for fuel.

Table 8: Current sulphur content of LNG compared with ISO 8217 marine fuel limits

	West Coast LNG	ULSD	DMA (MGO)	DMB (MDO)	RMG 180 (HFO)
Maximum sulphur content	0%	0.0015%	1.5%	2.0%	3.5%

4.1.2 Propulsion systems

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

Diesels

Diesel engines are the mainstay of the marine propulsion market. They are sophisticated machines and incorporate a range of auxiliary equipment to boost power and efficiency.

Gas turbines

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.

Figure 16: Caterpillar/MAK dual fuel, medium-speed LNG engine

LNG engines

As mentioned in Chapter 1, marine LNG engines use three basic technologies: spark-ignited pure gas, dual fuel and direct injection. Pure gas and dual fuel engines operate on the Otto cycle, which generates lower combustion temperatures than diesels. Most current LNG marine engines are dual fuel, medium-speed engines. Figure 16 shows an example.

4.2 Emissions

The main emissions from marine engines are GHGs, SO_X, NO_X and PM.

GHGs

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. Regardless of the type of engine or its operating speed, using LNG rather than oil reduces the amount of CO_2 produced by the engine. This is a result of the estimated 25 – 30% 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". LNG is primarily methane – a potent GHG. LNG-fuelled engines can release (or "slip") small amounts of unburned methane, so for LNG to offer a net environmental benefit in terms of GHG reduction, methane slip must be minimized.

SO_X

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

NO_X

NO_X engine emissions vary with the combustion temperature. The higher the cylinder temperature during combustion, the more NO_X is produced. Diesel engines, operating at higher temperatures regardless of the fuel type, have higher NO_X 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. Table 9 outlines the PM emissions, in grams per kilowatt hour (g/kWh), of common marine fuel oils and LNG. The sulphur content of the fuel oils is given as percentages.

Table 9: PM emissions of marine fuels as a function of sulphur content

	West Coast LNG Sulphur 0%	ULSD Sulphur 0.0015%	DMA (MGO) Sulphur 1.5%	DMB (MDO) Sulphur 2%	RMG 180 (HFO) Sulphur 3.5 %
PM (g/kWh)	0.04	0.25	0.95	1.18	1.88

4.3 Emissions compliance

The principal emission control regime worldwide is the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, which provides for the designation of ECAs. Figure 17 shows the North American ECA as of January 2014. From January 2015 onwards, vessels operating within the North American ECA must use fuel oils not exceeding 0.10% sulphur content. This will replace the current 1.0% limit.

Figure 17: The North American ECA as of January 2014

Under Annex VI, the level of sulphur in marine fuel will be drastically reduced over the next decade, especially in ECAs. Annex VI controls on NO_X emissions have been in effect for new ships since January 2000, but proposed new limits are more stringent. Compliance would require adding exhaust gas recirculation (EGR) or selective catalytic reduction (SCR) systems to standard marine diesel engines, or switching to LNG.

Another recent requirement under MARPOL is the Energy Efficiency Design Index (EEDI). The objective of the EEDI is to reduce the environmental impact of shipping by adopting 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 will apply to an even wider range of vessels in the future.

Meeting EEDI targets will be challenging for many vessel operators. Switching to "cleaner" distillate fuels will actually make it more difficult to comply, since distillates have higher calculated carbon values under the EEDI than even HFO. Using LNG, however, makes compliance easier since it has an EEDI carbon factor that is lower than that of both distillates and HFO.

4.4 Compliance options

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

4.4.1 Emission reduction strategies

The alternatives here include:

› **Fuel switching**

Vessels can use less expensive, higher-emission residual fuels outside ECAs and switch to cleaner distillates, such as ULSD, within them. An alternative is to use dual fuel engines to burn LNG inside ECAs and a residual fuel outside them. In either case, additional space is needed for the second set of fuel tanks and related fuel supply systems.

› **Use of SO_X scrubbers**

SO_X reductions can be achieved using scrubbers, which can reduce the SO_X content of the exhaust by 90 – 95%. The disadvantages of these systems include the space they require aboard ship and their increased power requirements.

- **Exhaust aftertreatment strategies**

Historically, diesel engine manufacturers have controlled NO_X emissions with internal, on-engine changes, rather than using exhaust after-treatment. To comply with proposed new NO_X emission standards, however, off-engine EGR and SCR systems will be required. These systems will affect onboard space and increase operating costs.

4.4.2 Design improvements and slow steaming

Ship design improvements can reduce fuel consumption and thus emissions. Such improvements include better streamlining of hulls and superstructures, and more efficient propellers and propulsion machinery. Reducing vessel speed, a tactic known as "slow steaming," can also cut fuel consumption. Many new ships are being designed to have lower service speeds as well as vessel design improvements which contribute to achieving compliance with EEDI requirements..

4.4.3 Legislative alternatives

Some emission control legislation contains measures that permit non-compliant operations to continue. One such measure is fleet averaging, which considers the total inventory of emitting vessels under one owner, rather than the emissions of individual vessels. A second legislative alternative may be market-based measures, which would allow lower-emitting operators to sell their surplus emissions capacity to higher-emitting operators.

4.5 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 non-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.

4.6 Emissions benefits modelling

Two separate analyses were undertaken to determine the emissions benefits associated with LNG use compared with oil-based fuels. The first analysis was carried out on a full "well-to-vessel" basis using Natural Resources Canada's GHGenius model. The second analysis integrated findings from the GHGenius results and focused on ship-level emissions.

4.6.1 GHGenius life cycle emissions modelling results

The GHGenius study compared LNG emissions to those of marine diesel and ULSD, using two sample vessels, two engine technology options and two LNG supply options. The vessels were a large coastal ferry operating on ULSD and a large cargo vessel operating on marine diesel with a 0.1% sulphur content.

The scenario results show that the GHG benefits of an LNG vessel versus an oil-fuelled vessel depend mainly on the supply chain for the LNG, including the type of energy used to liquefy the natural gas. The efficiencies of the different LNG engine technologies used on the ship were a secondary factor. The calculated life cycle GHG emissions benefits ranged from 10 – 26%, depending on the LNG source.

4.6.2 Ship-level emission modelling results

Building on the GHGenius results described above, it was assumed that the same supply chain variables would apply to the 14 West Coast ship types examined in the case studies in Chapter 3. Key data from the GHGenius results were applied to these vessels, with adjustments for engine types and sizes, operating profiles and other factors. The case studies were then analysed to determine how much CO_2, CO_2 equivalents, NO_X, SO_X and PM were produced annually. The results were as follows:

- CO_2: There was a 20–29% overall reduction in CO_2 emissions with LNG, primarily due to the lower carbon content of the fuel.

- CO_2 equivalent: Depending on the engine technology and type, and with methane emissions factored in, there was a 7–19% overall reduction in GHG emissions on a CO_2-equivalent basis. The calculation for CO_2-equivalent GHGs incorporates the higher global warming potential of methane.
- NO_X: There was a large overall reduction in the NO_X emitted by all the LNG-powered vessels compared with their liquid-fuelled counterparts. Otto cycle LNG engines demonstrated the greatest NO_X reduction with an estimated 85% decrease in NO_X emissions due to these engines' lower combustion temperatures. By contrast, diesel-cycle LNG engines achieved NO_X reductions of about 35%.
- SO_X: The reduction in SO_X production for pure gas engines is essentially 100%. For dual fuel engines, reductions can be 85% and greater, depending on the engine type and the selection of pilot fuel.
- PM: Using LNG reduced overall PM emissions by about 85%, regardless of the fuel oil with which it was compared.

4.7 West Coast emissions reduction

Assuming a medium adoption rate for LNG as a ship fuel, it is possible to calculate the level of emission reductions that could be expected on the West Coast between 2015 and 2025. The tonnages of emissions avoided are shown in Table 10.

Note that while these emission reductions are large in absolute terms, they represent small fractions of the total emissions of ships that call at West Coast ports. The reductions will, however, be more significant in British Columbia's coastal waters, since a higher percentage of coastal vessels as compared with deep sea ships is expected to adopt LNG.

Table 10: Emissions avoided with a medium LNG adoption rate

	Emissions Avoided (tonnes/yr)		
	2015	2020	2025
CO_2	6,760	720,000	1,730,000
CO_2 equivalent	5,860	597,000	1,450,000
NO_X	186	21,900	51,800
SO_X	116	31,100	76,500
PM	23	4,570	11,200

4.8 Conclusions

LNG can help reduce shipboard emissions and ensure compliance with current and pending environmental regulations. Depending on the engine and after-treatment technologies, LNG can lower the exhaust emissions of SO_X by over 85%; of NO_X by up to 35% for diesel-cycle engines and by up to 85% for Otto cycle engines; of PM by up to 85%; of CO_2 by up to 29%; and of GHGs by up to 19% on a CO_2-equivalent basis.

Since LNG is primarily methane, which is a potent GHG, it is important to ensure that methane slip from the combustion process is minimized and that venting and leaks associated with the fuel supply chain are reduced as much as possible.

Until LNG is widely adopted by the deep sea fleet, which currently uses the bulk of marine fuel, LNG use will have a modest, though positive, effect on total West Coast emissions.

Given that coastal vessels are the most likely early adopters of LNG, the emissions reductions will be concentrated in coastal areas, where it will most benefit local communities and human health. The potential for environmental damage due to LNG spills or shipping accidents is much reduced compared with marine oils, given that LNG dissipates rapidly and leaves no slicks or residues.

Chapter 5

Regulatory Challenges

This chapter defines proposed changes to Canada's regulatory framework in order to accommodate the use of LNG as a marine fuel. The recommended actions are critical to ensuring that marine LNG projects can move forward in Canada while ensuring safety, reducing risk and guiding the work of designers, suppliers and operators.

The recommendations for adapting Canada's existing regulatory framework have been developed by reviewing present and planned regulations, rules, standards and guidelines; by conducting hazard identification and risk assessment workshops; and by noting gaps and how best to address them. The recommendations are related to:

- Vessel design and construction
- Operations in coastal waters and waterways
- Bunkering and terminal facilities
- Security, in the sense of protection against malicious acts

5.1 Approach for Canada

Although a full international regulatory framework is not yet in place, there is a significant amount of work now available or in progress on which Canada can draw. Pending completion of the safety code being developed by the International Maritime Organization (IMO), for example, interim IMO guidelines and other safety measures can provide a sound basis for LNG use as a ship fuel. Accordingly, within the scope of this project, an alternate regulatory arrangement that provides an equivalent level of safety when using LNG as fuel aboard Canadian vessels has been drafted for consideration by Transport Canada.

5.2 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:

5.2.1 The 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 ship and the environment that result from the very low temperatures and high pressures involved in gas transport.

› ***International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels* (IGF Code)**

The IGF Code is targeted for completion in 2014 and will cover safety and operational issues for LNG-fuelled seagoing vessels. The mandatory Code will replace the current IMO Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships (adopted as *IMO RESOLUTION MSC.285(86) on 1 June 2009*).

› ***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 ship personnel, based on the IGF Code's personnel requirements for operating LNG-fuelled ships.

› ***International Safety Management Code* (ISM Code)**

The ISM Code establishes safety-management objectives. It requires the entity responsible for operating the ship to establish and implement a safety management system that will meet these objectives.

5.2.2 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, ship/facility interfaces, procedures for connection and disconnection, emergency shutdown and bunkering process control.

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

5.2.3 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 ships.

Classification societies

Transport Canada recognizes four classification societies, each of which has undertaken work with respect to LNG vessels. The societies and their LNG-related work are the American Bureau of Shipping (guides for propulsion and auxiliary systems for LNG-fuelled ships); Bureau Veritas (safety rules for gas engines in ships); Det Norske Veritas – Germanischer Lloyd (LNG engine installations, guidelines for the use of gas as a ship fuel); and Lloyd's Register (rules and regulations for the classification of LNG-fuelled ships).

5.3 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.

5.3.1 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 LNG-fuelled vessels, it has a number of regulations that could provide a basis for developing them. Among these are:

› **Marine Machinery Regulations**

Schedule XII of these regulations deals with all aspects of fuel oil systems for fixed installations. The permissible fuel flash points specified by these regulations, however, do not allow the use of natural gas as a fuel for Canadian-registered ships either domestically or abroad.

› **Marine Personnel Regulations**

These 2007 regulations are based on the most recent IMO and International Labour Organization standards. However, they do not specifically address competency or training requirements related to using LNG as a ship's fuel.

› **Technical Review Process of Marine Terminal Systems and Transhipment Sites Code (TERMPOL Code)**

Established in 1977, the TERMPOL Code was expanded in 1982 to include proposals for marine terminals designed to handle bulk shipments of LNG, liquefied petroleum gas and chemicals. A new edition appeared in 2001. TERMPOL's future is unclear, but its principles will likely be preserved in future codes.

› **Marine Transportation Security Regulations**

These came into force in 2004. They provide a framework for detecting security threats and preventing security incidents that could affect marine vessels and their facilities.

5.3.2 United States

US 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.

5.3.3 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.

5.4 Provincial considerations

Jurisdiction over shoreside LNG infrastructure in British Columbia will involve several provincial ministries, including:

- Ministry of Energy and Mines
- Ministry of Natural Gas Development
- Ministry of Forests, Lands and Natural Resource Operations
- Ministry of Environment
- Ministry of Transportation and Infrastructure

The BC Oil and Gas Commission will also have an important role, given that it is a regulatory agency with responsibilities for oil and gas operations in British Columbia, including exploration, development, pipeline transportation and reclamation. The BC Safety Authority would also be involved in the review of any shoreside LNG infrastructure.

5.5 Port Authorities

Port Authorities facilitate the movement of cargo and passengers by providing safe and dependable facilities, services and technologies. Each Port Authority has a harbour operations manual that complies with Section 56 of the *Canada Marine Act*. It contains location-specific procedures designed to promote safe and efficient navigation within the port and to protect the marine environment.

Port Authorities also publish procedures for safe bunkering within their harbours. These cover pre-delivery, actual delivery and post-delivery requirements, as well as compliance checks and documentation related to bunkering.

5.6 Risk identification and assessment

The risks associated with LNG-fuelled shipping include the hazards associated with operating any vessel – grounding or steering loss, for example – and the risks specific to LNG use, many of which result from LNG's very low storage temperatures as well as its flammability.

Project participants held a series of workshops to identify the hazards and risks that must be addressed by new regulations, standards and supporting documentation for the use of LNG as a marine fuel in Canada. Separate workshops focused on ship operation in coastal waters and waterways; bunkering operations; and shipboard/port/terminal security. The workshops were limited to the incremental hazards relating to the use of LNG instead of traditional liquid fuels.

As part of the workshops, hazards were identified and scored according to their severity and frequency. This gave a risk score, calculated as the severity score multiplied by the frequency score. Risks were identified in four main categories: ship design and construction, ship operation, bunkering and security. For risks with significant scores, the effects of current and proposed regulations were considered. Where one or more regulations was considered to reduce the severity and/or the frequency of the hazard, the risk score was re-assessed on the assumption that the regulation(s) would be applied.

The risk assessments were based on hypothetical scenarios. However, the participants considered the outcomes identified by the assessment process to be reasonably representative of the range of LNG-related hazards. As a result, the gap areas and the actions recommended to address them, as outlined below, offer a robust basis for policy formulation.

5.7 Gaps identified

Findings from the hazard identification workshops with respect to gap areas are outlined in Table 11. Recommended actions focusing on Canada's existing regulatory framework are also summarized in the table.

Table 11: Regulatory framework gaps and recommended actions

Gap Description	Recommended Action
1. There is no Canadian regulatory regime for inspection, construction and safety equipment for LNG-fuelled ships.	Transport Canada to publish an alternate regulatory regime (as provided for in CSA 2001) of inspection, construction and safety equipment for LNG-fuelled ships
2. There is no Canadian regulatory regime to cover the safety risks of operating LNG-fuelled ships in Canadian waterways and ports.	Transport Canada and other stakeholder departments to establish interim policy using the applicable principles drawn from the TERMPOL Code for ports with LNG bunkering facilities
3. There is no basis for assessing LNG bunkering facilities or processes in Canada.	The Province of British Columbia to define LNG fuelling facilities as "oil and natural gas operations-small' under the Environmental Management Act
4. Common guidelines for port rules on LNG bunkering procedures are not yet available.	Authorities to require proposals for LNG bunkering at ports to include Qualitative Risk Assessments, using the methodology of the ISO Guidelines
5. There is no definition of the LNG bunkering process or the division of responsibilities for it.	CSA 2001 Supplement for LNG-fuelled ships to apply the ISM Code to any LNG-fuelled ship
6. Regulations for the use, connection and disconnection of portable LNG fuel tanks are not defined.	Delay consideration of tank-exchange bunkering until the international community has developed approaches to the concept
7. Crew training standards for LNG-fuelled vessels need to be developed.	Participate in IMO development of LNG-fuelled ship crew training requirements, and apply to Canada by CSA 2001 Supplement

5.8 Recommended additions to Canada's regulatory framework

As previously noted, Canada lacks federal regulations specific to LNG-fuelled ships. However, the *Canada Shipping Act (2001)* allows for alternate regulatory regimes if they provide safety measures equivalent to the Act's provisions.

In the longer term, it is expected that new Canadian regulations for LNG-fuelled ships and their operation will be established. In the interim, a regime for applying IMO guidelines, codes and rules to LNG-fuelled ships has been drafted under this project. This proposed regime provides the basis for the following measures, which are recommended for supporting the near-term use of LNG vessels in Canada.

5.8.1 Design and construction of LNG-fuelled ships

It is proposed that Canada:

- Adopt a policy referring to international standards and any specific Canadian deviations
- Establish a Canadian Supplement that provides a high level of safety unique to national demands
- Use the Marine Technical Review Board process to achieve compliance with the *Canada Shipping Act (2001)*

5.8.2 Operation of LNG-fuelled ships in Canadian waterways and ports

It is proposed that Canada, ship owners and port authorities:

- Use the International STCW Convention, which will establish appropriate categories of crew for international LNG-fuelled ships and ensure that crews are qualified to work on LNG vessels

- Perform a risk assessment for any port or terminal for LNG-fuelled ships, using applicable principles drawn from the TERMPOL Code until such time as a new policy specific to LNG projects is available
- Apply the principles of the ISM Code to all LNG-fuelled ships
- Ensure that all harbour operations manuals or equivalent documents incorporate risk mitigation measures that are appropriate given the characteristics and risks of LNG

5.8.3 Bunkering of LNG-fuelled ships

It is proposed that:

- Existing relevant Canadian regulations, rules, guidelines and standards be applied
- Risk assessments be required for individual projects involving LNG bunkering facilities and operations
- The Province of British Columbia lead on regulating bunkering facilities under the *Oil and Gas Activities Act* and the *Environmental Management Act*
- The ship-to-shore interfaces of Canadian deep sea bunker facilities be aligned with the prescriptive parts of the ISO Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships (currently in draft)
- Canadian bunkering ports make it a condition of LNG bunkering that competent port personnel supervise the bunkering operation

5.8.4 Security

The provisions of the Marine Transportation Security Regulations provide a sufficient framework for detecting security threats and for preventing security incidents that could affect ships and their facilities.

5.9 Conclusions

Although a full international regulatory framework for LNG as a marine fuel is not yet in place, it is under development and there is a significant amount of work upon which Canada can draw. It is recommended that Transport Canada adopt an Alternate Regulatory Approval process for LNG-fuelled ships, based on the IMO's guidelines and draft codes for such ships and their crews. Other recommendations include:

- In the design and construction of LNG-fuelled ships, Canada should adopt policies that are based on both international standards and unique Canadian needs, and that comply with the *Canada Shipping Act (2001)*.
- Case-by-case risk assessments should be carried out by harbour authorities to identify and mitigate risks related to LNG vessel projects. The TERMPOL review process can be used as a guide for such assessments. The results should be incorporated into port operating procedures.
- Approvals of LNG bunkering facilities should be based on risk assessments that refer to ISO's draft standard for LNG bunkering, hazard identification and best practices drawn from past projects.
- The IGF Code should be applied to all LNG-fuelled ships, and their crews should be appropriately trained and qualified.
- Canadian ports should require that LNG bunkering operations be supervised by port personnel competent in LNG bunkering.
- Existing Canadian security measures for ships and in ports are considered adequate for dealing with security concerns related to LNG-fuelled ships and bunkering infrastructure. These measures should be applied to new projects in a way that takes the specific characteristics of LNG into account.

Chapter 6

Human Resources

This chapter provides an overview of the competencies required for personnel who are responsible for the safe use of marine LNG on the West Coast. Within the scope of the project, the defined competencies were used to develop outlines for several training courses. Audiences for the proposed courses include:

- Vessel designers
- Seafarers
- Certification and inspection authorities
- Shipyard personnel
- Bunkering personnel
- Emergency responders
- Original equipment manufacturers (OEM) personnel

This chapter also examines sources of knowledge and potential resources for training delivery. It is likely that many personnel qualifications will be subject to regulatory requirements, so the work under this task also influenced the training recommendations outlined in the Regulatory Challenges chapter.

6.1 Human resource categories and required competencies

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

› **Vessel designers**

The use of LNG as a marine fuel is new to most North American designers. Numerous design concepts have been completed, but few have led to construction contracts. It is important to note that the designs of LNG-fuelled vessels, such as ferries, differ significantly from those of other types of LNG vessels, such as bulk LNG carriers.

› **Seafarers**

The operation of an LNG-fuelled vessel differs from that of a oil-fuelled vessel in areas ranging from vessel layout to engine maintenance. Given these differences, officers and crew must be properly trained in order to ensure the safe operation of the vessel.

› **Certification and inspection authorities**

Most classification societies have experience in the LNG carrier industry. Their training programs can be adapted to teach certification and inspection personnel how to ensure that LNG-fuelled vessels comply with requirements.

› **Shipyard personnel**

Training is required to ensure that shipyard workers are aware of the hazards of LNG and of the requirements for constructing or repairing an 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. IMO has extensive training requirements for LNG bunker vessels, but such training is not currently offered on the West Coast.

› **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.

› **OEM personnel**

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. For the most part, such training is currently done in-house by the OEMs.

The project deliverables include a set of recommendations for training course content and the experience required in each of the categories listed above. In each area, the recommendations are drawn from existing sources of knowledge and expertise and are adapted to the needs of using LNG as a marine fuel.

6.2 Sources of knowledge

As the use of LNG-fuelled vessels increases, the experience of existing LNG industries will be invaluable to the marine sector. The following section reviews some useful sources of knowledge.

- **LNG carrier industry**

  The mandate of 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 had several years of experience with LNG-fuelled vessels such as ferries, RO/ROs and patrol vessels. These operators may be a valuable source of knowledge for West 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.

Training for safety

Addressing training needs for seafarers as well as for a range of other stakeholders is crucial to ensuring the safe operation of LNG-fuelled vessels and related operations. In this regard, it is vital to leverage the lessons learned from the existing LNG industry to ensure that LNG's safety record is maintained.

6.3 Training sources, demand and costs

The following organizations currently provide training for the West Coast marine industry. Course content ranges from navigation to naval architecture.

- British Columbia Institute of Technology
- Camosun College
- Justice Institute of British Columbia
- University of British Columbia
- Industrial Marine Training and Applied Research Centre

On the demand side, it is expected that coastal operators will account for most training needs. This is because deep sea vessels operate with international crews, and Canadian seafarers make up a relatively small proportion of their personnel. Table 12 shows the estimated demand for seafarers certified to operate LNG-fuelled ferries and tugs, based on a medium rate of LNG adoption, between 2015 and 2025.

The costs of training should be considered when operators evaluate LNG as a marine fuel. Representative training costs, based in general on existing courses, are given in Table 13.

Table 12: Demand for seafarers certified to operate LNG-fuelled ferries and tugs

Human Resources Demand by Type			
	2015	2020	2025
Crew	35	305	610
Deck Officers	25	230	450
Engineers	20	165	325
Estimated Vessels	5	60	150

Table 13: Representative LNG-related training costs

Course Name	Human Resource	Duration (hours)	Price Per Student
LNG-fuelled Vessel Course – Level A	All crew	30	\$650–\$990
LNG-fuelled Vessel Course – Level B	Officers and crew with LNG fuel responsibilities	90	\$1,950–\$2,970
LNG-fuelled Vessel Course – Level C	Engine and deck officers responsible for LNG operations	150	\$3,350–\$4,950
LNG Systems OEM Training	Engineers	40	\$3,700 (est.)
LNG Ships Training	Vessel designers	16	\$800–\$1,000
LNG Ship Survey Course	Inspection authorities	32	\$1,600–\$2,000
LNG Shipyard Training	Shipyard personnel	7.5	\$200–\$300
LNG Bunkering Operations	Bunkering personnel	30	\$1,000–\$1,500
LNG Fire Suppression and Spill Control	Emergency responders	30	\$1,350–\$1,850

6.4 Sample learning objectives and course outline

Within the scope of the project, learning objectives were identified and several sample course outlines were developed based on the needs of the various target audiences. These learning objectives and course outlines can be used as the basis for developing LNG-related curricula. In Table 14 below, sample learning objectives for seafarers are shown related to LNG fuel handling systems. In Table 15 on the following page there is a sample course outline for the LNG Fuelled Vessel Course – Level A.

Table 14: Sample learning objectives for LNG fuel handling systems

Objectives	Level A	Level B	Level C
1. Describe LNG piping arrangements on gas-fuelled vessels	X	X	X
2. Describe the importance and purpose of double-walled piping		X	X
3. Describe maintenance and testing of double-walled piping			X
4. Explain where remote and manually operated shut-off valves are required	X	X	X
5. Describe the emergency shutdown system	X	X	X

Table 15:
Sample course outline

Program	Level A – LNG-Fuelled Vessel Course
Total Hours	30
Prerequisites	Medium with respect to STCW safety
Course Description	This course familiarizes the seafarer with a basic understanding of the physical properties of LNG, as well as the hazards involved in the handling of LNG. There is a practical component to this course.
Evaluation	To be determined.
Course Learning Outcomes/ Competencies	Upon successful completion, the student will be able to: 1. Describe the properties and safe handling of LNG 2. Describe the technical properties of liquefied and compressed natural gas (CNG) 3. Describe explosion limits 4. Describe ignition sources 5. Describe risk-reducing and consequence-reducing measures 6. Describe rules and procedures that must be followed during normal operation and in emergency situations 7. Describe personal protection while handling LNG and CNG 8. Describe practical extinguishing of gas fires

6.5 Conclusions

Addressing human resources is crucial 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 and hazards, fuel handling requirements and emergency response. In addition to seafarers, a range of other stakeholders will also require training. It is vital to leverage the lessons learned from the existing LNG industry to ensure that LNG's safety record is maintained.

There are currently no national or international standards for crew competencies on LNG-fuelled ships. Training requirements are being addressed at an international level, but will take some years to finalize. In the interim, local delivery of the proposed training courses described above could meet West Coast seafarer training requirements.

Chapter 7

Implementation

The overall challenge for the West Coast marine LNG 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. To do so, it examines:

- LNG marine fuel projects now operating, principally in Europe
- LNG marine fuel projects now being implemented in Canada, the United States and elsewhere
- Current initiatives on the West Coast
- Demand forecasts for West Coast marine and transportation LNG
- Supply chain options to meet potential demand
- Economic and scheduling issues for these options

7.1 Existing projects

At present, Northern Europe is home to most of the installations specifically designed to supply LNG as a ship fuel, as distinct from loading it onto carriers for bulk transport. The following European projects exemplify how this has been done.

7.1.1 Norway

Norway's first LNG-fuelled ship was a ferry that entered service in 2000. Since then, more than 30 additional ferries and other vessels have been added. The country has abundant offshore gas supplies, with some major fuelling terminals being served by pipelines, while others use local networks supplied with LNG by sea. Ship bunkering is from tanker trucks or shore-based tanks, the latter being supplied by truck or feeder vessel.

Figure 18: SeaGas bunkering barge

7.1.2 Sweden

The MS *Viking Grace*, shown earlier in Figure 6, was the first large passenger ferry to be powered by LNG. Its LNG supply chain includes the Baltic Sea's first LNG hub and the first small-scale LNG bunker barge, the *SeaGas*, shown in Figure 18.

The overall LNG supply chain for the Viking Grace uses several transportation modes. At its longest, it begins at an import terminal in Rotterdam, uses an LNG carrier to move the fuel to Nynashamn in Sweden, then employs a tanker truck from Nynashamn to the *SeaGas*, which delivers the fuel to the *Viking Grace*.

Figure 19: MT Argonon

7.1.3 Europe

The MT *Argonon* (shown in Figure 19) is the world's first LNG-fuelled chemical tanker. It operates on the inland waters of Europe and was the first vessel to bunker LNG in Belgium's Port of Antwerp, which has been developing an LNG bunkering infrastructure. The port has already issued a tender for a bunker vessel and is working on a bunkering standard. The *Argonon* is a good example of how regulatory challenges can be overcome, while the Port of Antwerp demonstrates how ports in Europe are developing LNG infrastructure.

7.2 Emerging projects

These include projects for which contracts have been signed and which will eventually establish local LNG supply chains to support demand from LNG ships.

7.2.1 United States

Harvey Gulf International Marine is currently building several offshore supply vessels in Gulf of Mexico shipyards. These will be the first LNG-fuelled vessels, other than LNG carriers, to be built in North America. The first three will be delivered in early 2014 and will be bunkered at an LNG marine fuelling facility under construction in Port Fourchon, LA. Some of these ships will be on charter to Shell, which is planning an LNG barge-and-bunkering operation to transport LNG from a planned small-scale liquefaction plant in Geismar, LA.

7.2.2 Singapore

Singapore, the largest conventional bunkering port in the world, sees the provision of LNG fuel as crucial to maintaining its position as a regional transhipment hub. To help achieve this, Singapore is developing LNG bunkering for deep sea ships and recently opened a large LNG import terminal. Much of the LNG bunkering will be ship-to-ship in order to handle the huge volumes of fuel required by the very large vessels serving Singapore. Such LNG initiatives could complement those in British Columbia by fuelling ships at both ends of their routes, thus reducing the tankage/range challenge for ship owners.

7.2.3 Rotterdam

The Port of Rotterdam is rapidly building an LNG fuelling infrastructure and is planning to bunker early adopters via tanker truck delivery. This will soon be augmented by a shore-to-ship facility within the port. Rotterdam is unusual in that the legal framework for LNG bunkering was fully developed before its first fuelling operations took place. Rotterdam's forecast is that by 2015 there will be 50 deep sea, LNG-fuelled vessels using the Port, with rapid growth from then on.

7.3 West Coast initiatives

These initiatives include short sea shipping via coastal vessels and supply chain infrastructure development.

7.3.1 Short sea shipping

Short sea shipping is likely to provide many of the early LNG adopters on the West Coast. The short sea shipping fleet consists primarily of ferries, tugs and barges, many of which are approaching retirement. Several operators see the need for fleet renewal as a reason for considering LNG as a marine fuel.

BC Ferries, which has been considering LNG as a way to reduce fuel costs, recently issued a request for proposal for building three vessels. The proposal specifies propulsion options that include LNG as well as conventional fuels. British Columbia's Seaspan Ferries Corporation operates a drop trailer ferry service between the mainland and Vancouver Island; the company is beginning a fleet renewal program, which will explore the use of LNG. Washington State Ferries, a United States company, plans to convert six of its vessels to gas-fuelled engines; its close proximity to the operations of BC Ferries and Seaspan could lead to the development of a common LNG infrastructure for all three operations.

7.3.2 Overall demand forecasts and supply capacity

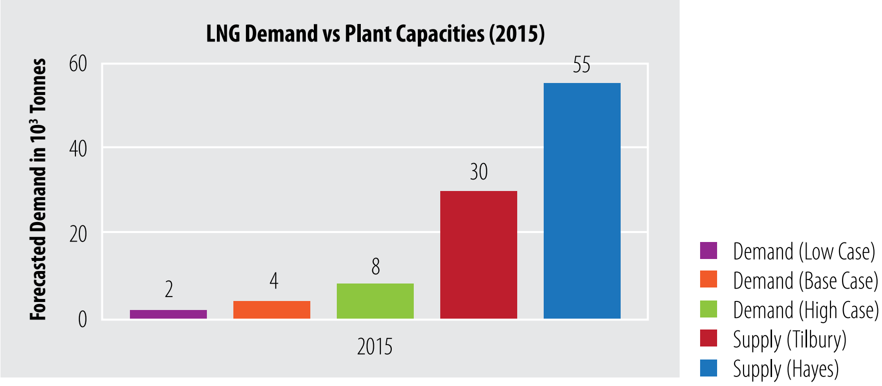
Projections suggest that the West Coast demand for marine LNG will grow rapidly between 2015 and 2025, depending on the LNG adoption rate (see Chapter 3) and on the development of LNG supply in other ports used by deep sea shipping. Demand forecasts are shown in Table 16.

The supply of natural gas required under the demand forecasts can be compared with the current availability from the two existing FortisBC plants at Tilbury and Mt. Hayes, and to plans for adding capacity over the forecast period. Figure 20 shows how the total demand in 2015, 2020 and 2025 compares with current LNG capacity and planned capacity. Planned capacity includes two alternative expansion options for Tilbury that are under consideration by FortisBC. Other LNG supply options may also emerge.

Table 16: Projected West Coast LNG demand by adoption rate, 2015–25

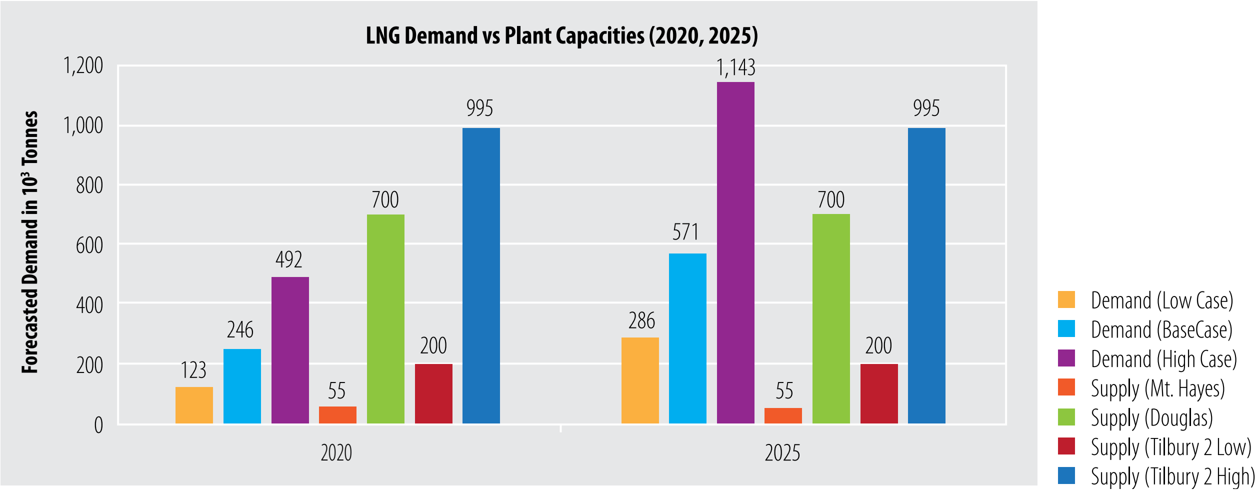
Projected West Coast LNG Demand in Tonnes/Year			
Adoption rate	**2015**	**2020**	**2025**
Low rate	2,100	123,000	286,000
Medium rate	4,200	246,000	571,000
High rate	8,400	492,000	1,143,000

Figure 20: Total West Coast LNG demand versus plant capacities (2015)



To illustrate the scale of demand envisaged, Figure 21 shows the planned capacity for the smallest export-oriented LNG project, located at Douglas Channel (Kitimat). It can be seen that in the short to medium term, there appears to be a reasonable balance of supply and demand. However, there is considerable potential for demand to outstrip supply in the future.

Figure 21: Total West Coast LNG demand versus plant capacities (2020 and 2025)



Projected LNG demand growth

Most of the demand for marine LNG is expected to be based around Port Metro Vancouver, the largest West Coast port. Significant volumes of LNG may also be needed in the Prince Rupert/Kitimat area and in Victoria.

7.3.3 Supply chain infrastructure

Most of the demand for marine LNG is expected to be based around Port Metro Vancouver (PMV), which is the largest West Coast port. Significant volumes of LNG may also be needed in the Prince Rupert/Kitimat area and in Victoria, with smaller requirements for coastal traffic in other areas.

Using PMV as an illustration, the port has multiple container, bulk carrier and cruise terminals, and a number of local ferry operations. Bunkering at each of the existing terminals may have somewhat different supply arrangements, and these may change with time as the demand for fuel increases. In all cases, it is important to operators that bunkering operations are integrated into their overall schedules and do not cause significant delays.

By 2025, an optimized supply chain system, as outlined in Table 17, could include one or more LNG feeder vessels, a small fleet of tanker trucks and several local storage tanks at different terminals. Bunkering operations may use a mix of truck supply, direct feeder vessel transfer to ships, and supply by short pipe runs from shoreside tanks. All of these have to be supplied by adequate liquefaction capacity.

Table 17: PMV Estimated Infrastructure Demand for 2025 – Base Case

Infrastructure Item	Units/Capacity required by 2025	Comments
5000 m3 Bunker Vessel	1	For ship to ship bunkering and supply of shore side tanks
1000 m3 Bunker Vessel	1	For ship to ship bunkering and supply of shore side tanks
Tanker Trucks	7	For truck to ship bunkering and supply of shore side tanks
1000 m3 Insulated Tank	3	Local storage at bunkering locations
5000 m3 Insulated Tank	1	Local storage at bunkering locations
Liquefaction plant	350,000 tonnes	Estimate of production capacity to meet PMV demand
Short-run Pipeline	4	From local storage systems

7.3.4 Investment requirements and scheduling

For ship owners, building vessels to use LNG requires larger capital investments than remaining with conventional fuels and engines. Using the study's demand forecasts, the total additional ship investment projected by 2025 is approximately $2.5 billion for the medium adoption scenario, and over $4.5 billion for the high adoption scenario.

The total shoreside investments needed over the same period are smaller but still substantial. The assets listed in Table 17 will cost at least $350 million and perhaps significantly more. Furthermore, building some of these assets, in particular the new liquefaction plants, may take longer than building the ships themselves. Timing differences could be a challenge for stakeholders in these new initiatives, as is the issue of risk sharing. Ship owners may need to make firm commitments to build LNG-fuelled ships in order to justify shoreside investments.

7.4 Approval process

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 ship in British Columbia 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
- British Columbia Environmental Assessment Office
- British Columbia Utilities Commission
- BC Oil and Gas Commission
- BC Safety Authority
- Port Authority
- Transport Canada
- Department of Fisheries and Oceans
- Environment Canada
- Natural Resources Canada
- National Energy Board

Both the federal and British Columbia governments have been trying to simplify their approval systems, particularly for smaller-scale projects. However, coordinating different approval processes is still a challenge for projects that are subject to multiple regulatory authorities.

7.5 Conclusions

Extensive knowledge about marine LNG projects can be derived from the experience of jurisdictions where they have already been implemented.

Early demand for LNG will come from ferries and other coastal traffic. This will build rapidly to encompass other ship types and stimulate an increasing volume of demand. Much of this will centre on PMV, which will become the primary West Coast port for LNG bunkering. Other British Columbia ports may also begin providing LNG as the market develops.

How LNG is supplied to ships will depend on the nature of the vessels and their operations. Both the ships and the necessary shoreside infrastructure will take a number of years to build and commission.

Chapter 8

Benefits to Canada

Using LNG as a marine fuel will directly and indirectly benefit a wide range of stakeholders, particularly if the West Coast becomes an early adopter. These 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 and contribute to climate change.

- **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 LNG. The availability of LNG at competitive prices could also provide a competitive advantage for British Columbia ports, encouraging shipping companies to select British Columbia as their North American import and export hubs.

8.1 Environmental benefits

Using LNG instead of oil fuels, both in domestic vessels and in deep sea ships entering Canadian waters, will reduce not only the emissions from engine exhausts but also the danger presented by fuel spills.

8.1.1 Emissions reduction

Earlier chapters examined how the marine use of traditional fuel oils produces GHGs, PM, SO_X and NO_X, all of which have undesirable effects on the environment. GHGs and PM contribute to climate change, while SO_X and NO_X produce acid rain, which can harm plants, aquatic animals, humans and infrastructure. PM have the most immediate effects on human health, including lung cancer and cardiopulmonary diseases. As for SO_X and NO_X, these can be oxidized in the atmosphere to form PM and smog that can also be damaging to humans.

LNG, however, produces fewer emissions than any other fossil fuel, and using it instead of oils would reduce emissions on the West Coast.

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.

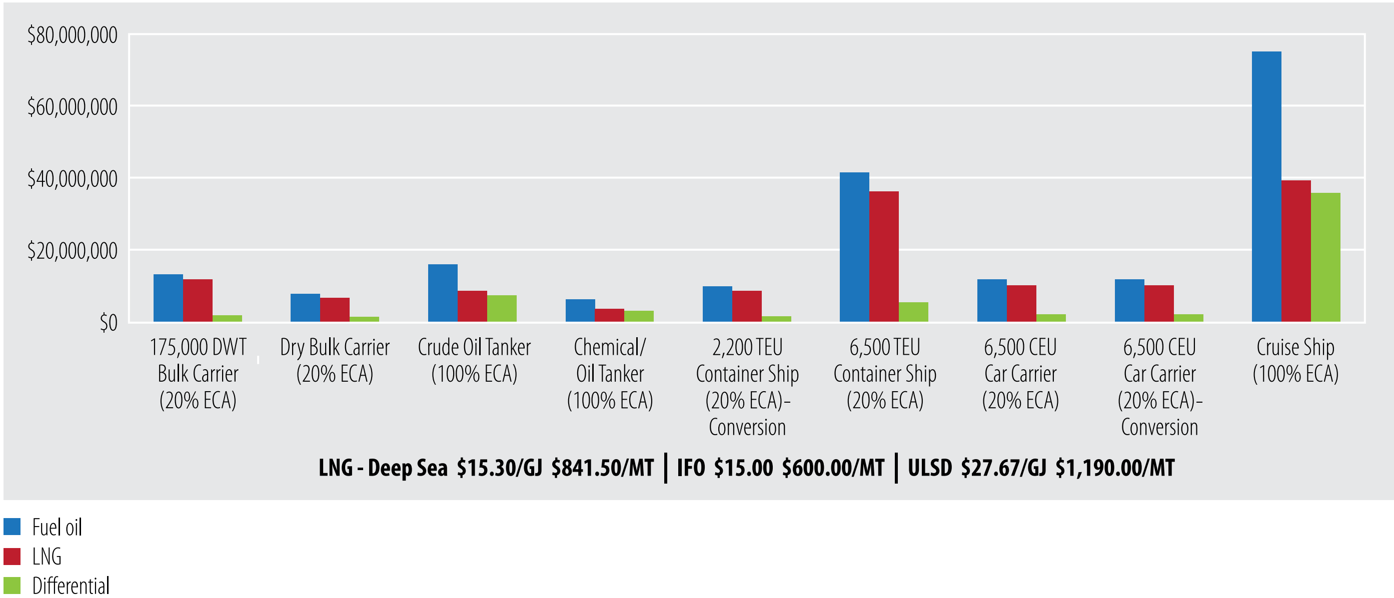
8.2 Economic benefits

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 reduce fuel costs. This provides an ongoing competitive advantage as shown in Figure 22.

Figure 22: Annual energy costs for deep sea vessels (savings differentials in green bars)



8.2.2 Gas producers and distributors

The North American exploitation of unconventional gas resources means that there is an excess of supply over domestic demand, which is expected to persist for some time. There is international demand for natural gas, but Canada's export capacity is currently limited and the projects to increase it are expensive and will take time to complete.

The marine sector represents a new market for natural gas for both domestic vessels and for deep sea ships that currently tend not to purchase fuel in Canada. This could be an opportunity to substitute LNG sales for those of conventional fuel and a way to increase LNG demand. For example, a large container ship consumes approximately 50,000 tonnes of HFO per year. This type of vessel, if operating on LNG, could instead be bunkered using British Columbia's natural gas. The medium adoption scenario, which involves approximately 571,000 tonnes of new LNG demand by 2025, represents annual LNG sales in the order of $300 million.

8.2.3 Industrial and services development

Adopting LNG could lead to a wide range of industrial and service opportunities, including construction, manufacturing, ship building and conversion, and technology development.

› **Infrastructure**

Creating new infrastructure could include the construction or expansion of liquefaction plants, storage facilities, transportation systems and other supply chain components.

› **Shipyards**

While Canadian shipyards are not suited for building very large vessels, they could win orders for specialist or domestic LNG-fuelled ships. Conversions are also a possibility, especially if there is a strong local LNG knowledge and experience base.

Figure 23: Harvey Gulf dual fuel offshore supply vessel

› **Suppliers**

Establishing British Columbia as a centre of excellence in marine LNG may spur suppliers to develop innovative technologies for the supply chain. Wide adoption of marine LNG will also present opportunities for equipment suppliers.

› **Ship designs**

Canadian firms have already won contracts for designing LNG-fuelled vessels, and their association with a new marine LNG infrastructure will help them market their services. As Canadian firms gain LNG design experience, they will be well placed to bid on domestic contracts and may find worldwide market opportunities. Harvey Gulf's new offshore support vessels, for example, are largely designed in British Columbia by STX Marine Inc. (see Figure 23).

› **Bunkering**

Natural gas prices in North America are low compared with those of other markets. Since deep sea ships try to bunker where fuel is cheapest along their routes, LNG-fuelled deep sea vessels represent an opportunity for markedly increasing West Coast bunkering sales.

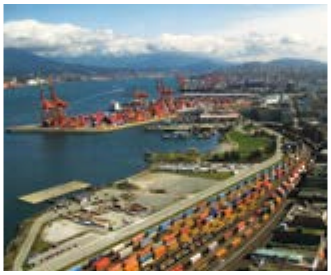
› **Training and services development**

As Canada builds and develops its LNG-related training and services sectors, their capabilities can be parlayed into international offerings of training and engineering expertise.

8.2.4 The Pacific Gateway and trade

Container transhipment is an important part of the West Coast's economy and the Pacific Gateway strategy. Port Metro Vancouver (PMV) can handle today's largest container ships and, in 2010, had over 11% of the container market on the Canada/United States West Coast. Given a fully developed LNG bunkering infrastructure and the expected increase in the number of LNG-fuelled ships, PMV could become an even more attractive destination for international trade.

Figure 24: Rail lines and ship basins at PMV



A second LNG-related advantage for the Pacific Gateway, and for PMV and other West Coast ports, is British Columbia's LNG pricing advantage due to lower feedstock costs. If the province's ports, together with existing and potential LNG suppliers, become early LNG providers, their market position in the bunkering sector could be difficult to challenge. Large-scale LNG bunkering facilities could thus help build trade volumes for the West Coast by attracting more of the deep sea ships that carry trans-Pacific trade. Figure 24 shows part of the transportation hub at PMV.

8.2.5 Non-marine LNG infrastructure

The introduction of the LNG infrastructure required for bunkering LNG-fuelled ships may promote wider adoption of LNG for communities and for road and rail transportation.

Coastal and inland communities could see economic benefits from LNG, since it would give them a way to replace diesel generating stations with an approach that uses a cleaner, lower-cost fuel.

Encouraging LNG use in the transportation sector is consistent with the Pacific Gateway's mandate to increase British Columbia's trade by reducing fuel costs. LNG use could also move into highway trucking, the public transit sector and municipal services such as waste disposal.

8.3 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
- 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 NO_X fund, which supports LNG-fuelled ship projects.

On Canada's West Coast, PMV provides an incentive for future LNG-fuelled ships through its EcoAction program, which reduces harbour dues by 47% for LNG vessels that qualify for the program's Gold level. FortisBC also has an incentive program that began in 2012 and covers marine vessels as well as road vehicles.

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 (such as Singapore) to help build the critical mass of deep sea shipping that will justify new investments by ship operators and LNG suppliers.

8.4 Policy as an enabler

Establishing LNG as a viable alternative to marine oil fuels will be a complex process and will demand a substantial effort in the area of policy development.

8.4.1 Regulatory policies

Creating marine LNG infrastructure will require policies for standards and regulations that deal with its construction, operation and maintenance. This will happen much more effectively if both the federal and provincial governments formalize their policies towards LNG ships and facilities. One key activity is to clarify how the existing regulatory framework can be adapted and used for approving and certifying both LNG projects and the personnel they employ. Additionally, all levels of government could assign the responsibility for approving LNG projects to clearly designated lead agencies.

Regulatory standards and infrastructure development

Creating marine LNG infrastructure will require policies for standards and regulations that deal with its construction, operation and maintenance. This will happen much more effectively if both the federal and provincial governments formalize their policies towards LNG ships and facilities.

8.4.2 Economic policies

It would be very useful to establish policies that help integrate new LNG infrastructure development with existing industry programs, and that support incentives for both developers and communities. Both federal and provincial governments could consider how to use existing projects to help promote LNG. At the provincial and local levels, policies that promote LNG, coupled with attractive LNG pricing, could help raise community interest and thereby encourage the economic, environmental and employment benefits of LNG.

8.4.3 Communications

Effectively communicating the economic and environmental benefits of LNG is important, given that its use as a marine fuel is new in North America. Efforts to proactively educate regulators, policymakers and the public can provide an essential boost for moving forward with greater LNG use in Canada given its potential economic and environmental benefits.

8.5 Recommended actions to achieve benefits

There are major potential environmental and economic benefits to be realized if Canada and British Columbia become early adopters of marine LNG. The following recommended actions could help this to occur.

- Stakeholders should continue to collaborate and use the findings of this report in order to support LNG adoption.
- It is recommended that Transport Canada adopt an Alternate Regulatory Approval process for LNG-fuelled ships, based on the IMO's guidelines and draft codes for such ships and their crews. The gaps in existing Canadian marine regulations, as related to LNG use, present a risk that many potential project supporters are unwilling to accept. As a result, an updated regulatory framework must be established before a significant adoption of marine LNG can take place.
- Federal and provincial governments could formalize their policies toward LNG ships and facilities. To support this, each level of government could designate a lead agency to coordinate all processes for marine project approvals.
- Given that LNG is a new fuel for the marine sector, there may be public concerns and questions related to safety. To help address this area, safety-related information, such as the results of risk assessments for LNG applications, should be disseminated and made easily accessible to the general public.
- The federal government is investing billions of dollars to rebuild Canadian shipyard capabilities. A small fraction of this investment could be designated to help shipyards pursue LNG conversions and new builds. This could help Canada develop a sustainable niche in the global shipbuilding sector.
- At present, ship owners are reluctant to award projects to Canadian shipyards due to their lack of recent experience. The provision of government guarantees could help bridge this gap.

Chapter 9

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9.2 Referenced rules, regulations, codes and standards

The rules, regulations and guidelines most relevant to ship design and construction are contained in numerous publications. The major documents are listed in Table 16.

Table 18. Referenced rules, regulations, codes and standards

Source	Title
IMO	• Resolution MSC.285(86), Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships (adopted on 1 June 2009) • International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk – Cargo Containment (IGC Code) • International Code of Safety for Gas-Fuelled Ships (IGF Code) This code is under development, with a target completion date of 2014 and ratification one to two years later.
ISO	• ISO/DTS 18683, Guidelines for systems and installations for supply of LNG as fuel to Ships (draft) • ISO 28460:2010, Petroleum and natural gas industries – Installation and equipment for liquefied natural gas – Ship-to-shore interface and port operations
SIGTTO / Oil Companies International Marine Forum (OCIMF)	• LNG Ship-to-Ship Transfer Guidelines

Class Rules	Many classification societies now have rules or guidelines for LNG and other low-flashpoint fuels. The list below addresses the five classification societies that are currently recognized in Canada. All societies issue annual updates of their rule sets.
	• American Bureau of Shipping
	  - Guide for Propulsion and Auxiliary Systems for Gas Fuelled Ships (updated July 2013)
	• Bureau Veritas
	  - Rule Note NR 481, Design and Installation of Dual Fuel Engines Using Low Pressure Gas
	  - Rule Note NR 529, Safety of Gas-Fuelled Engines Installation on Ships
	  - BV Guidance Notes for LNG Ship-to-Ship Transfer
	• Det Norske Veritas
	  - DNV Rules for Gas Fuelled Ship Installations
	• Germanischer Lloyd
	  - Guidelines for the Use of Gas as Fuel for Ships
	• Lloyd's Register
	  - Rules for Natural Gas Fuelled Ships

Transport Canada, *Canada Shipping Act 2001*	• TP13585, Acceptance of an Alternative Regulatory Regime for Inspection, Construction and Safety Equipment • TP15211, Canadian Supplement to the SOLAS Convention • TP 743, Technical Review Process of Marine Terminal Systems and Transhipment Sites (TERMPOL) Review Process 2001
USCG	• USCG 521 Policy Letter 01-12, April 2012: Equivalency Determination – Design Criteria for Natural gas Fuel Systems • 49 CFR Part 193: Liquefied Natural Gas Facilities • 18 CFR Part 153: Applications for Authorization to Construct, Operate, or Modify Facilities Used for the Export or Import Of Natural Gas • 33 CFR Part 127: Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas • 46 CFR Part 154: Safety Standards for Self-Propelled Vessels Carrying Bulk Liquefied Gases
CSA	• CSA Z276, Liquefied natural gas (LNG) – Production, storage, and handling • CSA Z662, Oil and gas pipeline systems
National Fire Protection Association (NFPA)	• NFPA 52: Vehicular Gaseous Fuel Systems Code • NFPA 59A: Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG) • NFPA 30: Flammable and Combustible Liquids Code
European Standard (EN)	• EN 13458-2 Cryogenic vessels. Static vacuum insulated vessels • EN 1473:2007 Installation and equipment for liquefied natural gas. Design of onshore installations • EN 1474-3:2008 Installation and equipment for liquefied natural gas. Design and testing of marine transfer systems. Offshore transfer systems
International Electrotechnical Commission (IEC)	• IEC 60079, Part 10, Electrical apparatus for explosive gas atmospheres: Classification of hazardous areas

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