

STANDARDS RESEARCH

Alternative Fuels and Energy Systems for the Marine Sector

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Authors

Jane Dalziel, Change Energy Services

Al Davidson, Change Energy Services

Bob Oliver, Change Energy Services

Rymal Smith, Change Energy Services

Taha Hussain, CSA Group

Mervah Khan, CSA Group

Iris Monner, CSA Group

Project Advisory Panel

Dick Kauling, KauliNG Solutions

Ray Kroll, FortisBC

Ted Williams, American Gas Association

Brent Hartman, CSA Group

Susan Oh, CSA Group

Hélène Vaillancourt, CSA Group

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Executive Summary

Maritime transportation is crucial to world trade. Approximately 90% of all goods traded are carried by marine vessels at some point in their supply chains. Of the more than 50,000 vessels registered worldwide, most are designed for either deep-sea shipping (transporting cargo) or short-sea shipping (moving people and freight in coastal locales). Nearly all are powered by fossil fuel oils, which are burned in combustion engines. These vessels generate 15% of global nitrogen oxide emissions, 13% of sulfur oxide emissions, and 2.2% of carbon dioxide emissions. The International Maritime Organization (IMO), which regulates ship-source pollution, has established progressive targets to manage overall emissions downward over time, achieving at least 50% reduction in greenhouse gases by 2050, en route to a phase out that is consistent with the Paris Agreement's temperature goals.

A transition to alternative fuels in the marine sector is considered critical to achieving the IMO's decarbonization goals. Candidate alternatives must be less-carbon intense than their supply chains today and have a pathway for ongoing decarbonization over the long term as well. In this report, an initial set of nine fuel types were considered, which were pared down to the following five priority systems: liquefied natural gas, biofuels, methanol, hydrogen, and battery-electric.

For each system, a fuel-by-fuel assessment was conducted with insights on marine applications, decarbonization pathways, business case factors, fuelling technology and supply chain readiness, and regulatory drivers and status. Each can leverage existing infrastructure and technology, and each can be made progressively less carbon-intense over time if synthesized from renewable, low-carbon, and carbon-neutral sources. Industry trials and commercial deployments of alternatives fuels are at a nascent stage, with only a handful of pilot projects from which to draw insight, and there is a need to move this work further ahead to ensure a successful transition to alternative fuels.

This research report resulted in the following findings that are critical to this transition to alternative fuels:

1. There is no distinct regulatory framework currently in place for alternative marine fuels, despite the significant number of guidance documents that exist, to guide the operators of ports, ships, and fuel providers in the adoption of alternative fuel bunkering systems. A suitable administrative and regulatory framework needs to be clearly defined so that approval processes are developed with the appropriate Authorities Having Jurisdiction (AHJs) and stakeholder input.

2. Currently, alternative fuel projects are considered and treated as exceptions. Regardless of whether that process follows the "normal" process or if a new process specific to that fuel type is developed, it needs to ensure that all the technical and safety requirements are met. There is significant value in certain AHJs officially adopting existing documents to standardize processes. This could include working with stakeholders and governments to ensure that any learnings and developments coming from their coastal waterways support international regulations, codes, and standards.

3. Standardized equipment and codified procedures are difficult to achieve in the early days of alternative fuel development. A standardized approach for design, deployment, and use of alternative fuels in the marine sector should be developed. This should include ensuring that all the technical and safety requirements are met and confirming the gaps and needs related to design and other technical and operational measures. There is significant value in certain AHJs officially adopting existing documents to standardize processes.



"The International Chamber of Shipping (ICS) estimates that 90% of world traded goods are carried by marine vessels at some point in their supply chains"

1 Introduction

1.1 Overview of the Marine Sector

Maritime transport is the movement of people and goods on navigable bodies of water, including seas, lakes, rivers, or canals that can accommodate the safe passage of vessels. As a commercial sector, it is estimated to comprise of as many as 100,000, by some estimates [1], under the flags of approximately 40 nations, including Canada and most of its major trading partners.

Passenger ships were once a major mode of international travel for people, but that role was ceded to airlines in the 20th century. Travel by passenger ships is now mainly composed of regional ferry services and cruise ships in tourism service. The transport of goods, however, has increased substantially in absolute terms, reaching 10.7 billion tonnes of cargo shipped in 2017, according to the United Nations Conference on Trade and Development (UNCATD) [2]. Perhaps more profoundly, the International Chamber of Shipping (ICS) estimates that 90% of world traded goods are carried by marine vessels at some point in their supply chains [3]. The ICS further reports that more than 1.6 million seafarers currently serve in the global merchant fleet – a figure that does not include indirect or induced employment on land. Looking ahead, these indicators are expected to keep pace with trade; the UNCATD projects that shipments will grow at 3.8% annually up to 2023 [2].

Indeed, many different types of vessels currently comprise the global fleet, and most were designed to perform a specific function. The following examples illustrate a range of distinct vessel designs and applications:

Figure 1: *Vessel designs and applications*

Bulk carriers



Bulk carriers include cargo ships with large hatches to access the holds, often incorporating cranes for loading and unloading dry bulk goods, usually in some unitized form – that is, packaged in bags, pallets and boxes – or liquid goods in drums.



Lake freighters ("lakers") are a type of dry bulk carrier commonly used throughout the Great Lakes and the St. Lawrence Seaway. These vessels tend to specialize in shipping raw materials for primary manufacturing (e.g., steel, cement). Cargoes include iron ore, coal, limestone, as well as some salt and grain (i.e., loose

bulk, non-unitized). Some lakers are equipped with self-unloading conveyors that substantially reduce the time moored at dock.



Tankers are one type of liquid bulk carrier, designed to transport oil or petroleum products. Liquefied natural gas (LNG) is a bulk liquid cargo that is expanding in trade volume. The first ocean cargo of LNG was shipped in 1959. There are now some 550 bulk LNG carriers in service around the world [4].

Container carriers



Intermodal containers represent an increasing share of the total value of global cargo shipped. The containers are generally used for packing unitized dry goods, and are loaded and unloaded from the vessel using shore-based crane systems.

Ferries



Most ferries operate regularly scheduled service for the local movement of people in coastal regions. Some degree of freight transport might be supported. Ferries often form a part of public transportation systems.

In addition to these major groupings of vessel types and functions, many more variations exist, including cruise ships and passenger liners, refrigerated cargo ships, coastal traders designed for local shipping, barges that mainly work inland waterways, tugboats and towing vessels, ice breakers, dredgers, and the list goes on. For the purposes of this report, which focuses on the North American context, maritime transport vessels can be separated into two groups:

- **Short-sea (coastal) and inland waterway vessels,** consisting of ferries, barges, tugs and towing vessels, coastal vessels, smaller cruise ships, Great Lakes freighters, ice breakers, and the Coast Guard fleet; and
- **Deep-sea (oceangoing) shipping vessels,** consisting of bulk carriers, container carriers, tankers, and passenger liners.

Canadian vessels are largely represented in the short-sea group. This fleet includes 113 registered ships in commercial service, of which dry bulk carriers constitute 43% of the ships and 29% of the fleet's shipping capacity (at 2.7 million gross tonnes) [5]. This is the backbone of the fleet, operating alongside a range of cargo vessels and tankers. As for passenger service, approximately 180 [6] ferry routes in Canada deliver an estimated 74 million passengers and vehicles each year [7].

In addition to short-sea transport, Canada's major marine ports on the east and west coasts also serve international deep-sea vessel traffic. The ports of Montreal, Vancouver, Prince Rupert, Saint John, Halifax, and Nanaimo all service container traffic, with Vancouver ranking among the ten largest in North America [8].

Fisheries and Oceans Canada reports [9] that marine sector activity, focusing on transportation (i.e., commercial shipping), tourism, and the building and maintaining of ships and ports, contributed approximately $5 billion to the national GDP in 2015, plus nearly $7 billion in indirect and induced contributions. These figures do not include fisheries and seafood activity or national defence and other public sector activities. Respectively, the associated direct

employment was approximately 80,000 jobs, plus an estimated 8,500 indirect and induced jobs. The Council of Canadian Academies conducted an independent assessment of the value of the commercial sector to Canada's economy, and it reported that *without* shipping, the country's long-run GDP would have been permanently reduced by 1.8% or around $30 billion in 2016 [10].

Looking ahead, one of the most significant challenges to face maritime transportation is that of ship-source emissions of air contaminants and of greenhouse gases from the combustion of marine fuels, which provide propulsion and auxiliary system power for almost all of the vessels. This issue is driving the adoption of cleaner fuel alternatives, and it has implications for all types of shipping and vessels used in North America and around the world. It is also the focus of this report.

1.2 Emissions from Energy Use on Ships

Marine transportation is one of the most energy efficient modes for moving goods [11]. Nonetheless, the sector is a major user of petroleum fuels due to the scale of vessel activity, globally. According to the U.S. Energy Information Adminstration (EIA), worldwide demand for marine fuels in 2018 was approximately 4.3 million barrels per day (approximately 4% of global oil demand) [12], mostly composed of heavy fuel oil (HFO) and marine fuel oil (MFO). HFO, also called "bunker oil," is a viscous, tar-like substance that is the residual of oil distillation into lighter fuels, such as kerosene, gasoline, and diesel. It is the hydrocarbon mixture that remains after the higher-value fuels have been synthesized from crude oil, and many of the undesirable compounds in those fuels remain in HFO, such as paraffins, aromatics, and sulfur. MFO can be considered a higher grade of bunker oil, as its classifications range from distillate to residual products. Both fuels are relatively inexpensive and are commonly used in the internal combustion engines that power ships.

Yet the combustion of these fuels results in emissions that compromise human and ecosystem health. In terms of public health, the types of emissions that are of most concern are nitrogen oxide (NO_X), sulfur oxide (SO_X), particulate matter (PM), and carbon dioxide (CO_2). NO_X and SO_X are classified as criteria air contaminants that contribute to acid rain, and can cause or aggravate respiratory illnesses. PM is also considered an air contaminant, as it threatens respiratory health and is increasingly recognized for its carcinogenic properties [13], [14].

In terms of climate change, CO_2 and PM both contribute to global warming (as do certain species of NO_X). CO_2 is the dominant greenhouse gas (GHG) of concern but PM, in the form of "black carbon," also plays a major role in climate change. Accordingly, the policy of the Government of Canada is to reduce ship-source emissions, similar to the efforts of the United States, and the International Maritime Organization (IMO) and its 175 member states [15].

1.3 International Action on Environmental Impacts

The IMO, an agency of the United Nations, regulates pollution from ships through the International Convention for the Prevention of Pollution from Ships (MARPOL). In 1997, an annex to the convention (Annex IV) established emission limits for SO_X and NO_X. In 2008, the Revised MARPOL Annex IV established a schedule for further reductions of SO_X, NO_X, and PM emissions, and introduced emissions control areas (ECAs) wherein more stringent limits can be adopted. Entering into force in 2010, the Annex IV introduced energy efficiency standards for new and existing ships that complement other efforts by the IMO to reduce GHG emissions.

IMO Strategy on Reduction of GHG Emissions from Ships

In 2018, the Marine Environment Protection Committee of the IMO adopted a resolution entitled Initial IMO Strategy on Reduction of GHG Emissions from Ships [16] that introduces, for the first time, a vision and strategy to reduce GHG emissions from international shipping, which could lead to their elimination as early as this century. The strategy identifies "levels of ambition," in regard to energy efficiency in ship operation and design, and decarbonization of energy use. The "levels of ambition" note that technological innovation and global introduction of alternative fuels and/or energy sources will be integral to achieving the overall ambition. The levels of ambition directing the strategy are as identified as follows in the resolution [18, p. 5]:

a) ***Carbon intensity of the ship to decline through implementation of further phases of the energy efficiency design index (EEDI) for new ships:*** to review with the aim to strengthen the energy efficiency design requirements for ships with the percentage improvement for each phase to be determined for each ship type, as appropriate;

b) ***Carbon intensity of international shipping to decline:*** to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and,

c) ***GHG emissions from international shipping to peak and decline:*** to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 while pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO_2 emissions reduction consistent with the Paris Agreement's temperature goals.

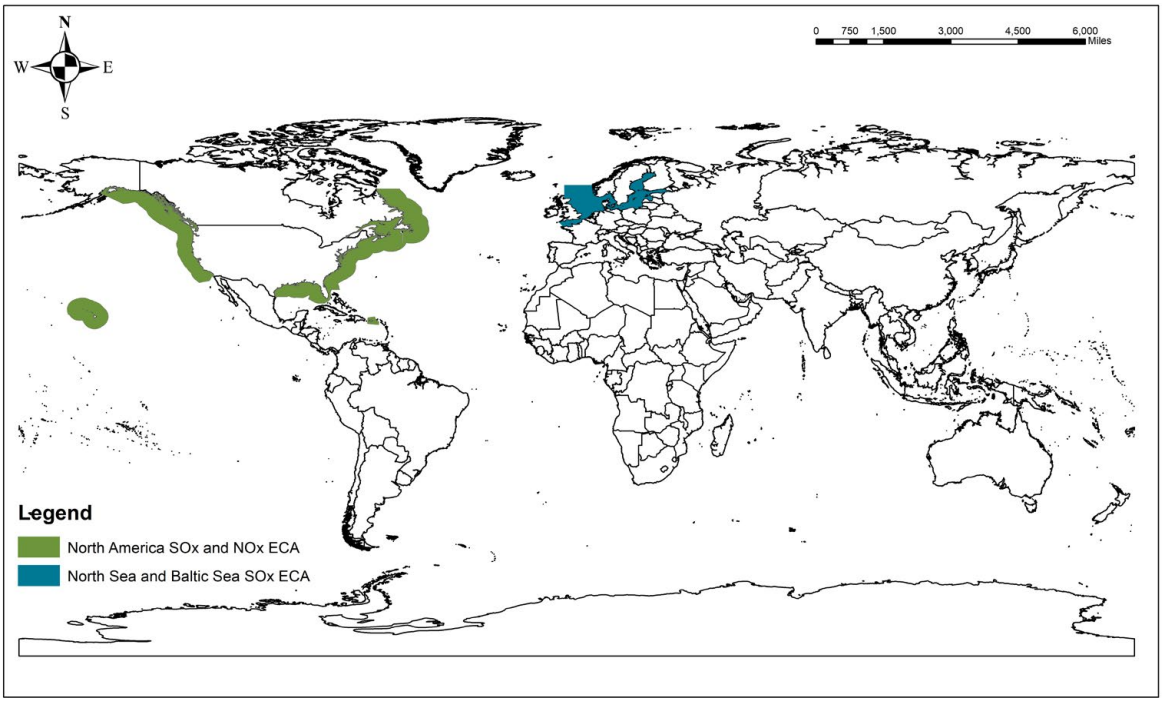
The resolution constitutes a framework for action and is a key driver of the development of alternative fuels and energy systems in the marine sector, both globally and in North America.

1.4 Role of Alternative Fuels

In the near term, fulfilling the IMO's goals will rely on measures that are immediately implementable, with minimal changes to equipment. For deeper reductions in GHG emissions, leading towards their complete elimination, the development of practical, low-carbon fuel alternatives is imperative.

Such alternatives include LNG, ammonia, methanol, hydrogen, and battery-powered electric motors. A desirable quality of HFO and MFO liquids is their relatively high energy density, meaning that the energy required for propulsion and other ship systems can be stored in a minimal volume. On the other hand, less carbon-intense fuels are often less energy-dense, meaning that space otherwise dedicated to cargo is sacrificed to accommodate a larger volume of fuel storage onboard. Both conventional and alternative

Figure 2: *Existing emission control areas around the world*



Reproduced with permission from: Mao, X., Chen, C., Comer, B., & Rutherford, D. (2019). Costs and benefits of a Pearl River Delta Emission Control Area. Retrieved from the International Council on Clean Transportation, www.theicct.org/publications/pearl-river-delta-eca-201907.

fuels can also be synthesized from renewable energy sources or a sustainably sourced biomass, which offers a pathway to decarbonizing energy use with minimal changes to ship engines and vessel refuelling systems. However, the marine sector's ambitions to eliminate GHG emissions is shared with many other transportation sectors, and competition for low-carbon fuel alternatives might limit availability. It is, therefore, difficult to foresee which alternative fuel will become the most practical solution in the long term.

Moreover, the number of short-sea and inland vessels is much larger than the number of deep-sea vessels, but collectively these only contribute around 20% of marine sector emissions. Deep-sea vessels contribute the other 80% [17] and thus carry more of the burden to fulfill the longer-term IMO targets. Yet short-sea vessels, especially in North America, operate more often in coastal ECAs and refuel more frequently. So, short-sea shipping may be the more promising proving ground for technology and infrastructure that can scale up to deep-sea applications.

2 Purpose and Approach

The adoption of alternative fuels in maritime transportation represents a major shift away from long-established processes and procedures within the industry, about which numerous codes, standards, and regulations have been developed and maintained for decades. New supply chains and delivery methods will be needed to bring alternative fuels to vessels in a safe and practicable manner. Some guidance and recommended best practices are already being documented based on early deployments and trials.

The purpose of this report is to review the current landscape for alternative marine fuels, including conducting a needs assessment to identify issues, gaps, and discrepancies related to relevant codes and standards. The report provides insight into priority fuel types, the current landscape of regulations, codes, and standards, and recommendations to move towards using alternative fuels/energy sources leading to decarbonization of marine propulsion.

The scope of the assessment includes:

a) energy/fuel storage on shore;

b) energy/fuel transfer/bunkering (including controls and communication);

c) energy/fuel storage onboard a vessel.

3 Methodology

The general approach consists of the following:

a) Literature review and environmental scan to understand the industry and drivers of change;

b) Prioritization analysis to narrow the scope of alternative fuels to the most practical set of immediate options for the marine sector;

c) Stakeholder engagement comprising a series of interviews and a workshop with marine sector professionals based in Canada and internationally to gather practical insight from those directly involved in alternative fuels and energy systems deployment;

d) Analysis of gaps in the current catalogue of codes, standards, and regulations that apply the use of alternative fuels in the marine sector and analysis of results to identify how standardization can help support the marine industry in Canada; and

e) Development of actionable recommendations based on the assessments.

The outcomes of this approach, including findings and next steps, are presented in the sections that follow.

3.1 Literature Review and Environmental Scan

An environmental scan and a literature review of existing national and international standards, other relevant regulations, and guidelines and their applicability to alternative fuels for marine applications were identified and reviewed. Literature sources included:

a) Government and government agencies;

b) Best practice organizations, including classification societies[1];

c) Industry;

d) Non-Governmental Organizations (NGOs);

e) Media;

f) Research (academia and government).

3.2 Prioritization analysis

The prioritizations of fuels for ongoing consideration (i.e., having a viable role in decarbonization of the marine industry to meet 2050 goals) were analyzed. A fuel-by-fuel overview was provided and assessments completed on the following:

a) Types of vessels that would apply;

b) Potential role in decarbonization pathway;

c) Status and readiness factors, including (i) supply infrastructure, (ii) propulsion technology, (iii) on-shore storage capability, (iv) bunkering capability, (v) onboard storage, and (vi) current regulatory status;

d) Current understanding of the business case;

e) Other factors that might affect adoption; and

f) Relevance to North America.

3.3 Stakeholder Input

Select stakeholders were identified based on their experience and expertise in alternative marine fuels. They were interviewed to understand the extent to which standards on alternative fuels for marine applications are available and implemented. These interviews provided additional context and understanding to determine recommendations that could address the gaps identified from the scoping review.

To further inform this report and seek feedback, a workshop was hosted with marine experts, with the following objectives:

a) Assess and validate content of the research findings to ensure accuracy and comprehensiveness of current industry practices, including:

- Fuel prioritization in terms of short- and long-term fuel and energy choices;
- Current list of standards *used* in North America and determine gaps;
- Relevant regulatory framework and their interface between onshore, bunkering, and on-vessel to determine gaps within the regulatory framework.

b) Validate and refine gaps and recommendations for supporting marine fuel decarbonization.

c) Inform potential development of placemats (pictorial representation) for priority fuels, including regulatory and standards framework.

The results of the workshop have been incorporated into this report.

4 Administrative and Regulatory Frameworks Applicable to Marine Fuels and Fuel Alternatives

This section provides an overview of how marine operations are currently administered within the context of fuels and fuel alternatives and assesses the existing framework of regulations, codes, and standards by region.

4.1 International Framework

The international framework for alternative fuels in the marine sector has become clearer in recent years, driven by interest and investment in LNG systems. The key components of this framework, as detailed below, tend to be more objective based than prescriptive.

Conventions. The IMO governs two international conventions that have direct relevance to the adoption of alternative fuels. The International Convention for the Safety of Life at Sea is the most important treaty,

[1] A non-governmental organization that establishes and maintains technical standards for the construction and operation of ships and offshore structures.



"The international framework for alternative fuels in the marine sector has become clearer in recent years, driven by interest and investment in LNG systems."

dealing with maritime safety, including terms and provisions. On the environmental side, the main IMO pollution convention is MARPOL. Originally created for ocean pollution, MARPOL now addresses air pollution and GHG emissions.

International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code). This compulsory code, in effect since January 2017, applies to all gaseous and other low-flashpoint fuel vessels. It contains mandatory provisions for the arrangement, installation, control, and monitoring of machinery, equipment, and systems using such fuels. While applying to all low-flashpoint fuels, the current IGF Code only has detailed provisions for natural gas, both liquefied natural gas (LNG) and compressed natural gas (CNG) [18]. At the present time, vessels installing fuel systems to operate on other types of low-flashpoint fuels need to demonstrate that their design meets the IGF Code's general requirements. This requires the use of an alternative design approach. While this process can slow the adoption of alternative fuels not yet covered by the IGF Code, relevant class rules such as those comprehensively developed by Det Norske Veritas – Germanischer Lloyd (DNV GL) [19] and Lloyd's Register [20] are typically used to facilitate a resolution.

The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code). This IMO code applies to vessels that are engaged in the carriage of liquefied gases. It applies to alternative fuels in that it allows a vessel's cargo (e.g., LNG) to be safely transferred from the cargo storage to a fuel tank in order to provide energy to the vessel.

ISO Standards and Guidelines. ISO (International Organization for Standardization) is not a regulatory authority; however, ISO standards figure into the overall picture of the international framework as they are seen to be generally applicable in all regions, as is necessary for worldwide marine applications. For this reason, they are referenced here.

To date, the efforts of the ISO on alternative marine fuels have focused on LNG systems. In 2018, ISO/TC 67/SC9 produced a mapping of all existing best practices for LNG equipment and installations [21]. In the case of practices specific to marine fuels (e.g., ISO TS 18683 Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships), these currently only exist as guidelines with no plans to formalize to the level of standards. The mapping includes additional ISO standards not specific to LNG that may be applicable to LNG installations, facilities, and applications. The intent of this mapping was to identify potential gaps and needs for additional standards within the scope of ISO/TC 67/SC9.

Classification Societies. Classification societies deal with the compliance of products and systems onboard a vessel. To do so, they set and apply technical standards (class rules) relating to the design and construction of vessels and carry out extensive

surveys of vessels and their main systems. Global classification societies in the marine sector include DNV GL, Lloyd's Register, Bureau Veritas, and the American Bureau of Shipping (ABS). Of these, ABS is North American-based, while all others are European.

Today, these classification societies are taking a leadership role in the development and sharing of knowledge as it relates to the future decarbonization of the marine industry. The International Association of Classification Societies (IACS), of which all the above are key members, is recognized as the principal technical advisor of the IMO.

Blending of marine fuels is being considered in Europe. Lloyd's Register of Rules and Regulations for the Construction and Classification for the Carriage of Liquefied Gases in Bulk is an amendment to the IGC Code, and is reflected in the list of regulations, codes, standards, policies, and procedures. In Europe, one challenge is that if you bunker in different countries, the jurisdiction is completely different. The European Maritime Safety Agency (EMSA) has a European guideline and provides a roadmap.

European leadership has set the pace for the global adoption of alternative fuels, with initial focus on LNG. Thus, this region has the most experience and the most material on hand to produce a consolidated set of regulatory and best practice instruments for the adoption of LNG. The ISO and the EMSA have organized international and European best practice instruments into a single document. However, all marine-specific technical guidance remains at a guideline level with no immediate plans to develop more formalized regulatory instruments. To date, Canada has taken the position to follow Europe's lead on regulatory matters while ensuring that differences in national marine regulation are identified and addressed [22].

4.2 Canada and U.S. Regulatory Frameworks

While the international framework has set a structure to work from, it leaves significant aspects to the discretion of national administrations. Many countries have developed regulations and codes that, although not necessarily specific to alternative marine fuels, may be used to govern their use and provide a basis for ongoing regulatory development. It's a complex system that varies region to region, and is not consistent across continents.

Countries are considered flag administrations with the legal authority and responsibility to enforce regulations upon their "flagged" vessels and other vessels operating in their waters. Such regulations generally relate to inspection, certification, safety, and pollution. Flag administrations often rely on the expertise of classification societies to guide the development and management of domestic marine vessel requirements.

4.2.1 Canada

At a national level, Transport Canada administers the Canada Shipping Act (2001) which applies to all Canadian flagged vessels and all vessels in Canadian waters (with the exception of Canadian Forces and foreign government vessels). Currently, Canada's only specific rules for alternative fuels applies to the design and construction of LNG-fuelled vessels, in the form of Policy Letter RDIMS: 11153519 Policy Requirements for Vessels Using Natural Gas as Fuel (Transport Canada, 2017) [23]. Other federal authorities that participate at the national level include Marine Occupational Safety and Health, Canadian Centre for Occupational Health and Safety, Impact Assessment Agency, Environment and Climate Change Canada, and Fisheries and Oceans, including the Canadian Coast Guard.

At a more regionalized level, various bodies oversee compliance of shoreside installations and operations.

4.2.1.1 Provincial Authorities

As required, provincial ministries and agencies are involved in the shoreside aspects of bunkering alternative fuels – with LNG being the only such fuel deployed to date. The jurisdictions involved include British Columbia, Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador [22]. Requirements regarding the natural gas supply chain are generally consistent across provinces. The development and operation of new facilities requires some level of environmental impact screening and health and safety oversight. Other authorities at the provincial level include worksafe authorities (e.g., Worksafe NB, Technical Safety BC), utilities, energy regulators, including oil and gas (e.g., Régie de l'énergie, BC Oil and Gas Commission, Technical Standards and Safety Authority), and other provincial environmental assessment agencies.

4.2.1.2 Port and Municipal Authorities

The role of port authorities is to provide safe and reliable services and facilities for vessels at harbour. Each authority has its own harbour operations manual that specifies port practices and procedures developed and published in compliance with the Canada Marine Act.

> **The St. Lawrence Seaway Management Corporation.** The St. Lawrence Seaway Management Corporation governs operations in that waterway and publishes the Seaway Handbook. No specific requirements for alternative fuels currently exist. Other pilotage authorities could include those associated with Atlantic, Great Lakes, Laurentian, and Pacific pilotage. Municipal authorities include local cities such as Vancouver, Delta, and Quebec City that provide permits to operate.

4.2.2 The United States of America

The United States has a regional regulatory oversight structure similar to the one that exists in Canada. In addition to this, it is notable that the US Coast Guard has developed three Policy Letters that encompass vessel design, operation, training, and bunkering practices for LNG:

- CG-521 01-12 (Change 1): Equivalency Determination – Design Criteria for Natural Gas Systems [24]
- CG-OES 01-15: Guidelines for Liquefied Natural Gas Transfer Operations and Training of Personnel on Vessels using Natural Gas as Fuel [25]
- CG-OES 02-15: Guidance Related to Vessels and Waterfront Facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations [26]

Other federal authorities for the United States include the Federal Emergency Management Agency, US Coast Guard, Maritime Administration – Department of Homeland Security, and the Environmental Protection Agency.

5 Scoping the Alternatives for Marine Fuels in North America

To progressively reduce GHG emissions from marine vessels such that their virtual elimination can be achieved, a transition to fuels and energy systems that are less carbon-intense – and eventually net-zero in carbon intensity – is needed. Carbon intensity refers to the sum of GHG emissions released into the atmosphere in the production, transport, and distribution of that fuel to users, as well as the conversion of that fuel to motive power for ship propulsion and to electrical power or heat for other ship systems (e.g., auxiliary machinery, navigation, crew, and passenger systems).

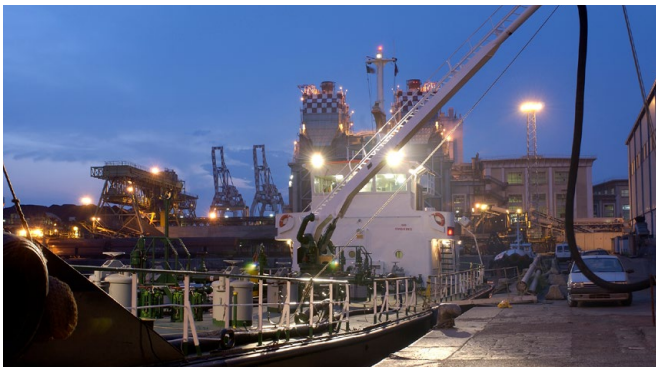
With traditional marine fuels, most emissions usually occur at the time of combustion in an engine. By contrast, the carbon intensity of some alternative fuels may be determined by the emissions produced upstream – in the making of the fuel. Therefore, it is important to consider alternative fuels across the entire supply chain when evaluating the options for specific marine applications.

In this section, a range of alternative fuels will be assessed and prioritized for further consideration in the context of regulatory frameworks.

5.1 Supplying Fuels to Ships – Bunkering

The supply of fuel *for use by ships* is called "bunkering." Note that this differs from the loading of fuel onto a ship as cargo to be delivered; rather, it is loaded as fuel to be used to power the ship's systems. Bunkering is commonly executed in three distinct ways:

Figure 3: *An oil tanker taking on fuel, or bunkering*



Shore-to-ship: While docked ships can take on fuel from a land-based dispensing system, large ports often have storage terminals where fuels are accumulated for dispensing to ships. This method can facilitate fast turnaround and is appropriate for large volumes of fuel transfer.

Ship-to-ship: Fuel is transferred from a *bunker supply ship* to a *bunker receiving ship* while on the water. This method is used when docking at port is impractical.

Truck-to-ship: For smaller ships, a road tanker can park adjacent to a docked ship or simply drive onto its deck and complete a transfer of fuel. This process can be slow, but it forgoes the need for an elaborate bunkering infrastructure. Depending on the situation, several tanker trucks could dispense fuel simultaneously to improve turnaround time.

A variant on the above methods is a containerized transfer, in which a standardized container with fuel is hoisted or driven onto the ship.

5.2 Characterizing and Prioritizing Alternative Fuels

A range of fuels and energy systems are currently under consideration for use in marine applications. An initial set of nine fuel types were considered, as referenced in Table 1. Through a review of available literature and a scan of relevant market data, this initial list was pared down to five systems and prioritized for more detailed study, as follows:

- Liquefied Natural Gas (LNG), including renewable methane;
- Biofuels;
- Methanol, including renewable methanol (i.e., biomethanol);
- Hydrogen (liquid, primarily renewable H_2); and
- Battery-electric – standalone or in hybrid configuration.

Notably, all nine of the candidate alternative fuels/energy systems are either currently petroleum-based or in a form that requires a large energy input to convert them into a viable alternative fuel/energy system. At present, these represent potential pathways to GHG reductions that align with IMO targets.

Details of the five high priority options are described in Table 1 and in the discussion that follows.

5.3 Assessment of Alternative Fuels for Marine Sector Applications

The following is an assessment of the alternative fuels and associated energy systems that were identified as "high priority" in the foregoing assessment. The perspectives shared are informed by the literature review and by interviews with marine sector stakeholders.

5.3.1 Liquefied Natural Gas (LNG)

Figure 4: *LNG storage tank*



Liquefied natural gas (LNG) is natural gas that has been refrigerated to cryogenic temperatures, converting the gas to liquid form. One volume of liquid is produced from about 600 volumes of gas. This makes feasible the transport by ship of LNG as cargo. However, it requires significantly different storage, handling, and infrastructure. To be used as a propulsion fuel, LNG is re-gasified upon injection into the combustion chambers of an engine.

5.3.1.1 Marine Applications

As a marine fuel, LNG has seen most of its early adoption by LNG carriers. In such vessels, the IGC Code enables the diversion of LNG from the tanker load to the fuel container for the engine. Increasingly, LNG is being used in a wider range of vessel types, including tugboats, very large container carriers, tankers, and cruise ships.

As of December 2018, more than 525 LNG carriers were in service (or on order) globally and most were designed to operate using LNG boil-off[2] gases as fuel[3] [27].

[2] The vaporization of a liquid (such as liquefied natural gas).

[3] Even under insulated conditions, heat from the surrounding environment transfers to cryogenic liquids. As the liquid slowly warms, some evaporation occurs. The resulting gases can be vented, captured and stored, or used as fuel.

Table 1: *Fuel Prioritization*

Fuel/Energy System	Infrastructure Readiness	Deep Decarbonization Potential	Status of Best Practices in Marine Applications	Comments	Priority
Natural gas / internal combustion engine (ICE)	**For LNG:** Existing for other transportation and industrial applications. Significant deployment underway for marine applications. **For CNG:** Mature, existing for many other sectors and applications.	Currently capable of delivering a significant but limited reduction in GHG emissions. Broadly applicable for most deep-sea vessel types, particularly LNG carriers. Deep reductions possible through a transition to synthetic LNG, derived from renewables.	First to receive technical provisions through IMO's IGF Code[4]; Canadian and US policy letters, other national frameworks (e.g., Norway), multiple classification rules, guidelines by government and industry organizations (e.g., EMSA, SGMF, SIGTTO).	Embraced early within the marine sector, there is more experience handling LNG compared to other alternative fuels. North America has large reserves of natural gas available for domestic use and export. Constraints to volume onboard a vessel for fuel storage limits the practical use of CNG.	High (for LNG) Low (for CNG)
Methanol / usable in both ICE and fuel cells	Mature, existing as a broadly used industrial commodity.	Generally sourced from carbon-intense fossil sources, but feedstock could transition to renewable feedstock enabling deep decarbonization goals. Broadly applicable for most deep-sea vessel types, particularly methanol carriers.	Technical provisions are currently being fast-tracked in the IGF Code and are expected to be complete next year.	Physical properties of methanol present fewer handling and storage challenges than LNG. Slow to be considered as a marine fuel, its profile could rise rapidly, requiring development of further guidance and best practices.	High
Hydrogen (H_2) / usable in both ICE and fuel cells	Existing industrial commodity with localized infrastructure, mainly for industrial users, but not distributed in volumes that support marine fuel end uses.	Generally sourced from natural gas today, which delivers some GHG emission reductions, but dedication of renewable feedstocks would enable deep decarbonization. Low- or zero-carbon hydrogen, if successfully scaled up, could fulfill GHG elimination goals.	IMO recognizes hydrogen as a fuel for which technical provisions under the IGF Code need to be developed. No timeline set yet.	While there are considerable technology unknowns regarding H_2 for deep-sea shipping, it is still considered a feasible option by stakeholders. In the near term, it's applicability for short-sea shipping is viewed as an important learning ground for infrastructure and regulatory development.	High (for liquefied H_2) Medium (for gaseous H_2)

[4] IGF Code: "The purpose of the International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels is to provide an international standard for ships, other than vessels covered by the IGC Code, operating with gas or low-flashpoint liquids as fuel. The basic philosophy of the Code is to provide mandatory criteria for the arrangement and installation of machinery, equipment and systems for vessels operating with gas or low-flashpoint liquids as fuel to minimize the risk to the ship, its crew and the environment, having regard to the nature of the fuels involved." Quoted from The International Marine Organization (IMO website, under Maritime Safety; Safety Topics; IGF Code).

Fuel/Energy System	Infrastructure Readiness	Deep Decarbonization Potential	Status of Best Practices in Marine Applications	Comments	Priority
Battery / full propulsion power by battery	Very location-specific and reliant on local electricity grid capacity. Infrastructure development for all modes is expanding rapidly.	Zero emission, but at this time limited to smaller vessels running shorter routes.	To date contained in Classification Rules. There are several demonstration projects at this time (e.g., ferries) for which internal guidelines have been developed and used.	Current applicability to deep-sea shipping is not practical, but Li-Ion battery technology development is well-resourced, such that battery chemistry that can serve larger propulsion demands remain an option.	High
Biofuels	Biofuel usage and technical development is considered to be in its infancy for marine applications. Funding available for research is tied to the current price of crude oil. When oil prices are low, there is little economic incentive to switch to an alternative fuel, considering the already established infrastructure catering to fossil-based fuels.	Offer potential synergistic benefits when blended with petroleum fuels by reducing sulfur content and by offering better emission profiles. Initial research and development work for biofuels in marine applications has been sponsored by various US government departments in a bid to reduce reliance on energy imports.	Regulatory guidance specific to marine biofuel usage in the North American marine sector has not been identified. The application of existing guidance is being used as a proxy.	A wider initial introduction of biofuels is likely to depend upon increased environmental regulation of particle and greenhouse gas (GHG) emissions or new business models, including a low carbon footprint. The supply of specific biofuels may be regional and such may not be reliable over the long term, depending on the continued availability of the feedstock and on the processing capacity.	High
Ammonia (NH_3) / usable in both ICE and fuel cells	Existing industrial commodity with localized infrastructure, mainly for industrial uses and fertilizer production.	Ammonia is a carbon-free fuel and its supply chain can be decarbonized if the hydrogen feedstock is from renewable sources, making it a potential deep reductions solution.	None at this time.	Potential exists to use ammonia as a medium to store hydrogen at modest pressures and temperatures, obviating the need for complex cryogenic hydrogen systems. Ammonia could thus enable hydrogen-fuelled propulsion.	Medium
Liquid petroleum gas (LPG) / ICE	Mature, commonly used as an energy commodity with extensive distribution infrastructure currently in place.	Capable of modest reductions in GHG emissions, but not a solution for deep decarbonization. Possibly applicable to LPG carriers.	IMO is not putting any priority on creating specific technical provisions in the IGF Code for the use of LPG as a marine fuel.	Current markets offer higher price-points than the marine sector will likely accept. Current use (as fuel by LPG carriers only) does not require infrastructure-related best practices.	Low

Fuel/Energy System	Infrastructure Readiness	Deep Decarbonization Potential	Status of Best Practices in Marine Applications	Comments	Priority
Battery-based hybrid / electric propulsion, but energy source is non-electric	No unique infrastructure requirements.	Can facilitate zero-emission operation by large vessels for navigation in coastal waters and ECAs.	To date contained in Classification Rules.	No special bunkering solutions are required. Recharging of the batteries is an onboard process involving the ICE.	Low
Dimethyl Ether (DME) / ICE	Dedicated infrastructure is limited, but DME is made from methanol, for which an infrastructure and distribution system exist.	Deep reductions are possible if made from renewable sources (e.g., biomethanol). The advantage of DME over methanol is higher energy density, but the availability of DME is a function of low-carbon methanol production.	None at this time.	Physical properties of DME do not appear to pose severe challenges for storage or bunkering.	Low

Excluding LNG carriers, at the end of January 2019, there were 163 LNG-fuelled vessels in the global fleet, with the biggest subsectors — ferry and off-shore support ships — mainly serving under European flags, notably Norway and Germany. According to DNV GL, the number of (non-carrier) LNG-powered ships is expected to reach between 400 and 600 by 2020 [28].

5.3.1.2 Decarbonization Pathways

Although LNG's carbon content is less than HFO and MFO, it remains hydrocarbon fuel (i.e., methane, CH_4). During combustion, heat energy is released more through the formation of water (H_2O) and less through the formation of carbon dioxide (CO_2), compared to traditional marine fuels. A straight fuel switch to LNG, therefore, directly delivers a reduction in GHG emissions of approximately 21%, all else being equal. This is a significant reduction, but not sufficient to fulfill the IMO targets for 2030 or 2050.

LNG can also be biogenically sourced through various organic waste treatment processes or from agricultural and forestry byproducts. Through these methods, some GHGs are either diverted from the atmosphere or carbon dioxide is taken out of the atmosphere in the growth of feedstock. Biobased or renewable LNG can thus deliver more GHG reductions than traditional natural gas, which is fossil-based. Still, there are practical limits to the amount of biogenic LNG that can be sustainably produced.

Synthetic LNG, produced by combining hydrogen and carbon, can be even less carbon-intense. If the hydrogen is produced from a zero-emission source, such as wind, solar, nuclear, or hydro power, and if the carbon is taken from industrial emitters (or the atmosphere), then the natural gas synthesized could deliver deep GHG reductions.

The long-term pathway may thus begin with an expansion of LNG as an alternative marine fuel, with all the supporting infrastructure and bunkering systems established, followed by a progressive transition to biogenic LNG, and finally to low-carbon synthetic LNG. Since the commodity itself does not change over time, this energy system and infrastructure would remain useful over the long term.

5.3.1.3 Business Case Factors

LNG-fuelled vessels can cost 1.25 to 1.4 times as much as a conventional vessel [29]. Operating cost savings depend on the price differential between natural gas and fuel oil, which has been volatile in recent years. Today, reliable supplies of LNG at stable pricing are emerging, which compete favourably in North America against MFO, even accounting for liquefaction, compression, and distribution costs. The EIA expects LNG to hold this price advantage for the foreseeable future [30].

5.3.1.4 Other Factors

As a light gas, methane can escape into the air at various points in the fuel supply chain. Additionally, "methane slip"[5] is a common occurrence, whereby a small amount of methane leaks from an engine unburned. Methane is a potent GHG, with 25 times the global warming potential of carbon dioxide [31]. These releases can be addressed through industry best practices.

5.3.1.5 Fuelling Technology and Supply Chain Readiness

LNG has been produced and transported internationally in bulk, over very long distances, for more than 50 years. Through a large network of shore-side terminals, there are 20 countries today that export LNG and 42 countries that import it [32]. Global reserves of natural gas were estimated in 2017 by the EIA at 7,124 trillion cubic feet, or enough for at least 60 years at the current rates of global consumption [30].

Offered across a range relevant capacities, LNG engines are usually four-stroke, medium-speed engines, operating with pilot fuel or spark ignition. For the highest power capacities, two-stroke engines are also an option. It is relatively straightforward to retrofit diesel engines on vessels to operate on LNG, using commercially available conversion kits.

LNG bunkering is currently available in over 60 locations around the world, with most in Europe and 70 more facilities being planned. The European Clean Power for Transport Directive requires all larger seaports and Trans-European Transport Networks' core inland ports to have LNG-bunker facilities by 2025. While North America does not have any equivalent initiatives, LNG bunkering is expanding. In the United States, LNG bunkering is available in Jacksonville, Florida, and Port Fourchon, Louisiana. A third facility is being developed in Tacoma, Washington, and bunkering to serve LNG-fuelled cruise ships is in the planning stages for Port Canaveral, Florida [33]. On Canada's west coast, BC Ferries has five vessels in their fleet that are bunkering 22 tonnes of LNG each week [34].

There is a need for LNG storage facilities and debunkering at ports when a ship is to be anchored for an extended period. Without special LNG debunkering facilities in port, large methane losses to the atmosphere would occur as the gas boils off. This is a handling issue for which existing codes and standards might be applied, however the AHJs are usually not clear.

Adequate space onboard a vessel to accommodate LNG storage tanks is a barrier for many vessels. The size of storage is a function of the energy density of the fuel, the amount of energy needed to be bunkered, and the insulation to keep the fuel chilled. Also, the cylindrical shape of tanks that are currently available does not use the space onboard a vessel efficiently. The consequence is that LNG storage can require three-to-four times the volume occupied by conventional fuels. Prismatic tanks are under development, which are expected to reduce the space requirements somewhat.

5.3.1.6 Regulatory Drivers and Status

Most of the progress made towards assisting ports to develop practices and procedures for the bunkering of LNG has occurred in Europe. For example, the EMSA Guidance on LNG Bunkering to Port Authorities/ Administrations offers a comprehensive and current resource designed for this critical stakeholder group [35]. The International Association of Ports and Harbours has also developed checklist tools for various bunkering modes [36]. Further examples of guidelines include:

- ISO TS 18683 Guidelines for systems and installations for supply of LNG as fuel to ships (2018)
- ABS Guide for LNG Bunkering (2017)
- ABS Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America (2013)
- LNG Bunkering Guidelines (IACS Rec 142)

[5] CNG or LNG fuel that escapes from the system unburned. Although this includes leaks from storage and supply systems, it usually refers to methane that is either not burned during combustion (due to a rich fuel mixture) or that escapes past the piston rings.



"Biofuels offer potential synergistic benefits when blended with petroleum fuels by reducing sulfur content and by offering potentially better emission profiles"

Industry guidance for the bunkering of LNG is also available through the Class Societies' Guidelines and the Society for Gas Marine Fuel (SGMF), which were used in launching LNG bunkering along the British Columbia coast.

A comprehensive list of existing regulations, conventions, policy letters, codes, standards, and other documents are found in the Appendix, Tables 2 to 5.

5.3.2 Biofuels

Biofuels are defined as combustible fuels created from plant matter that was recently living (i.e., biomass). There are many types of biofuels and many means of creating them. Biofuels offer potential synergistic benefits when blended with petroleum fuels by reducing sulfur content and by offering potentially better emission profiles. Depending on the biomass feedstock and processing conditions, biofuels can be low in sulfur and nitrogen while also providing a low carbon intensity [37].

5.3.2.1 Marine Applications

In North America, initial research and development work for biofuels in marine applications has been sponsored by various US government departments in a bid to reduce reliance on energy imports [38]. Other pilot projects and trials are taking place around North America, including within the St. Lawrence Seaway. However, biofuel usage and technical development is in its infancy for marine applications.

5.3.2.2 Decarbonization Pathways

There are many factors that determine the carbon intensity of any biofuel, including the type, feedstock, locality processing method, and source of processing energy.

5.3.2.3 Business Case Factors

The cost of biofuels is variable and is based on the type and cost, or lack of cost, of the feedstock. Some biofuels are priced higher than the cost of fossil fuels; however, this cannot be said of all biofuels.

Another factor to consider is that proponents may benefit from the cost of biofuels being sold in the regional currency and being less dependent on the fluctuations in crude oil prices.

5.3.2.4 Other Factors

Biofuels are classified as first, second, or third generation biofuels. First-generation biofuels are produced directly from food crops such as corn, palm, rapeseed, soybeans, or vegetable oil. Unlike first-generation biofuels, second-generation biofuels are waste products from food crops or from plant material not used as food crops. Third-generation biofuels are derived from algae [39]. Using a first-generation versus a second- or third-generation biofuel has implications on the cost as well as on social responsibility and public acceptance.

5.3.2.5 Fuelling Technology and Supply Chain Readiness

In terms of fuelling technology, depending on the type of biofuel, the fuel may be either "drop-in" or only suitable as a blend stock. A drop-in fuel is one that is compatible with the traditional petroleum-based fuel's engine, fuel system, and distribution network.

The supply of specific biofuels may be regional; for example, there may be reliable, viable sources of a specific biofuel in one region, but no capacity to refuel in another region. Furthermore, a regional supply of biofuel may not be reliable over the long term, depending on the continued availability of the feedstock and the processing capacity.

5.3.2.6 Regulatory Drivers and Status

Regulations specifically addressing biofuel usage in the North American marine sector have not been identified, as the usage is not widespread and is typically on a trial basis. As additional projects begin to use biofuels, the need for specific regulations is expected to become a priority.

5.3.3 Methanol

Methanol is classified as a low flashpoint liquid fuel that is colourless and tasteless at ambient temperatures and pressures. Although most of the alternative fuel attention has been paid to LNG in recent years, the profile of methanol (also referred to as methyl alcohol) as a marine fuel has begun to rise. Methanol readily dissolves in water and is biodegradable, so the potential environmental impact of a methanol "spill" is considered to be much lower than that of fuel oil. This also advances the consideration of methanol as a fuel in sensitive marine areas, including polar areas and inland waterways.

5.3.3.1 Marine Applications

As a result of methanol having a lower energy density than LNG, its comparative suitability as a replacement for conventional marine fuels is likely limited to coastal, inland, and short-sea sectors. Large-scale deployment of methanol as a marine fuel has been limited to the conversion of the *Stena Germanica* ferry on the Kiel-Gothenburg route in Sweden. Otherwise, the use of methanol as fuel has been restricted to methanol carriers (tankers).

5.3.3.2 Decarbonization Pathways

Almost all current methanol production methods generate GHG emissions. However, the use of methanol as a fuel (e.g., in an ICE) produces lower levels of SO_x (sulfur levels in methanol tend to be negligible), NO_x, and PM emissions than fuel oil. Its clean-burning properties make methanol a compliance solution under the IMO 2020 sulfur regulations.

Methanol can be produced from biogenic sources, such as landfill gas or biomass. Such feedstocks can lower the effective carbon intensity of the fuel. Methanol can also be produced using low- or zero-carbon sources of power in a process that produces syngas – a mixture of carbon monoxide and hydrogen. Fed into a methanol synthesis reactor, these gases can be converted into synthetic methanol with very low GHG emissions across its supply chain. Yet other methanol production processes are being demonstrated that use carbon dioxide captured from industrial emitters. Thus, there are prospective pathways to net-zero carbon methanol.

5.3.3.3 Business Case Factors

Methanol fuel is currently more expensive than LNG, making operational costs higher (aside from the special case where a methanol carrier uses the cargo as a fuel). However, methanol terminals can be built at about one-tenth the cost. To cover the significant incremental cost, LNG terminals require high-volume throughputs to be financially viable. Methanol may be viable at a more modest scale.

A drawback for long-distance, non-carrier applications is that methanol's lower energy density and heating value requires fuel tanks to be approximately 2.5 times larger than fuel oil tanks and 1.5 times larger than LNG tanks.

5.3.3.4 Other Factors

Methanol is commonly produced around the world, including in Canada, and can be sourced through various processes. Methanol may also be synthesized from hydrogen and oxygen (produced from local green power sources) and from carbon (captured as a byproduct of other processes), resulting in a low-carbon fuel.

5.3.3.5 Fuelling Technology and Supply Chain Readiness

The methanol supply chain is mature, and many of the components have been used in the marine sector for many years. With annual production at about 110 million tonnes, methanol is one of the highest volume chemical commodities shipped around the world each year. Its distribution is served by an existing global terminal infrastructure [40].

Currently, both two- and four-stroke engines are being adapted to use methanol in dual-fuel mode. In these engine adaptations, the fuel-injection system is modified to deliver methanol at high pressure, which is required for ignition. There has been a recent development of a two-stroke dual-fuel ME-LGI engine for low flashpoint liquid fuels such as methanol. This engine was developed to fulfill an order of seven new-build chemical carriers, which will be used as a methanol shipping service [41].

Requirements for the storage of methanol are very similar to gasoline, allowing it to be stored in standard fuel tanks for liquid fuels with some modest modifications [42]. While facilities for loading methanol as cargo are widespread, facilities for the bunkering of methanol as a marine fuel do not exist. The transfer of methanol to vessels can be accomplished by truck or by bunker vessel using common fuel handling technology.

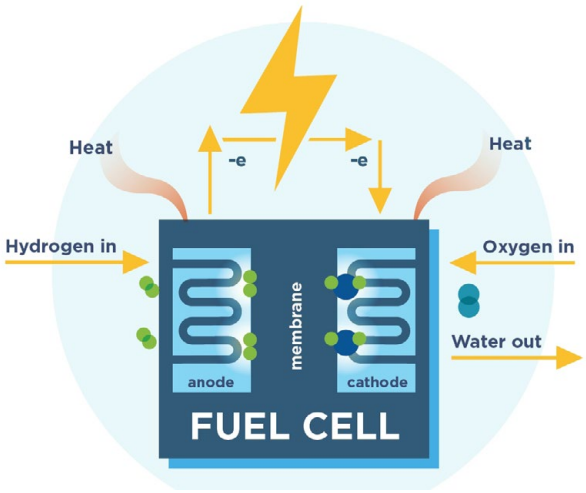
5.3.3.6 Regulatory Drivers and Status

North American ports are regulated as ECAs with sulfur-in-fuel limits, for which methanol provides a compliance solution. Methanol can be a solution for short-sea and Great Lakes vessels that are larger than what is practical for batteries and hydrogen fuel cells at this time. Compared to the scarcity of ports that can bunker LNG, methanol terminals exist at most major ports and, as a liquid, methanol offers an easier and less expensive pathway to develop bunkering capabilities. Canada's large pulp and paper industry can be a source of "black liquor" that is needed to produce renewable methanol (i.e., biomethanol).

Work is currently underway to develop a chapter in the IGF Code to cover technical provisions specifically for methanol. Full regulatory approval is expected by 2023. In the meantime, classification rules for low flashpoint liquid fuels, such as the Lloyd's Register of Rules for the Classification of Methanol Fuelled Ships [43] and rules by DNV GL [19], provide an alternative design and risk assessment process that facilitates approvals by relevant authorities.

Published best practices for bunkering of methanol were not found. On a case-by-case basis, projects should be able to proceed because methanol properties allow it to be bunkered in a manner that is similar to incumbent fuels. Safety guidelines are also available, such as the Methanol Safe Handling Manual [42].

Figure 5: *Fuel cell and hydrogen basics.*



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5.3.4 Hydrogen

Hydrogen is a colourless, odorless, non-toxic gas that can be stored and transported as compressed gas or in liquefied form. As a fuel, hydrogen can be combusted in an engine to generate heat and mechanical power. Hydrogen can also be used in a fuel cell to generate electrical energy through an electrochemical reaction. Both processes produce only water emissions and some waste heat.

Hydrogen engines and fuel cells are mature technologies in niche applications. In most sectors, however, hydrogen is still in an early stage of deployment. For example, two hydrogen fuel cell electric trains entered commercial passenger service in Germany as recently as 2018.

5.3.4.1 Marine Applications

As with other gaseous fuels, space for onboard hydrogen storage is a constraint for many vessel types. Hydrogen is probably best suited for smaller coastal or inland applications, such as ferries and barges. Defined routes and timing of such vessels' arrivals and departures will enable optimal sizing of onshore hydrogen infrastructure and dispensing equipment. Such optimization will be necessary to improve utilization and to keep costs down.

The first hydrogen-powered car ferry is in operation in Norway. On the US west coast, Golden Gate Zero Emission Marine (a private ferry service), supported by funding from the California Air Resources Board, is building a 70-foot hydrogen fuel cell–powered vessel that will transport up to 84 passengers across the San Francisco Bay, beginning in early 2020 [44].

5.3.4.2 Decarbonization Pathways

Currently, at least 95% of hydrogen worldwide is produced through the reformation of fossil fuels [18] – most often natural gas – resulting in a release of GHG emissions (mainly carbon dioxide). If this carbon dioxide can be captured and sequestered, or upgraded into a useful product, then the hydrogen would be considered net-zero in carbon intensity. Hydrogen can also be produced via electrolysis of water. If the electricity used is generated by low- or zero-carbon sources, such as passive renewables (i.e., solar and wind power), or by nuclear or hydro power, then the carbon intensity of the hydrogen is similarly low or zero. Hydrogen can also be synthesized from biogenic sources, in which hydrogen gas can be a direct product of the biodigestion of organic materials and waste.

For deep-sea shipping, hydrogen could provide a deep decarbonization pathway, but the storage challenge may require an unusual solution: hydrogen may need to be bunkered in a liquid organic chemical carrier, such as ammonia. The chemical carrier would be stored appropriately on the vessel and the hydrogen would be extracted as needed, likely through a catalytic process. Deep-sea shipping of hydrogen is currently being tested by Australian agencies using an organic chemical carrier [45].

5.3.4.3 Business Case Factors

The cost of manufactured fuel cells in transportation applications have dropped approximately 60% from 2006 to 2016 [46]. There is potential for the marine sector to benefit from reductions in the price of low-carbon hydrogen that may arise from large-scale hydrogen system deployment on land. For example, hydrogen is considered a decarbonization option for long-haul trucking, steelmaking, and cement manufacturing [47]. Low-cost electricity powering grid-scale electrolysis plants are a potential source of large volumes of hydrogen fuel. For example, a 20 MW electrolysis plant in Quebec is being built to produce hydrogen using the province's low-carbon hydroelectricity system [48]. Such developments could make hydrogen more accessible to the marine sector at a suitable price.

5.3.4.4 Other Factors

In vehicle applications, hydrogen fuel cell electric powertrains usually integrate a battery pack. The fuel cell is the prime generator of power. It can deliver propulsion power directly but it can also be used to maintain the battery pack at an ideal state-of-charge. In such systems, the battery manages the fluctuating demand for power, while the fuel cell manages the overall demand for energy. The more hydrogen energy stored onboard a vessel, the greater the operational range. This design keeps the fuel cell and the battery pack minimally sized, which controls cost. As the cost of battery technology drops, hydrogen fuel cell systems may also become more economical.

5.3.4.5 Fuelling Technology and Supply Chain Readiness

Infrastructure to support hydrogen production and distribution as a transportation fuel is nascent and regionally concentrated. Also, most industrial hydrogen is produced via steam-methane reforming, a process that releases GHGs into the atmosphere. Ramping up production of low-carbon and renewable hydrogen will require considerable investment.

Hydrogen storage technology is well established with codes and standards in place for compressed gas and liquefied hydrogen. Super-insulated, low-pressure vessels are the most common way to store

large quantities of liquid hydrogen. Standard 40-foot containers hold around 3,600 kilograms of hydrogen but stationary use tanks can hold up to 6,700 kilograms [18]. For gaseous storage, Type I metal cylinders are the most common and currently the least expensive.

Norway is currently the only location undertaking initiatives to bunker hydrogen. Local authorities are engaged in the development of acceptable procedures. Otherwise, bunkering practices and facilities for hydrogen do not exist. In their publication entitled Use of Fuel Cells in Shipping, EMSA discusses the development of LNG bunkering practices that can be a guide for practices that will likely be required for hydrogen [49].

The main challenge facing hydrogen storage is volumetric energy density. As a compressed gas, it requires 10 to 15 times as much volume as HFO to achieve the same energy [18]. Even as a liquid it requires almost five times the volume. This tends to put hydrogen fuel at a disadvantage for the propulsion of deep-sea shipping vessels.

5.3.4.6 Regulatory Drivers and Status

The IGF Code covers the use of hydrogen as a marine fuel; however, no hydrogen-specific technical requirements have been developed yet. As such, a hydrogen fuelling project needs to be treated as an alternative design accompanied by a full risk assessment. Note that early efforts to develop hydrogen as a bunker fuel currently leverage LNG practices [49].

5.3.5 Battery-Electric

Batteries can store and dispatch electrical energy onboard a vessel to help optimize engine fuel efficiency or to facilitate zero-emission, fully electrified operations. Among the battery chemistries currently available, lithium-ion technology is one of the most promising and popular [50].

On marine vessels, battery-electric systems are likely to be configured in one of three ways: fully electric, plug-in hybrid, and hybrid. Fully electric means that the batteries store all energy required for ship systems and deliver power as needed. This depletes the charge in the batteries, which must be recharged by "plugging into" an external source of electrical power. A plug-in hybrid ship has batteries that can be recharged by an external power supply, but it also has a conventional internal combustion engine. Such a ship can shut down the engine and operate strictly on batteries on specific parts of the route, such as when manoeuvring in port. A hybrid ship uses batteries primarily to increase the performance of an engine; the batteries are not recharged by an external supply of power. Rather, the batteries work in an integrated manner with the engine, sharing the load for propulsion power. The batteries are recharged by a generator connected to the engine when demand for power is low, and they dispatch power to the electric propulsion system when demand for power is peaking.

5.3.5.1 Marine Applications

Relative to conventional liquid fuels, batteries have poor energy density. The amount of useful energy retrievable for the volume that they occupy makes them comparatively large and heavy, limiting their practical use for the propulsion of deep-sea shipping vessels. Batteries are better suited to smaller coastal or inland vessels where the zero-emission, high-efficiency performance of electric motor propulsion is highly valued and where opportunities for frequent recharging exist [51].

Several ferries (both newbuild and retrofit) have been equipped with large battery systems in a hybrid configuration. The biggest to date is the 2.7 MWh battery system installed on Scandlines' *Prinsesse Benedicte,* operating between Shælland (Denmark) and Puttgarden (Germany). Three sister ships are now equipped with similar systems.

The first fully battery-electric ferry, *MF Ampere,* with a capacity of 360 passengers and 120 cars, went into service in 2015 in Norway's Sognefjord. The ferry makes the 5.6-kilometre crossing 56 times a day and is powered by lithium-ion batteries that are recharged during the ten-minute period at dock between crossings, using power from the shore-based grid access point. In Canada, BC Ferries aims to add 12 hybrid-electric vessels to its fleet in the near term. These are smaller ferries, capable of transporting up to 50 cars in regular coastal service. Two of the 12 have recently been built and will be received shortly.



"The first fully battery-electric ferry, MF Ampere, with a capacity of 360 passengers and 120 cars, went into service in 2015 in Norway's Sognefjord."

Figure 6: *Ferry with electric propulsion.*

5.3.5.2 Decarbonization Pathways

At the point of use, where battery packs discharge energy to power the electric propulsion and auxiliary systems of a vessel, no emissions are produced. However, if the mix of generating sources powering the grid includes some carbon-intense processes, such as the burning of coal, then the battery solution is not zero-carbon. Efforts to decarbonize grid power will make ship electrification an increasingly important pathway to eliminating GHG emissions.

5.3.5.3 Business Case Factors

Battery systems powering electric motors are capable of converting 90% of the energy received into motive power at the propellers – about twice that of ICEs. This reduces running costs. However, the capital and installation expense of battery systems is currently high. Prices are dropping – by 50% over the past four years [18], and this trend is expected to continue. The business case for battery-based ship propulsion requires the initial expense to be recovered through operational savings. In areas with low electricity prices, capital costs can be recovered more quickly.

In the case of BC Ferries' program of electrification, recharging must occur very quickly, while vessels are docked and transferring passengers. This requires a rapid transfer of large amounts of electrical energy, which requires a large power connection. The rate structure for electricity incorporates charges that increase according to the level of the customer's power connection. These additional charges increase the cost of the electrical charging solution, yet they are still less than the expense of fuelling the ferries with diesel. A possible solution for avoiding demand charges is to establish energy storage at port, which charges at a modest rate over longer periods and then rapidly discharges to the vessel while docked. However, the cost of most energy storage technologies still exceeds grid operator demand charges.

5.3.5.4 Fuelling Technology and Supply Chain Readiness

Supplying electrical power for recharging batteries onboard a vessel in port does not require new onshore infrastructure technology. However, the ship-to-shore interface may require some innovative solutions. In the case of BC Ferries, for example, the power connection for its first fully electric ferry must accommodate tidal levels that can vary by as much as six to seven feet and a rate of electrical energy transfer of 2.5 to 3 megawatts for up to ten minutes. The design voltage for the ferry's main electrical architecture is 1,000 volts for direct current. This implies a charge current over the ship-to-shore interface of 2,500 to 3,000 amps. Physically, this

interface must operate reliably in harsh environmental conditions, characterized by heavy weather and saltwater spray. Also, the scheduled stops at port are very brief, which is why rapid transfer of electrical energy is so important.

The fully electric vessels that BC Ferries plans to deploy are being purchased as hybrid ships. Upon receipt, the vessels will be retrofitted for fully electric propulsion before entering service. This involves upgrading the 800-kWh battery that is part of the original hybrid system to 2,000 kWh, using lithium-ion batteries supplied by Corvus, based in British Columbia. The original engine remains onboard to serve in a back-up capacity for propulsion power if the batteries are depleted. Crossings are relatively short – 10 to 40 minutes and covering a distance of two to five nautical miles. These parameters press the technical limits of the battery solution.

BC Ferries' longer-term fleet plan envisions additional vessels with progressively lower-carbon propulsion solutions to serve longer routes, such as Vancouver to Victoria. With as little as 25 minutes at dock to recharge, these larger vessels could require power levels as high as 35 MW, which is unprecedented in marine applications. For smaller ports, some new grid infrastructure may need to be installed as the power demand of a vessel recharging may exceed the capacity of the existing wires and transformer stations. Alternatively, passive renewable power systems could be installed at nearby ports, providing zero-carbon energy directly to an onshore energy storage system (e.g., a bank of batteries, mechanical flywheel), which could assist in ship recharging.

5.3.5.5 Regulatory Drivers and Status

The IMO does not provide any explicit technical provisions for the use of batteries for marine propulsion. The primary focus of relevant regulations is the safety of battery systems and their onboard installation. Classification societies have developed rules for this purpose and continue to refine them as battery technology evolves and is adopted.

Shore connections for recharging are governed by regulations and other requirements that have been established for the electricity grid.

BC Ferries operations are governed by Transport Canada regulations, with Bureau Veritas effectively acting as the delegated authority on ship classification services. On the landward side, the safety authorities are also recognized and understood. The main challenges lie with the ship-to-shore interface, which are technical and procedural, in that the AHJs are not always identified. Only a few reference cases currently exist in Norway. Industry standardization must confront a challenge that all ferry operations are unique in their own way, meaning that custom solutions are usually needed.

6 Findings and Recommendations

6.1 Findings

6.1.1 Onshore

The analysis of the priority alternative marine fuels and associated energy systems as identified in Section 5.3 reveals that the onshore storage systems and on-vessel systems are sufficiently covered in existing regulatory frameworks. For onshore storage systems, the alternative fuels are considered to be commonly transported commodities, with many being the same chemical compounds that are regularly shipped to and stored at shoreside terminal facilities. Additionally, as LNG, CNG, and hydrogen have been introduced as fuels for road transportation, this has resulted in the development of a regulatory framework with codes and standards for storage and handling that can be referenced to support shoreside use of these fuels.

6.1.2 On-vessel Systems

Similarly, for on-vessel systems, the IGC and IGF Codes, complemented by rigorous classification rules (by fuel or energy system) such as those developed and administered by DNV GL and Lloyd's Register, address all on-vessel needs for vessel design, construction, and operation. Flag administrations may engage a classification society to issue their own interpretation of the IGF Code (e.g., through a policy letter) to ensure that national priorities are addressed.

6.1.3 Bunkering

The main gap that exists is the bunkering systems, specifically the process of bunkering an alternative fuel across the shore-to-ship interface. For the identified



"As part of the regulatory framework gap, there is a lack of clarity on identifying the proper authority to accept the design and installation as it is being developed."

alternative fuels, there is currently varying levels or no standardized approach to guide the operators of ports, ships, and fuel providers in the adoption of alternative fuel bunkering systems and approve projects for marine applications through the regulatory framework. As an example, Transport Canada has processes available for equivalent levels of safety for the use of a fuel onboard a vessel; however, it does not cover all aspects of an alternative fuel project such as bunkering and processes for transferring fuel from source to ship.

Although there are significant numbers of documents that provide general guidance for fuel bunkering, with the technical means existing to develop these systems, there is no mechanism to authorize the guidance documentation, to approve the design, or to certify the installation. Many projects are at the early stages of trials and adoptions, where the bunkering of cryogenic liquids (e.g., liquefied natural gas or hydrogen), high-pressure gaseous fuels, electrical energy, or liquids with properties that differ from typical marine fuels (e.g., methanol, ammonia), require engineering solutions that, as discussed in Section 5 of this report, are often first-of-a-kind, custom-designed for specific applications, scales of operation, and local port conditions that may be unique. As a result, alternative fuel projects are currently considered and treated as exceptions. For example, in Canada, proponents are required to submit a regulatory exemption or replacement to the Transport Canada Marine Technical Review Board. This may require showing compliance to existing requirements or guidelines meant for other types of fuels and lead to unnecessary steps, additional work, confusion, and cost, in some cases.

As part of the regulatory framework gap, there is a lack of clarity on identifying the proper authority to accept the design and installation as it is being developed. The AHJs can vary among different regions, and it is unclear what organizations are obliged to select and enforce the regulations deemed to apply in different alternative fuel bunkering projects. While Transport Canada has jurisdiction over the vessel, it is unclear whether Transport Canada has oversight of the fuelling stations (i.e., bunkering) or if this falls under another AHJ that have jurisdiction of the port and of risk-level related requirements such as port authorities, which are independent. Although it may not be feasible to have a single AHJ cover all project aspects in order to provide clarity to the process and regulations, the approval process for alternative fuels could be made simpler.

Another finding that emerges from the literature review is the need for standardization. The large number of guidance documents reflects the regional and somewhat ad hoc development of alternative fuel projects. For example, transferring one guidance document that was developed for a project in one region over to a project in another region – where it is potentially applied to a different technology, in a different application, and in a different climate. For example, ISO 7536 refers to the duration of oxygen stability but does not provide a clear indication of its applicability to marine use. For other fuels like methanol and ammonia, there are

transfers of cargo frameworks but no standards on bunkering. Similarly, for electrical systems, there is a gap for addressing the energy transfer with existing ISO standards for the plug only. There is a need to confirm the technical aspects of the framework for design as well as technical and operational measures, such as bunkering activities and consideration of the AHJs and supplier needs. This should include a thorough review of existing documents and processes to better understand and determine the framework for the full fuel lifecycle of low- and zero-carbon fuels or alternative energy sources. Therefore, once a regulatory framework is in place, it is important that the significant array of existing documents be distilled into a properly developed and vetted set of codes and standards.

6.2 Recommendations

At this early stage of the evolving alternative marine fuels market, the primary gap identified suggests the need to establish **a framework that guides stakeholders through the process of designing and commissioning new systems**, such that risks are duly assessed and safe operations are assured. A suitable administrative and regulatory framework needs to be clearly defined so that approval processes are developed with the appropriate input from AHJs and stakeholders. This should include guidance on which regulation applies to which activities, how existing standards can be used, in what order, and which ones. It could also help identify gaps and the need for new standards and regulations.

It is recommended that various stakeholder groups be established to address specific aspects of the framework. Specifically, an industry association of interested parties could help address the needs and gaps for design and technical measures, including innovation, operational measures, and low- and zero-carbon fuels. Furthermore, it will be critical to further engage fuel suppliers and AHJs to confirm gaps and needs (technical aspects) of the framework for design and technical measures and operational measures.

For example, as reported in Section 5.3.1, LNG projects largely proceed based on ad hoc collaboration among local authorities and project proponents, relying on guidance documents developed by interested organizations. As a result, LNG has been more broadly applied in marine applications than other prospective fuel alternatives, with early projects from which to draw insight and learnings. This includes some of the following guidance:

- EMSA Guidance on LNG Bunkering also contains an overview of the process that needs to be followed for LNG specifically. This can be used to create a roadmap for Canada for LNG and can be used as the framework for other fuel types.
- For bunkering fuels, ISO has developed two documents: ISO 18683 Guidelines for systems and installations for supply of LNG as fuel to ships, and ISO 20519 Ships and marine technology – Specification for bunkering of liquefied natural gas fuelled vessels.
- SGMF provides SGMF FP07-01. As well, ISO/TS 18683 provides requirements for the design and operation of the LNG bunkering facility, including requirements on the interface between the LNG supply facilities and receiving ship.
- The IGF Code by the IMO covers LNG and there are interim guidelines for methanol and fuel cells that are in the process of being finalized.
- Lloyd's Register of Rules and Regulations for the Construction and Classification for the Carriage of Liquefied Gases in Bulk is an amendment to the IGC Code.

There should be a thorough review of existing documents and processes to better understand and determine the process for a framework and draw insights to develop a roadmap for North America. This could include a review of EMSA document(s) to see if a similar guideline can be produced for North America to deter an overall framework.[6] Moreover, action should be taken to identify all the relevant documents (regulations, codes, standards) necessary for the duration of a project and confirm their applicability for each priority fuel type. In addition, a training certification program for both trainer and trainee should be developed.

[6] In Europe "EMSA" recognizes differences between European states and ports. A document was created that puts the relevant information into one place and helps provide guidance as to how to obtain approvals for a given project. It was suggested that Canada could create a similar approach for specific fuels.

For example, the following framework could be used for LNG:

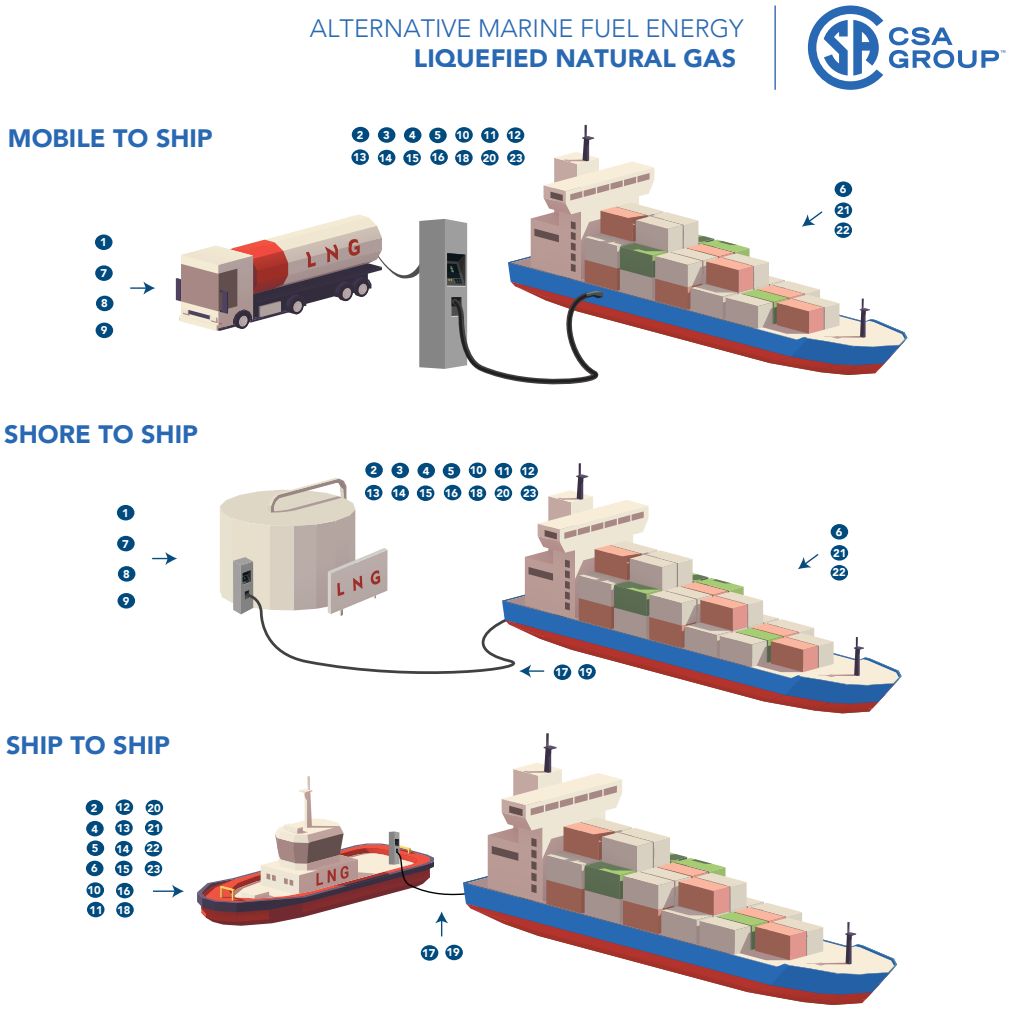
- International Codes/ Standards / Guidelines
  - IMO IGF Code
  - IMO IGC Code
  - ISO 20159
  - ISO/TS 18683
  - SGMF guidelines
  - SIGTTO guidelines
- National North America Standards / Guidelines
  - CSA standards (e.g., modify CSA B108, CSA Z276, or CSA/ANSI LNG 4.1, to be more applicable to marine applications)
  - USCG policy letters
  - Transport Canada policy letters
- Other rules and regulations
  - Class rules and regulations

It is recommended that placemats be developed for the alternative fuels in consideration. Placemats are useful tools used to visualize frameworks by summarizing information through simplified graphics that demonstrate the infrastructure associated with various alternative fuels and including a comprehensive list of relevant codes and standards. Examples of placemats for LNG, biofuel, hydrogen, and battery-electric are provided in Figures 7 to 10.

Each of the placemats shown identifies a roadmap of potential scenarios for each fuel type and includes non-exhaustive lists of codes and standards. Further assessments need to be completed to identify relevant documents that apply throughout the life cycle, with input from all affected stakeholders. Also, some of the codes and standards cited in the placemats may not be fully applicable to each scenario but have been included even if partial relevance is indicated.

Standards provide metrics for, and a quantifiable means of, determining whether a process or component meets an established minimum level of performance. They are often intended to serve as the foundation for the regulations that aim to increase public safety and reduce operational risks. Lack of industry standards can result in poorly informed regulations and an ad hoc approach to operational safety. With the use of many alternative marine fuels still in a relatively early stage, this is a critical time for the evaluation of national and international applicable standards. While the gap analysis identified weaknesses, this may be a significant time for Canada to contribute meaningfully to the development of national and international standards for the marine sector.

Figure 7: *LNG Placemat*



1. **CSA Z276**
   Liquefied natural gas (LNG) - Production, storage, and handling
2. **EMSA (European Maritime Safety Agency)**
   Guidance on LNG Bunkering to Port Authorities / Administration
3. **PIANC MarCom WG 172**
   Design of Small to Mid-Scale Marine LNG Terminals Including Bunkering
4. **USCG (US Coast Guard): 33 SCF 127**
   Waterfront Facilities Handling LNG and Liquefied Hazardous Gas
5. **SIGTTO (Society of International Gas Tanker and Terminal Operators**
   Canadian Electrical Code
6. **Transport Canada (TC)**
   Policy Letter RDIMS: 11153519 Policy Requirements for Vessels Using Natural Gas as Fuel
7. **CSA B620**
   Highway Tanks and TC Portable Tanks for the Transportation of Dangerous Goods
8. **CSA B621**
   Selection and Use of Highway Tanks, TC Portable Tanks, and Other Large Containers for the Transportation of Dangerous Goods, Classes 3, 4, 5, 6.1, 8, and 9
9. **CSA B622**
   Selection and Use of Highway Tanks, TC Portable Tanks, and Ton Containers for the Transportation of Dangerous Goods, Class 2
10. **USCG (US Coast Guard): 33 CFR 154**
    Facilities Transferring Oil or Hazardous Material in Bulk
11. **ISO/TS 18683:2015**
    Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships
12. **SGMF (The Society for Gas as a Marine Fuel)**
    Recommendation of Controlled Zones during LNG Bunkering
13. **SGMF (The Society for Gas as a Marine Fuel)**
    Simultaneous Operations (SIMOPS) during LNG Bunkering
14. **World Port Climate Initiative (WPCI)**
    Bunkering Checklist
15. **USCG (US Coast Guard**
    Policy Letter CG-OES 01-15: Guidelines for Liquefied Natural Gas Transfer Operations and Training of Personnel on Vessels using Natural Gas as Fuel
16. **USCG (US Coast Guard)**
    Policy Letter CG-OES 02-15: Guidance Related to Vessels and Waterfront Facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations
17. **ASTM F3312/F3312M-18**
    Standard Practice for Liquefied Natural Gas (LNG) Bunkering Hose Transfer Assembly
18. **ISO 20519:2017**
    Ships and marine technology - Specification for bunkering of liquefied natural gas fueled vessels
19. **ISO 21593:2019**
    Ships and marine technology - Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas
20. **ABS - American Bureau of Shipping**
    LNG Bunkering: Technical and Operational Advisory
21. **IMO (International Maritime Organization)**
    International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF Code)
22. **IMO (International Maritime Organization**
    International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (Gas Carrier Code) (IGC Code)
23. **ISO 28460**
    Petroleum and natural gas industries - Installation and equipment for liquefied natural gas - Ship-to-shore interface and port operations

Figure 8: *Biofuel Placemat (includes Methanol)*

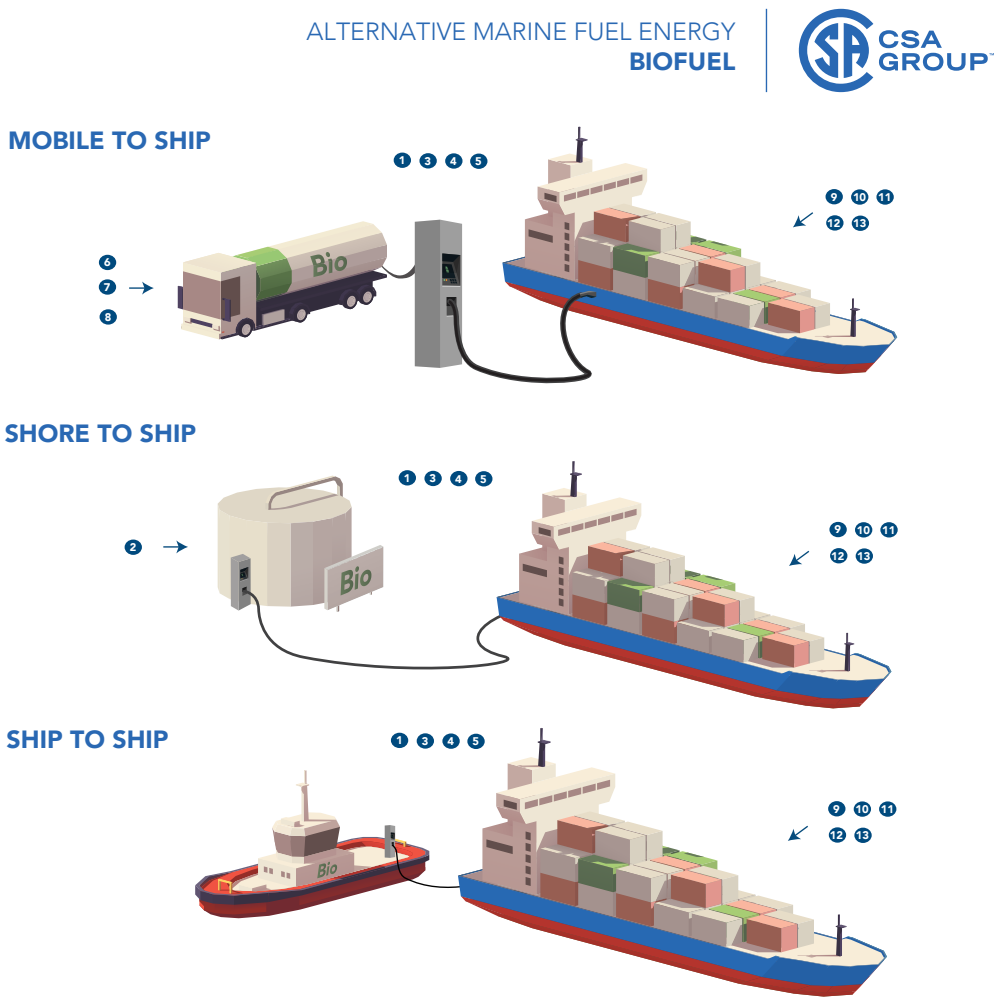
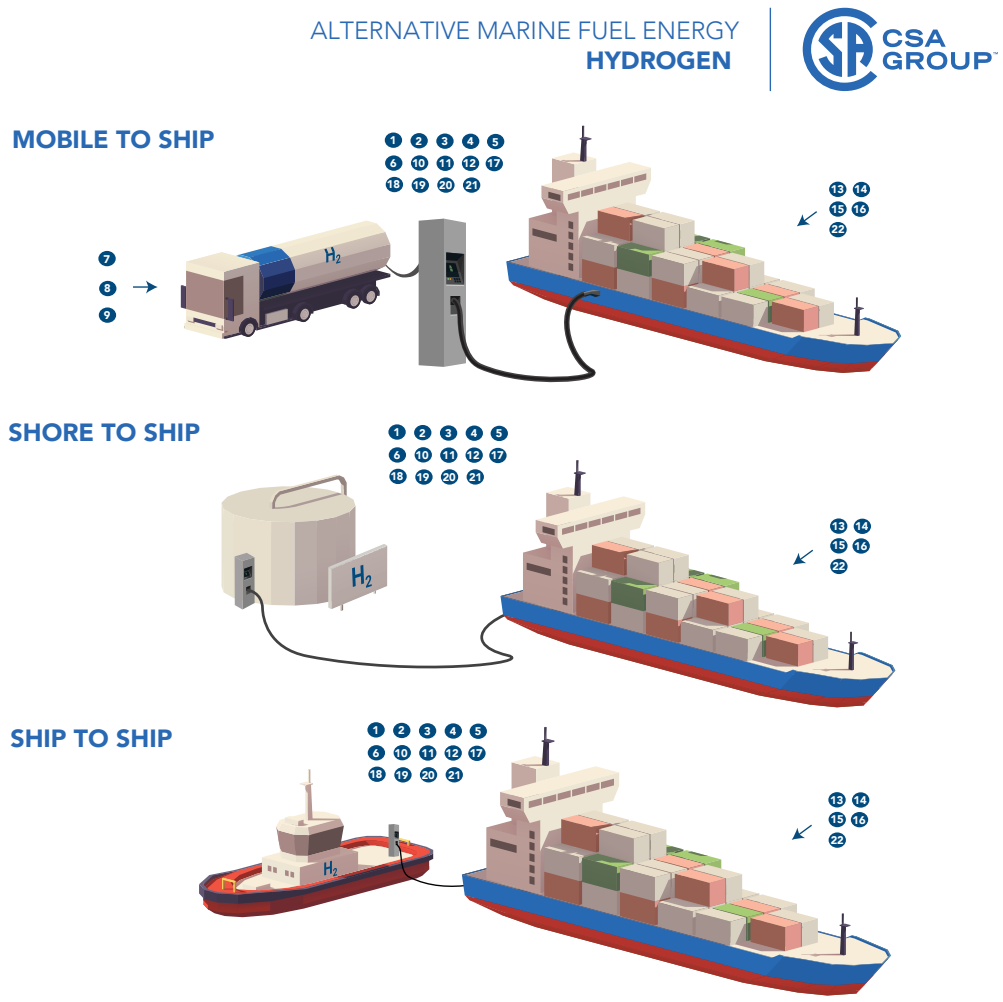


Figure 9: *Hydrogen Placemat*

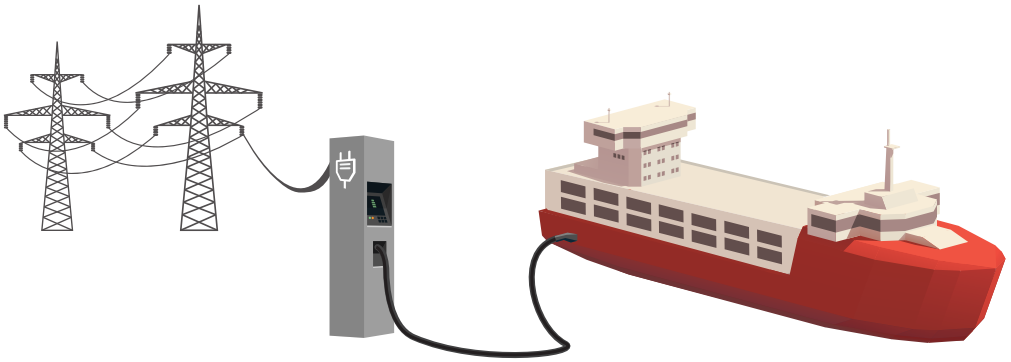


1. **BNQ 1784-000**
   Canadian Hydrogen Installation Code
2. **CSA C22.2**
   Canadian Electrical Code
3. **API 2003**
   Production against ignitions arising out of static, lightning, and stray currents
4. **USCG (US Coast Guard): 33 SCF 127**
   Waterfront Facilities Handling LNG and Liquefied Hazardous Gas
5. **NFPA 2**
   Hydrogen Technology Code
6. **NFPA 30A**
   Code for Motor Fuel Dispensing Facilities and Repair Garages
7. **CSA B620**
   Highway Tanks and TC Portable Tanks for the Transportation of Dangerous Goods
8. **CSA B621**
   Selection and Use of Highway Tanks, TC Portable Tanks, and Other Large Containers for the Transportation of Dangerous Goods, Classes 3, 4, 5, 6.1, 8, and 9
9. **CSA B622**
   Selection and Use of Highway Tanks, TC Portable Tanks, and Ton Containers for the Transportation of Dangerous Goods, Class 2
10. **USCG (US Coast Guard): 33 CFR 154**
    Facilities Transferring Oil or Hazardous Material in Bulk
11. **OSHA 29 CFR 1910.119**
    Process Safety Management of Highly Hazardous Chemicals
12. **USCG (US Coast Guard) 33 CFR 105**
    Maritime Security: Facilities
13. **DNV-GL**
    Rules for Classification - Ships
14. **EMSA (European Maritime Safety Agency)**
    Study on the use of fuel cells in shipping
15. **IEC 60092-502:1999**
    Electrical Installations in Ships: Tankers - Special Features
16. **Lloyd's Register**
    Rules and regulations for the classification of ships using gases or other low flashpoint fuels
17. **OCIMF (Oil Companies International Marine Forum)**
    Mooring Equipment Guidelines
18. **PIANC**
    MarCom WG 116: Aspects Affecting the Berthing Operations of Tankers to Oil and Gas Terminals
19. **SIGTTO (Society of International Gas Tanker and Terminal Operators)**
    Guide to Contingency planning for marine terminals handling liquefied gases in bulk
20. **SIGTTO (Society of International Gas Tanker and Terminal Operators)**
    ESD Arrangements and Linked Ship/Shore Systems for Liquefied Gas Carriers
21. **SIGTTO (Society of International Gas Tanker and Terminal Operators)**
    Recommendations for Liquefied Gas Carrier Manifolds
22. **IMO (International Maritime Organization**
    International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (Gas Carrier Code) (IGC Code)

Figure 10: *Electric Batteries Placemat*

ALTERNATIVE MARINE FUEL ENERGY
ELECTRIC BATTERIES

CSA GROUP



1. **USCG (US Coast Guard) 33 CFR 105**
   Maritime Security: Facilities
2. **OSHA (Occupational Safety and Health Administration) 29 CFR 1910.119**
   Process Safety Management of Highly Hazardous Chemicals
3. **ABS - American Bureau of Shipping**
   Guide for Use of Lithium Batteries in the Marine and Offshore Industries
4. **DNV-GL Infocus - The Future is Hybrid**
   A Guide to the Use of Batteries in Shipping
5. **CSA C22.2**
   Canadian Electrical Code
6. **NFPA 70**
   National Electrical Code
7. **DNV-GL Rules for Classification**
   Ships
8. **USCG (US Coast Guard) 33 CFR 154**
   Facilities Transferring Oil or Hazardous Material in Bulk
9. **OCIMF (Oil Companies International Marine Forum) Mooring Equipment Guidelines**
10. **DNV-GL Handbook for Maritime and Offshore Battery Systems**
11. **IEC (International Electrotechnical Commission) IEC 60092-502:1999**
    Electrical Installations in Ships: Tankers - Special Features
12. **API (American Petroleum Institute) Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents**

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ABBREVIATIONS

ABS	American Bureau of Shipping
AHJs	Authorities Having Jurisdiction
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BSI	British Standards
CAN/BNQ	Bureau de normalisation du Québec
CEN	European Committee for Standardization
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
COTIF	Convention Concerning International Carriage by Rail
CSA	Canadian Standards Association (operating as CSA Group)
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
DME	Dimethyl Ether
DNV GL	Det Norske Veritas – Germanischer Lloyd
ECA	Emission Control Area
EMSA	European Maritime Safety Agency
EN	European Standard
ESA	Electrical Safety Authority
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
IACS	International Association of Classification Societies
IEA	International Energy Agency
IEC	International Electrotechnical Commission
ICE	Internal Combustion Engine
ICS	International Chamber of Shipping
IGC Code	International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF Code	International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels

IMO	International Maritime Organization
ISGINTT	International Safety Guide for Inland Navigation Tank-Barges and Terminals
ISGOTT	International Safety Guide for Oil Tankers and Terminals
ISO	International Organization for Standardization
LNG	Liquefied Natural Gas
MFO	Marine Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships **
NFPA	National Fire Protection Association
NGO	Non-Governmental Organization
NO_x	Nitrogen Oxide
OCIMF	Oil Companies International Marine Forum
OSHA	Occupational Safety and Health Administration
PIANC	World Association for Waterborne Transport Infrastructure
PM	Particulate Matter
SGMF	Society for Gas as a Marine Fuel
SIGTTO	Society of International Gas Tanker and Terminal Operators
SO_x	Sulfur Oxide
TC	Transport Canada
USCG	US Coast Guard
UNCATD	United Nations Conference on Trade and Development
US DOT	US Department of Transportation
PHMSA	Department of Transportation – Pipeline and Hazardous Materials Safety Administration
WPCI	World Port Climate Initiative

Appendix A – Alternative Fuels and Energy Systems for the Marine Sector

Applicable Standards and Related Documents

Table 2: *LNG Documents*

LNG Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	Onshore	Bunkering	Onboard
USCG	33 CFR 105 – Maritime Security: Facilities	2018	Code	Y	USA	X	X	X
IMO	The Seafarers' Training, Certification and Watchkeeping Code of the IMO (STCW Code)	1978	Code	Y	Global	X	X	X
NFPA 52	Vehicular Natural Gas Fuel Systems Code	2019	Code	Y	USA	X	X	X
IMO	International Convention for the Prevention of Pollution from Ships Annex	2005	Convention	Y	Global	X	X	X
OSHA	29 CFR 1910.119 Process Safety Management of Highly Hazardous Chemicals	2018	Guideline	N	USA	X	X	X
SIGTTO	LNG Operations in Port Areas	2003	Guideline	Y	Global	X	X	X
SIGTTO	The Selection and Testing of Valves for LNG Applications	2005	Guideline	Y	Global	X	X	X
CCNR	Rhine Vessel Inspection Regulations	1995	Regulation	Y	Global	X	X	X
CEN	EN 12838 – Installations and equipment for liquefied natural gas – Suitability testing of LNG sampling systems	2000	Standard	N	Europe	X	X	X
ISO	ISO 16903:2015 Petroleum and natural gas industries – Characteristics of LNG, influencing the design, and material selection	2015	Standard	N	Global	X	X	X
ISO	ISO 31010 – Risk management – Risk assessment techniques	2019	Standard	N	Global	X	X	X
ISO	ISO 8216-1: 2017 – Petroleum products – Fuels (class F) classification – Part 1: Categories of marine fuels	2017	Standard	Y	Global	X	X	X
ISO	ISO 8217: 2017 – Petroleum products – Fuels (class F) – Specifications of marine fuels	2017	Standard	Y	Global	X	X	X
ISO	ISO 8943 – Refrigerated light hydrocarbon fluids – Sampling of liquefied natural gas – Continuous and intermittent methods	2007	Standard	N	Global	X	X	X

LNG Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	Onshore	Bunkering	Onboard
NFPA 30A	Code For Motor Fuel Dispensing Facilities and Repair Garages	2018	Code	Y	USA	X	X	
CSA Z246.2	Emergency preparedness and response for petroleum and natural gas industry systems	2018	Code	N	Canada	X	X	
CSA Z276	Liquefied natural gas (LNG) – Production, storage, and handling	2018	Code	N	Canada	X	X	
CSA/ANSI LNG 4.1	LNG Vehicle Dispensing Systems	2018	Code	N	Canada	X	X	
CSA B108	Natural gas refueling stations installation code	2018	Code	N	Canada	X	X	
CSA Z246.1	Security management for petroleum and natural gas industry systems	2017	Code	N	Canada	X	X	
EMSA	Guidance on LNG Bunkering to Port Authorities / Administration	2018	Guideline	Y	Europe	X	X	
SIGTTO & SGMF	Standards and Guidelines for Natural Gas Fuelled Ship Projects	2015	Guideline	Y	Global	X	X	
PIANC	MarCom WG 172: Design of Small to Mid-Scale Marine LNG Terminals Including Bunkering	2016	Report	Y	United Kingdom	X	X	
EMSA	Study on Standards and Rules for Bunkering of Gas-fuelled Ships	2013	Rules	Y	Europe	X	X	
DSEAR	Energy Institute Model Code of Safe Practice Part 15: Area Classification Code for Installations Handling Flammable Fluids	2015	Code	N	United Kingdom	X		X
SIGTTO	ESD Arrangements and Linked Ship/Shore Systems for Liquefied Gas Carriers	2009	Guideline	Y	Global	X		X
USCG	33 SCF 127 – Waterfront Facilities Handling LNG and Liquefied Hazardous Gas	2018	Code	Y	USA	X		
US DOT PHMSA	49 CFR 193 LNG Facilities: Federal Safety Standards	2018	Code	N	USA	X		
CSA C22.2	Canadian Electrical Code	2017	Code	Y	Canada	X		
NFPA 59	Utility LP-Gas Plant Code	2018	Code	N	USA	X		
SIGTTO	Guide to Contingency planning for marine terminals handling liquefied gases in bulk	2001	Guideline	Y	Global	X		
SIGTTO	Site Selection and Design for LNG Ports and Jetties	1997	Information Paper	Y	Global	X		
COTIF	Regulations Concerning the International Carriage of Dangerous Goods by Rail	2019	Regulation	N	Global	X		

LNG Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	**Onshore**	**Bunkering**	**Onboard**
PIANC	MarCom WG 116: Aspects Affecting the Berthing Operations of Tankers to Oil and Gas Terminals	2012	Report	Y	United Kingdom	X		
CEN	EN 13645 – Installations and Equipment for Liquefied Natural Gas – Design of onshore installations with a storage capacity	2002	Standard	Y	Europe	X		
CEN	EN 1473 – Installation and equipment for liquefied natural gas – Design of onshore installations	2007	Standard	N	Global	X		
CEN	EN 1474-1 – Installation and equipment for liquefied natural gas – Design and testing of marine transfer systems Part 1: Design and testing of transfer arms	2008	Standard	Y	Europe	X		
CSA B620	Highway Tanks and TC Portable Tanks for the Transportation of Dangerous Goods	2014	Standard	N	Canada	X		
ISO	ISO 16904:2016 – Design and testing of LNG marine transfer arms for conventional onshore terminals	2016	Standard	Y	Global	X		
CSA B621	Selection and Use of Highway Tanks, TC Portable Tanks, and Other Large Containers for the Transportation of Dangerous Goods, Classes 3, 4, 5, 6.1, 8, and 9	2014	Standard	N	Canada	X		
CSA B622	Selection and Use of Highway Tanks, TC Portable Tanks, and Ton Containers for the Transportation of Dangerous Goods, Class 2	2014	Standard	N	Canada	X		
TC	Policy Letter RDIMS: 11153519 Policy Requirements for Vessels Using Natural Gas as Fuel	2-Nov-17	Policy Letter	Y	Canada		X	X
DNV-GL	Part 6 Chapter 13, Gas Fuelled Ship Installations	2016	Rules	Y	Global		X	X
DNV-GL	Rules for Classification - Ships	Jan-17	Rules	Y	Global		X	X
USCG	33 CFR 154 - Facilities Transferring Oil or Hazardous Material in Bulk	2018	Code	N	USA		X	
ISO	ISO/TS 18683:2015 Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships	2015	Guideline	Y	Global		X	
SGMF	Recommendation of Controlled Zones during LNG Bunkering	2018	Guideline	Y	United Kingdom		X	
SGMF	Simultaneous Operations (SIMOPS) during LNG Bunkering	2018	Guideline	Y	United Kingdom		X	
WPCI	Bunkering Checklist		Other: Webpage	Y	Global		X	
USCG	Policy Letter CG-OES 01-15: Guidelines for Liquefied Natural Gas Transfer Operations and Training of Personnel on Vessels using Natural Gas as Fuel	2015	Policy Letter	Y	USA		X	

LNG Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	**Onshore**	**Bunkering**	**Onboard**
USCG	Policy Letter CG-OES 02-15: Guidance Related to Vessels and Waterfront Facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations	2015	Policy Letter	Y	USA		X	
BSI	BS 4089:1999 Specification for Metallic Hose Assemblies for Liquid Petroleum Gases and Liquefied Natural Gases	1999	Specification	N	Global		X	
ASTM	F3312/F3312M-18: Standard Practise for Liquefied Natural Gas (LNG) Bunkering Hose Transfer Assembly	2018	Standard	Y	USA		X	
ISO	ISO 20519:2017	2017	Standard	Y	Global		X	
ISO	ISO 21593:2019 – Ships and marine technology – Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas	2019	Standard	Y	Global		X	
ABS	LNG Bunkering: Technical and Operational Advisory	2017	Code	Y	Global		X	
IMO	International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code)	2016	Code	N	Canada			X
CSA LNG 2	Liquefied natural gas vehicle fuel containers	2017	Code	N	Canada			X
CSA LNG 3.1 – 3.19	Road vehicles – Liquefied natural gas (LNG) fuel system components	2018	Code	N	Canada			X
IMO	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (Gas Carrier Code) (IGC Code)	2016	Code	Y	Global			X
CSA SPE - 2.1	Best Practices for Defuelling, Decommissioning, and Disposal of Compressed Natural Gas Vehicle Fuel Containers and Liquefied Natural Gas Vehicle Fuel Tanks	2018	Guideline	N	Canada			X
ASTM	F3285-18: Standard Guide for Installation and Application of Type C Portable Tanks for Marine LNG Service	2018	Guideline	Y	USA			X
OCIMF	Mooring Equipment Guidelines	2013	Guideline	Y	Global			X
SIGTTO	Recommendations for Liquefied Gas Carrier Manifolds	2018	Guideline	Y	Global			X
IMO	Maritime Safety Committee.285(86)	2009	Guideline	Y	Global			X
SIGTTO	International Safety Guide for Inland Navigation Tank-barges and Terminals	2010	Guideline	Y	Global			X
SIGTTO	International Safety Guide for Oil Tankers & Terminals	2006	Guideline	Y	Global			X
ISO	ISO TC 67 WG 10 Guidelines – Materials, equipment and offshore structures for petroleum		Guideline	N	Global			X

LNG Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	**Onshore**	**Bunkering**	**Onboard**
USCG	Policy Letter CG-521 01-12 (Change 1): Equivalency Determination – Design Criteria for Natural Gas Systems	2017	Policy Letter	Y	USA			X
Lloyd's Register	Rules and Regulations for the Classification of Ships Using Gases or Other Low-flashpoint Fuels	2018	Rules and Regulations	Y	United Kingdom			X
IEC	IEC 60092-502:1999 – Electrical Installations in Ships: Tankers – Special Features	1999	Standard	Y	Global			X
ISO	ISO 10976 – Refrigerated light hydrocarbon fluids – Measurement of cargoes on board LNG carriers	2015	Standard	Y	Global			X
ISO	ISO 17776 – Petroleum and natural gas industries – Offshore production installations – Major accident hazard management during the design of new installations	2016	Standard	N	Global			X
ISO	ISO 28460 – Petroleum and natural gas industries – Installation and equipment for liquefied natural gas – Ship-to-shore interface and port operations	2010	Standard	Y	Global			X

Table 3: *Methanol Documents*

Methanol Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	**Onshore**	**Bunkering**	**Onboard**
USCG	33 CFR 105 – Maritime Security: Facilities	2018	Code	Y	USA	X	X	X
OSHA	29 CFR 1910.119 Process Safety Management of Highly Hazardous Chemicals	2018	Guideline	N	USA	X	X	X
NFPA 30A	Code For Motor Fuel Dispensing Facilities and Repair Garages	2018	Code	Y	USA	X	X	
ABS	Guide for LNG Bunkering	Jan-17	Guideline	Y	USA	X	X	
Methanol Institute	Methanol Safe Handling Manual	4th Edition	Guideline	Y	USA	X	X	
DSEAR	Energy Institute Model Code of Safe Practice Part 15: Area Classification Code for Installations Handling Flammable Fluids	2015	Code	N	United Kingdom	X		X

Methanol Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	**Onshore**	**Bunkering**	**Onboard**
CSA C22.2	Canadian Electrical Code	2017	Code	Y	Canada	X		
API RP 2003	Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents	2003	Guideline	N	USA	X		
CSA B620	Highway Tanks and TC Portable Tanks for the Transportation of Dangerous Goods	2014	Standard	N	Canada	X		
CSA B621	Selection and Use of Highway Tanks, TC Portable Tanks, and Other Large Containers for the Transportation of Dangerous Goods, Classes 3, 4, 5, 6.1, 8, and 9	2014	Standard	N	Canada	X		
CSA B622	Selection and Use of Highway Tanks, TC Portable Tanks, and Ton Containers for the Transportation of Dangerous Goods, Class 2	2014	Standard	N	Canada	X		
Lloyd's Register	Rules for the Classification of Methanol Fuelled Ships	Jul-19	Rules	Y	United Kingdom		X	X
USCG	33 CFR 154 – Facilities Transferring Oil or Hazardous Material in Bulk	2018	Code	N	USA		X	
OCIMF	Mooring Equipment Guidelines	2013	Guideline	Y	Global			X
Lloyd's Register	Rules and Regulations for the Classification of Ships Using Gases or Other Low-flashpoint Fuels	2018	Rules and Regulations	Y	United Kingdom			X
IEC	IEC 60092-502:1999 – Electrical Installations in Ships: Tankers – Special Features	1999	Standard	Y	Global			X

Table 4: *Liquid Hydrogen Documents*

Liquid Hydrogen Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	**Onshore**	**Bunkering**	**Onboard**
USCG	33 CFR 154 – Facilities Transferring Oil or Hazardous Material in Bulk	2018	Code	N	USA		X	
NFPA 2	Hydrogen Technologies Code	2020	Code	N	USA	X	X	X
OSHA	29 CFR 1910.119 Process Safety Management of Highly Hazardous Chemicals	2018	Guideline	N	USA	X	X	X
NFPA 30A	Code For Motor Fuel Dispensing Facilities and Repair Garages	2018	Code	Y	USA	X	X	

Liquid Hydrogen Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	**Onshore**	**Bunkering**	**Onboard**
CAN/BNQ 1784-000	Canadian Hydrogen Installation Code	2007	Code	N	Canada	X	X	
DSEAR	Energy Institute Model Code of Safe Practice Part 15: Area Classification Code for Installations Handling Flammable Fluids	2015	Code	N	United Kingdom	X		X
SIGTTO	ESD Arrangements and Linked Ship/Shore Systems for Liquefied Gas Carriers	2009	Guideline	Y	Global	X		X
CSA C22.2	Canadian Electrical Code	2017	Code	Y	Canada	X		
USCG	33 SCF 127 – Waterfront Facilities Handling LNG and Liquefied Hazardous Gas	2018	Code	Y	USA	X		
SIGTTO	Guide to Contingency Planning for Marine Terminals Handling Liquefied Gases in Bulk	2001	Guideline	Y	Global	X		
API RP 2003	Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents	2003	Guideline	N	USA	X		
CSA B620	Highway Tanks and TC Portable Tanks for the Transportation of Dangerous Goods	2014	Standard	N	Canada	X		
CSA B621	Selection and Use of Highway Tanks, TC Portable Tanks, and Other Large Containers for the Transportation of Dangerous Goods, Classes 3, 4, 5, 6.1, 8, and 9	2014	Standard	N	Canada	X		
CSA B622	Selection and Use of Highway Tanks, TC Portable Tanks, and Ton Containers for the Transportation of Dangerous Goods, Class 2	2014	Standard	N	Canada	X		
DNV-GL	Rules for Classification - Ships	Jan-17	Rules	Y	Global		X	X
USCG	33 CFR 154 – Facilities Transferring Oil or Hazardous Material in Bulk	2018	Code	N	USA		X	
OCIMF	Mooring Equipment Guidelines	2013	Guideline	Y	Global			X
SIGTTO	Recommendations for Liquefied Gas Carrier Manifolds	2018	Guideline	Y	Global			X
Lloyd's Register	Rules and Regulations for the Classification of Ships Using Gases or Other Low-flash-point Fuels	2018	Rules and Regulations	Y	United Kingdom			X
IEC	IEC 60092-502:1999 – Electrical Installations in Ships: Tankers – Special Features	1999	Standard	Y	Global			X

Table 5: *Battery Documents*

Battery Table						Applicability		
Publication	**Title**	**Year**	**(Code, Standard, Guideline, Rule, Policy Letter)**	**Specific to Marine (Y/N)**	**Origin**	**Onshore**	**Bunkering**	**Onboard**
USCG	33 CFR 105 – Maritime Security: Facilities	2018	Code	Y	USA	X	X	X
OSHA	29 CFR 1910.119 Process Safety Management of Highly Hazardous Chemicals	2018	Guideline	N	USA	X	X	X
ABS	Guide for Use of Lithium Batteries in the Marine and Offshore Industries	Aug-18	Guideline	Y	USA	X	X	X
DNV-GL	Infocus – The Future is Hybrid – A Guide to the Use of Batteries in Shipping	2015	Guideline	Y	Europe	X	X	X
CSA C22.2	Canadian Electrical Code	2017	Code	Y	Canada	X		
NFPA 70	National Electrical Code	2020	Code	Y	USA	X		
DNV-GL	Rules for Classification – Ships	Jan-17	Rules	Y	Global		X	X
USCG	33 CFR 154 – Facilities Transferring Oil or Hazardous Material in Bulk	2018	Code	N	USA		X	
OCIMF	Mooring Equipment Guidelines	2013	Guideline	Y	Global			X
DNV-GL	Handbook for Maritime and Offshore Battery Systems	19-Dec-16	Guideline	Y	Europe			X
IEC	IEC 60092-502:1999 – Electrical Installations in Ships: Tankers – Special Features	1999	Standard	Y	Global			X
API	Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents	2003	Guideline	N	USA			

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