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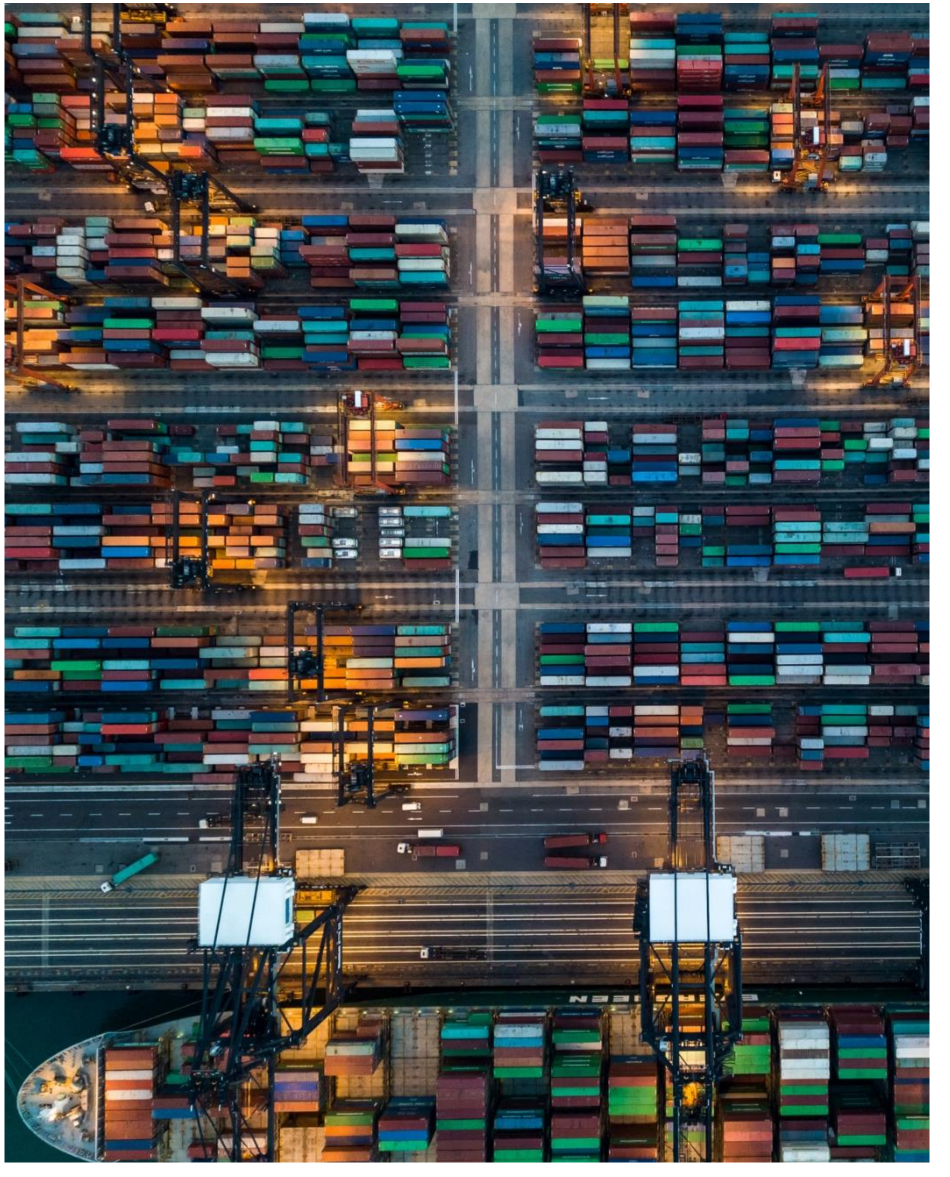

Oceans North Conservation Society

Canadian Green Shipping Corridors Preliminary Assessment

Final Report

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Contents

Acronyms

AIS	Automatic Identification System
BC	British Columbia
CAD	Canadian Dollars
CCS	Carbon Capture and Storage
CMC	Chamber of Maritime Commerce
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP	Conference of the Parties
DAC	Direct Air Capture
ESG	Environmental, Social and Governance
GDP	Gross Domestic Product
GW	Giga-Watt
H_2	Hydrogen
HFO	Heavy Fuel Oil
HFOe	Heavy Fuel Oil (Energy) Equivalent
IMO	International Maritime Organisation
ktpa	Kilo-tonnes per annum
LNG	Liquefied Natural Gas
MOU	Memorandum of Understanding
MW	Mega-Watt
NS	Nova Scotia
PPA	Power Purchase Agreement
R&D	Research & Development
RVA	Real Value Added
Ro-Ro	Roll-on / Roll-off
TEU	Tonne Equivalent Unit
USA	United States of America
USD	United States Dollars
VLSFO	Very Low Sulphur Fuel Oil

1. Introduction

Accelerated action is needed to tackle greenhouse gas emissions from shipping

Commercial shipping activity in Canada has been estimated to contribute approximately $30 billion to the Canadian economy annually [1]. Meanwhile, vessels operating in Canadian waters produced more than more than 13 million tonnes of CO_2 emissions in 2019 [2], or around 1.7% of Canada's total greenhouse gas emissions, directly contributing to global climate change. These vessels also produce thousands of tonnes of air pollutants that impact the health of port and coastal communities, pollute oceans, and can themselves have a significant climate impact.

An urgent transition away from fossil fuels is required

Much of the activity to address shipping emissions has been at the International Maritime Organisation (IMO) level. The IMO has introduced regulations to address air pollutant emissions and has progressed with measures to improve the energy efficiency of ships and therefore reduce greenhouse gas emissions. At a national level, Canada has a legislated commitment to achieve net-zero emissions by 2050 and, through the 2030 Emissions Reduction Plan, is developing a national action plan to enable the marine sector to reduce its emissions, including engagement with stakeholders on energy efficiency and carbon intensity requirements for domestic vessels in-line with requirements for international vessels.

This report uses the term 'zero emission fuels' to refer to those with zero lifecycle greenhouse gas emissions. In the context of this report, 'low emission fuels' refers to fuels with lifecycle greenhouse gas intensity of $20gCO_2e/MJ$, which is approximately 80% lower than conventional shipping fuel oils. These terms are discussed in more detail at Section 3.

Energy efficiency measures and exhaust treatment technologies represent some progress; however they will only contribute to marginal reductions in emissions. A global transition is required away from fossil fuels to zero emission alternatives if deep greenhouse gas emissions cuts are to be achieved. Widespread uptake of these fuels will be required from the end of this decade to follow a decarbonisation trajectory in line with Paris Agreement goals. However, although progress is being made, availability of these fuels is still extremely low while high costs make their use uneconomical where they are available. Coordinated action in the short term can help to develop and demonstrate the technical, regulatory, and commercial viability of these fuels, laying the groundwork for subsequent proliferation of their use across the industry.

The transition represents a significant infrastructure opportunity and Canada is well placed to maximise the benefits

The capital investment required to decarbonise international shipping by 2050 has been estimated to be up to USD$1.6 trillion, around 87% of which will be needed to develop the fuel production facilities and other landside infrastructure [3]. In many cases, this infrastructure will be entirely new and include renewable electricity generation, hydrogen electrolysers, and fuel synthesis plants. This represents a significant opportunity for countries around the world to achieve their environmental objectives while fuelling economic prosperity, realising social co-benefits, and protecting themselves from the impact of divestment from fossil fuel industries. As an existing energy producer with a skilled workforce and substantial land and natural resource availability, Canada is well placed to seize the opportunity to become a producer, or even exporter, of zero emission fuels.

Green shipping corridors can accelerate maritime decarbonisation in Canada

A variety of technical, regulatory, and commercial barriers have slowed uptake of low and zero emission fuels in the shipping sector to date. Green shipping corridors are a means of bringing together actors from across the shipping and fuel value chain to work together to address these barriers. In doing so, corridors aim to demonstrate the feasibility of using these fuels on specific routes in the short to mid-term and therefore catalyse their uptake more broadly. Several corridor partnerships involving Canadian Ports have already been announced and Transport Canada has released a national green shipping corridors framework to guide their implementation.

This report is intended to demonstrate the opportunity for Canada

Oceans North has commissioned Arup to undertake this preliminary assessment into the potential impact that green shipping corridors - and maritime decarbonisation more broadly - could have in Canada. Arup's study is supported by analysis by Lloyd's Register Maritime Decarbonisation Hub estimating the potential development of low and zero emission fuel uptake from shipping using three Canadian ports under a variety of different scenarios.

In this report, we introduce the background to green shipping corridors, the characteristics of the emerging initiatives, and how these might be applicable in the Canadian context. We explore the main low and zero emission marine fuel production pathways and their feedstocks that have the potential to support long term decarbonisation of shipping. We describe key considerations that influence their suitability to different regions. We have also explored how green corridor partnerships can be used to mobilise key stakeholder groups in the fuel production value chain to drive the uptake of these fuels.

Lloyd's Register have estimated the potential demand evolution for low and zero emission fuels under different scenarios at three different Canadian ports based on vessel traffic data and forward-looking assumptions around demand development. We have approximated the size, type, and capital cost of energy and fuel production infrastructure required to meet demand. We have described illustrative fuel supply typologies at the three ports, as a means of exploring the challenges and opportunities they face in meeting this demand.

Finally, we have applied a 'Total Value' framing approach to explore some of the key financial, social, and economic co-benefits that could be realised through effective delivery of this new infrastructure.

2. Green shipping corridors in Canada

2.1 Green shipping corridors are intended to accelerate maritime decarbonisation

Despite growing decarbonisation ambition in the shipping industry, there are numerous barriers hampering the development and deployment of zero emission marine fuels. Green shipping corridors are one way of helping to address these and accelerate decarbonisation of the industry.

Approaches vary but the deployment of zero emission shipping is the common aim among green shipping corridors

The concept of green shipping corridors first emerged in 2021 and was brought into the spotlight by the Clydebank Declaration made at COP26 and now signed by 24 nations, including Canada. The declaration set out a collective aim by the signatories to establish at least six green shipping corridors by the middle of the decade, including international and domestic routes. The concept of green corridors was developed by research from the Global Maritime Forum (GMF) and their partners in the 'The Next Wave' report [4]. This sets out the core definition of a green shipping corridor as:

"Specific shipping routes where the technological, economic and regulatory feasibility of the operation of zero-emission ships is catalysed by a combination of public and private actions."

This has created a wave of green shipping corridor commitments across the globe, with different interpretations of the definition. Additional definitions include:

"Maritime routes that showcase low- and zero-emission lifecycle fuels and technologies with the ambition to achieve zero greenhouse gas emissions across all aspects of the corridor in support of sector-wide decarbonization no later than 2050." US State Department Green Shipping Corridors Framework [5]

"A green shipping corridor is a maritime route between two or more ports on which vessels running on scalable zero-emission energy sources are demonstrated and supported." UK Shipping Office for Reducing Emissions (UK SHORE) [6]

"Focused action/intention by a group of companies/countries/institutes, related to the entire Zero Emission Shipping Value Chain with the aim to deliver a commercial product/offer throughout the value chain." Maersk McKinney Møller Centre [7]

It is important to view green shipping corridors as emergence-phase initiatives to catalyse feasibility of zero-emission shipping, working in tandem with development of policy at a national and international level. As illustrated in Figure 1, this dual approach can lead to rapid uptake during the subsequent diffusion phase.

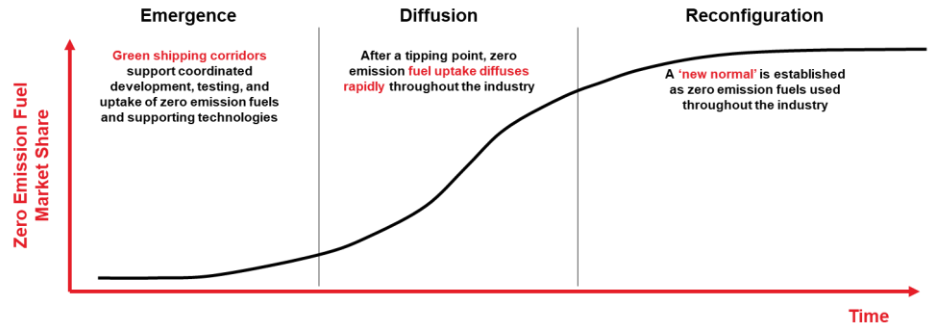

Figure 1 - Green Corridors in a transition context

(Adapted from Global Maritime Forum [8])

First mover corridors can help the shipping industry reach a 'tipping point' in the uptake of zero emission fuels

At their core, green shipping corridors aim to mobilise stakeholders across the value chain to address the barriers to zero emission fuel uptake. The focus of these initiatives is on the initial stages of the fuel transition taking place over the short to mid-term, while the technical and commercial readiness of the required solutions are still developing. By fostering this development and facilitating the first uptake of zero emission shipping fuels, these initiatives can contribute to the industry as a whole reaching a 'tipping point' where they start to rapidly scale without such focussed support and coordination. It has been estimated [9] that this point could be crossed if 5% of the fuel used by international shipping industry and 15% of the fuel used by domestic shipping has zero lifecycle greenhouse gas emissions by 2030; helping to align shipping's decarbonisation trajectory with Paris Agreement Goals.

Governance structures, shipping routes and goals vary widely between corridor initiatives

Dozens of green shipping corridor initiatives have been announced and are being developed globally; several of which involve Canadian ports. This number is expected to increase rapidly over the coming months and years as countries move to fulfil their obligations under the Clydebank Declaration. These initiatives all differ in how they are led, the type of routes being examined, the overall aims and objectives, and the methodologies being applied to their development. All the initiatives are still at an early stage, and it is too early to measure their relative success. However, there is an opportunity for lessons to be shared between corridor partnerships and wider stakeholder groups as they develop.

By understanding the benefits and challenges of the different approaches, Canadian stakeholders can ensure that green shipping corridors involving Canadian ports contribute most effectively to realising the long-term uptake of zero emission fuels at scale and position Canada to benefit from this transition.

Partners & leadership	The leadership and key partners involved in a green shipping corridor initiative can have a major bearing on its focus and activities. For example, government and public-private led initiatives may focus on unlocking opportunities for economic and social development while industry led initiatives may seek to position their partner organisations to develop new commercial models. The makeup of the partnership is also important as it will affect where efforts are focussed in the value chain, either focussing on the supply of fuels or mobilising their demand.
Routes	A corridor may focus on vessels operating between two ports (end-to-end), in the area around or between one or more ports (clusters) or across an entire geographic region (regional). The scope of the route will have an impact on the complexity of the corridor's implementation. In some cases, initiatives may start by assessing routes in a whole region, before focussing on the most promising end-to-end routes or clusters.
Goals & aims	Corridors focusing on incremental emissions reductions risk deployment of efficiency measures or transition fuels that may not support the uptake of zero carbon fuel solutions in the longer term. Corridors may take a hybrid approach to their aims, targeting emissions reductions over time while focusing efforts of the multi-stakeholder partnerships on the more challenging topic of zero carbon fuels uptake.

Figure 2 – Review of existing green shipping corridor initiatives

2.2 Government and industry have already shown support for green shipping corridors in Canada

The Government has indicated strong support for the decarbonisation of shipping

In 2021, Canada passed the Net-Zero Emissions Accountability Act which enshrines a commitment to achieving net-zero greenhouse gas emissions by 2050 across all sectors. The legislation puts in place a legally binding process to set 5-yearly emissions reduction targets with credible plans to reach them.

The ‘2030 Emissions Reduction Plan’ [10], the first plan under the net zero legislation that was released in March 2022, outlines Canada’s aim to cut emissions by 40-45% below 2005 levels by 2030 and go on to achieve net-zero emissions by 2050. The plan includes measures applied across all economic sectors, including support for clean energy projects like wind and solar power, the development of zero-emission fuels, a plan to decarbonise transportation as well as a commitment to reduce methane emissions from oil and gas production by 75%. For the maritime sector, the plan includes the commitment to develop a ‘national action plan’ for emissions reductions in the marine sector as well as to take direct action to reduce emissions from government operated vessels.

At an international level, Canada has been collaborating at the International Maritime Organisation (IMO) on lifecycle assessment guidelines for marine fuels and regulatory measures for emission reductions. Canada, the United States, and the United Kingdom have cosponsored a submission that proposes increased levels of ambition in the IMO’s revised greenhouse gas strategy. This includes proposals for shipping emission reduction targets that align with the Paris Agreement's goal of pursuing efforts to limit global temperature rise to 1.5°C, including to reduce total annual greenhouse gas emissions from international shipping, on a life cycle basis, by at least 37% by 2030 and 96% by 2040, compared to a 2008 baseline, and to zero emissions by no later than 2050 [11]. The submission also proposes that the revised strategy enshrine the goal that least 5% of the global fleet operating on fuels and technologies with zero or near-zero emissions on a lifecycle assessment basis by 2030.

Canada has joined the ‘Declaration on Zero Emissions Shipping’ [12] in which partners agree to strengthen global efforts to achieve zero emissions from international shipping by 2050. Canada has also confirmed support for the Green Shipping Challenge [13], which encourages announcements that support alignment of shipping’s decarbonisation with a trajectory to limit global temperature rise to 1.5°C.

Delivering the required emissions reductions from domestic and international shipping, in line with a 1.5°C decarbonisation trajectory, requires a rapid transition to zero emission fuels over the coming years. Green shipping corridors are an opportunity for the government to work with voluntary industry participants to accelerate this transition through the development, testing and use of scalable zero emission fuels and supporting technologies.

Canada has set out a framework for development of green shipping corridors

Canada is a signatory to the Clydebank Declaration [14], supporting the establishment of at least six green shipping corridors ‘by the middle of this decade’; including both domestic and international routes. Transport Canada has published a ‘Canadian Green Shipping Corridors Framework’ [15] to help guide the development of green shipping corridors and ensure consistent implementation.

The framework recognises the challenges to Canadian shipping achieving net-zero emissions by not later than 2050 and sets out the government’s support for scalable solutions that can be implemented in the short term while facilitating a path to net-zero. This could include efficiency measures, provision of shorepower, as well as alternative zero emission fuels. Regardless of the measure, the importance of considering the whole lifecycle environmental impacts is reiterated.

The framework also identifies the importance of aligning local and national actions with international efforts to ease their implementation, particularly in the case of international corridor partnerships. Finally, it underscores the importance of mobilising a broad range of industry stakeholders in the implementation of green shipping corridors while ensuring the involvement of all implicated parties such as local communities and indigenous groups.

Several green shipping corridor initiatives involving Canadian ports have already been announced

There have been at least four green shipping corridor announcements involving Canadian ports made to date, as shown in Figure 3, demonstrating the strength of industry support for maritime decarbonisation in Canada. Canada has an opportunity to build on this early progress and establish itself as a leader in maritime decarbonisation.

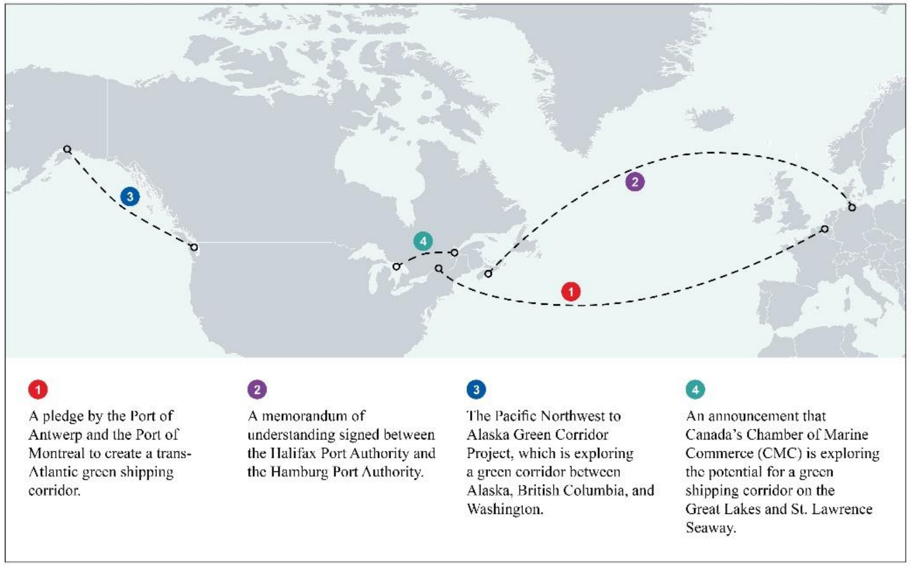

Figure 3 - Green shipping corridor initiatives announced in Canada to date

Canada's abundant energy resources make it well-placed to be a supplier of low and zero lifecycle emission marine fuels

Canada has one of the cleanest electrical systems in the world with more than 83% of output coming from non-emitting sources [16] and the government has committed supporting clean energy projects to further reduce emissions from power generation. The country is also a producer of oil and gas; meaning that the sector has the financial resources, infrastructure, energy expertise, and skilled workforce that can be leveraged to develop zero emission fuel pathways.

The Hydrogen Strategy for Canada [17] was released in December 2020 by the Government of Canada. It outlines opportunities for Canada to leverage its natural resources to drive the domestic production and use of clean hydrogen including the potential for Canada to become global producer of low-carbon hydrogen. In 2022 the Government of Canada signed a joint declaration of intent with the Government of the Federal Republic of Germany on establishing a Canada-Germany Hydrogen Alliance which aims to create a transatlantic supply chain for hydrogen before 2030.

3. Fuels for green shipping corridors

3.1 Production of low and zero emission shipping fuels

As identified above, scaling the production of low and zero emission fuels to meet growing demand and deliver on global climate goals is a key challenge.

There are numerous possible alternative fuels, but focus is on a few core options

There are numerous fuel options that could be considered, with no 'silver bullet' applicable across all shipping segments, however the industry is coalescing around a few core fuels that are expected to make up the majority of the future fuel mix for deep sea shipping; methane, methanol, and ammonia as well as drop-in fuel oils from renewable sources [18, 19, 20]. The use of molecular hydrogen and electrical energy stored in batteries are also likely to play a key role in the decarbonisation of in-port or short sea vessels, however their low energy density make them unsuitable for deep sea vessels and are therefore expected to meet only a small portion of shipping's total energy demand.

It is critical to consider the full lifecycle greenhouse gas emissions from marine fuels

The greenhouse gas emissions produced at the point of use of each fuel option can be readily compared, regardless of how the fuel was produced and distributed to the vessel. However, to reflect true climate impact, the full lifecycle greenhouse gas emissions generated during the feedstock generation, fuel production, distribution, and eventual use onboard must also be considered.

This report refers to fuels with low or zero lifecycle greenhouse gas emissions as 'low and zero emission fuels'. However, it should be noted that, depending on how the fuels are converted to energy on board, they may still produce air pollutant emissions, some of which could themselves contribute to climate change. Further discussion around the potential air quality impacts of the new fuels is discussed in more detail in Section 4.

Each fuel has a range of production pathways which influence its lifecycle greenhouse gas emissions

A fuel's lifecycle emissions are heavily influenced by the feedstocks and production pathway used to produce it. Each fuel option discussed in this report has numerous production pathways – including fossil-, bio-, e- and ccs-enabled routes – each with different feedstocks and production technologies that will influence these lifecycle emissions. This report has focussed on production pathways that can produce fuels with low or zero lifecycle emissions.

The sector needs to minimise lifecycle emissions and avoid carbon lock-in

The lifespan of energy, fuel production, and port infrastructure, as well as of ships themselves, typically spans several decades. Much of the infrastructure being planned now and developed over the coming years will therefore still be operating in 2050, the year in which Canada and the majority of major economies have committed to achieving net-zero emissions. It is therefore critical that infrastructure for the supply alternative shipping fuels is designed to deliver, or have the ability to deliver, low or zero lifecycle emission fuels in order to avoid 'carbon lock-in'.

There are a number of ways of defining what constitutes a low emission fuel

There are various government and industry standards that can be applied to define thresholds for the lifecycle emissions of hydrogen-derived fuels. These thresholds are a key measure to ensure that government support and investment is directed towards projects that can contribute to greenhouse gas emissions reduction.

The Hydrogen Strategy for Canada recommended that a carbon intensity threshold is set in Canada at which hydrogen may be termed 'clean' and that it should "coordinate with efforts underway internationally" [17]. The strategy made specific reference to the European voluntary 'CertifHy' scheme and its recommended threshold of 36.4gCO2e/MJ. The same threshold is recommended in British Columbia's provincial hydrogen strategy [21]. The threshold is set at 60% below the carbon intensity of hydrogen produced from natural gas without CCS.

Other standards either published or in development include:

- More recent rules published by the European Commission which set a lower lifecycle emissions threshold of 3.38kg-CO_2e/kg-H_2 (~28gCO_2e/MJ) [22].
- The 'UK Low Carbon Hydrogen Standard' which sets an emissions intensity threshold of 20gCO_2e/MJ [23] below which the hydrogen can be considered 'low carbon'.
- The 'U.S. Department of Energy Clean Hydrogen Production Standard (CHPS) Draft Guidance' [24] proposes a less stringent target of 4 kgCO_2e/kgH_2.

The threshold in the UK standard (20gCO_2e/MJ) is the most stringent of those listed above and has been selected as the preferred approach in the absence of a standard specifically agreed for Canada. Therefore, this report uses the term 'low emission fuel' to refer to fuels with lifecycle greenhouse gas intensity below 20gCO_2e/MJ, which is approximately 80% lower than for conventional shipping fuel oils. Since this threshold is for hydrogen production only, it is assumed that further processing to produce ammonia or methanol is powered by renewable electricity only and that the source of CO_2 for methanol is net carbon zero over its lifecycle.

Green shipping corridors should focus on building supply chains for low and zero emission fuels

Green shipping corridors are an opportunity for high-ambition partners to drive the uptake of low and zero emission fuels in the short term. This report has therefore considered fuel production pathways that could offer significant reductions in lifecycle greenhouse emissions compared to conventional fuels and are therefore able to support the decarbonisation of shipping in line with a trajectory aligned with a 1.5°C Paris Agreement goal. A high-level overview of the production pathways considered in this report is shown in Figure 4.

The fuels can be grouped and defined as follows:

- **CCS-enabled fuels**, referring to those derived from hydrogen produced by reforming natural gas feedstocks and capturing the resulting carbon using a Carbon Capture and Storage (CCS) process. These fuels may also be referred to as 'blue' fuels. For these fuels to meet the emissions intensity threshold, the CCS process must have a high capture rate, the resulting carbon permanently and securely sequestered, fugitive methane emissions must be tightly controlled, and hydrogen used to fuel the reformer.
- **Bio-fuels**, referring to those produced with carbon from biomass feedstocks. For these fuels to be meet the emissions intensity threshold, the biomass feedstocks must be from sustainable sources without detrimental climate, environmental, or social impacts and with robust certification and traceability.
- **E-fuels**, referring to those derived from hydrogen produced by electrolysis. To meet the emissions intensity threshold, the electricity used in the fuel's production must be from low or zero carbon generation sources. These fuels are sometimes also referred to as 'green' fuels. For carbon containing e-fuels, such as methane or methanol, the carbon must be removed from the atmosphere via biogenic processes or Direct Air Capture (DAC).

Geographical and technological characteristics will influence the uptake of each fuel and production pathway in the short, medium, and longer term

Each fuel and production pathway presents its own challenges and opportunities that may affect its short- and mid-term development as well as long-term technical, economic, and environmental viability as a full-scale shipping fuel. As well as the fuel's production, there are also challenges associated with the bunkering, storage and use onboard of the fuels that will need to be overcome.

Location of production infrastructure is key to delivering cost competitive fuels

In the absence of market influencing policy or regulations, the cost of production of low and zero emission fuels will be higher than that of their fossil fuel equivalents. Aside from technology costs, which are broadly comparable regardless of location, the cost of production is highly dependent on:

- **Availability of low-cost renewable energy -** The production of e-fuels requires significant input of electrical energy for hydrogen electrolysis and subsequent synthesis of the fuels. Electrical energy may also be required to power desalination plants to provide water for electrolysis or, in the case of methanol and methane, for energy intensive carbon capture processes. To minimise lifecycle emissions of the fuels, the electricity must be generated from low or zero emission sources such as renewables or nuclear power. Furthermore, the electrical generation capacity used in the production of fuels should be introduced in addition to those required to decarbonise the electrical grid in any country or region. Since long distance electrical transmission presents a range of challenges, including

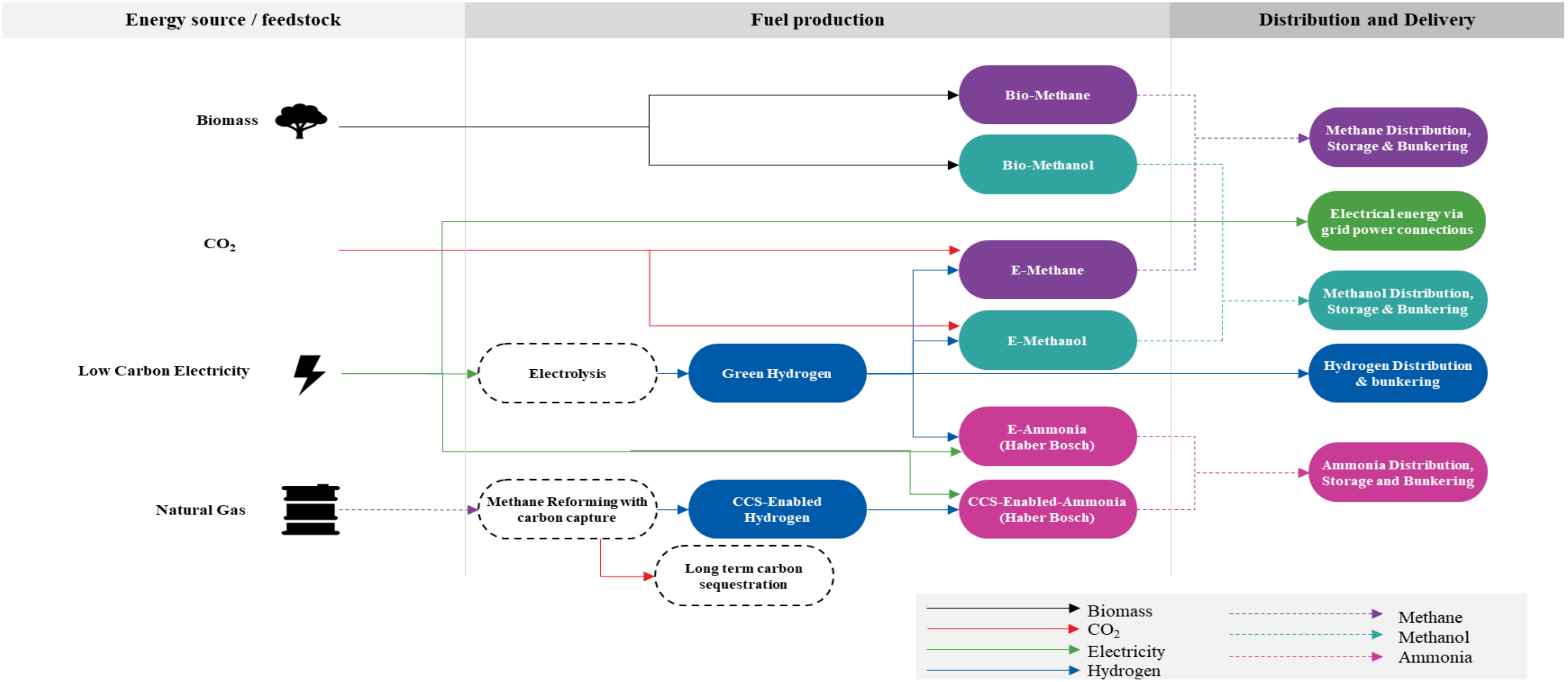

Figure 4 - The key energy sources, feedstocks, and production processes involved in the main carbon fuels under consideration

high costs and power losses, location of the production plants in regions with ample renewable power available at low cost is preferable.

- **Proximity to the point of use -** There are existing global supply chains for methane, methanol, and ammonia, with the products transported by pipeline, road, rail, or ship. However, transporting the fuels over greater distances will add cost and logistical challenges; hence impacting the commercial competitiveness of the delivered fuel. Producing fuels in proximity to the point of delivery to the end user could be preferable where this is balanced with the relative production cost at that location.

- **Sustainable supply of carbon -** The lifecycle emissions associated with carbon containing fuels, such as methane or methanol, will heavily depend on the source of the carbon used as a feedstock during production. Although this could be captured from the exhaust streams of existing fossil fuel plants, the preference should be for this carbon to be sequestered permanently rather than released to the atmosphere when the fuel is used. For the fuel to be considered low or zero emission on a lifecycle basis it needs to be from sustainable biogenic sources or extracted from the atmosphere by a DAC process. In the case of biomass, the energy required to transport the feedstock, often by road, can have a significant impact on the lifecycle emissions as well as the cost of the end-product. Similarly, transporting carbon dioxide over significant distances, by road, rail, ship, or pipeline, is equally costly and presents infrastructure development challenges.

- **Availability of carbon sequestration facilities -** In the case of CCS-enabled fuels, where hydrogen is separated from fossil fuel feedstocks, there is an additional requirement for long term sequestration of the carbon; a process that relies on suitable geological conditions, often in depleted natural gas or oil fields. Situating CCS-enabled fuel production facilities in proximity to the source of natural gas as well as sequestration locations will remove the need to transport these products and hence reduce production costs.

The location of the fuel production plant in relation to the energy source, feedstock, point of use and carbon sequestration location is therefore key to minimising production costs and making these fuels commercially viable. The availability of these key resources in a region will influence which fuel and production pathways would make the most economic sense – a topic which is explored in more detail later in this report.

Liquefied Natural Gas

Liquefied Natural Gas (LNG) – a gaseous mixture of hydrocarbons predominantly made up of methane – has seen uptake as a marine fuel in recent years as a means of complying with new regulations on air pollutant emissions as well as to reduce the carbon intensity of vessels. More than 10% of the global fleet, either operating or on order, are now capable of operating on LNG fuel [60] and bunkering availability is increasing around the world. However, LNG has not been considered in this report for the following reasons:

- LNG is a fossil fuel that is only able to offer limited greenhouse gas emissions reductions of up to just 23% [61] on a lifecycle basis in comparison to fossil fuels. Widespread uptake of LNG as a shipping fuel does not enable a decarbonisation trajectory for the shipping sector that is aligned with the Paris Agreement goals and achieving net zero greenhouse gas emissions by 2050.

- Since methane is itself a highly potent greenhouse gas - 86 times more potent that carbon over a 20 year time frame - tight controls of fugitive emissions are required through the supply chain from production to use in ship engines. Unless fugitive emissions are tightly controlled, the use of LNG fuel could have a detrimental effect on the overall climate impact of shipping.

- The purpose of green shipping corridor initiatives is to accelerate development of supply chains for zero emission fuels that are currently immature.

The potential role of LNG in meeting existing emission reduction targets has been covered in more detail in a number of industry papers [61, 62, 63]. For the purpose of this report, natural gas has been considered as possible feedstock in the production of CCS-enabled fuels.

3.2 Mobilising the fuel supply value chain

There are a number of commercial, regulatory, and technical barriers to the production, supply, and use of low and zero emission fuels at scale. A green shipping corridor initiative is an opportunity for an engaged group of stakeholders, from across the supply and demand side of the marine fuel value chain, to collaborate on means of addressing these. This could include development of new commercial approaches, agreeing safety standards for bunkering of new fuels or collaborating on technology demonstration projects.

Figure 5 outlines the key groups of value chain actors involved in the supply of low carbon marine fuel value. Each of these groups can play a key role in the supply of fuels to green shipping corridors and, in the longer term, to shipping as a whole. This section explores these roles and the ways in which the stakeholders can work together to accelerate low and zero emission fuel uptake.

Close collaboration between energy, feedstock and fuel producers can minimise fuel production costs

As discussed above, the cost of energy and material feedstocks is one of the key price drivers for many low and zero emission fuels. Close collaboration or integration between feedstock and fuel producers is important to support commercial viability by minimising and stabilising costs. For CCS-enabled fuels, natural gas could be procured from the open market however more niche renewable feedstocks may require dedicated production or collection facilities local to the fuel production facility.

For electricity supply, agreements between energy companies and fuel producers should therefore prioritise minimising and stabilising costs to support viability of the fuels. Stabilisation can be achieved through specific power purchase agreements (PPAs) which might be delivered virtually from a remote renewable electricity production facility, or physically using a direct wire connection.

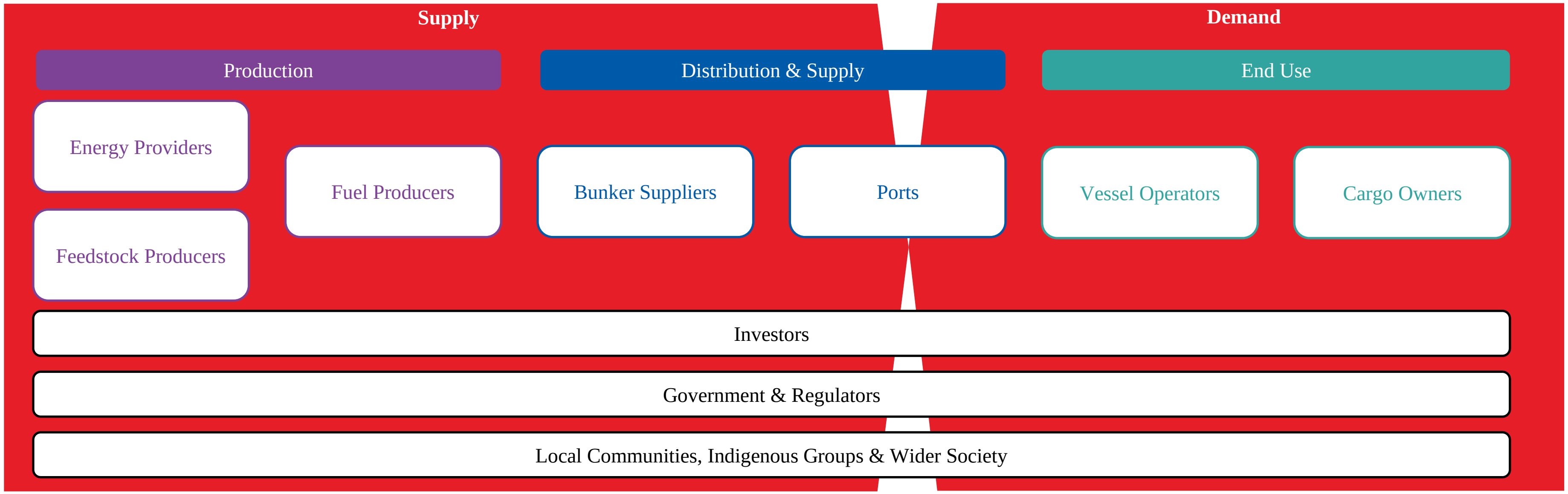

Figure 5 – Key stakeholder groups involved in production, supply and use of low and zero carbon marine fuels

Fuel offtake agreements will help to stabilise prices and de-risk infrastructure investments

Producers of low carbon fuels will include start-ups developing new production infrastructure as well as established organisations adapting existing facilities. In either case, making significant investment in new infrastructure can represent a significant risk. Establishing offtake agreements with bunkering services or vessel operators can offer longer-term stability of pricing for both the producer and the user, increasing the certainty required to invest in costly new infrastructure. For this reason, first mover fuel producers are likely to seek partnerships with upstream suppliers (which may be exposed to a similar risk from economy-wide decarbonisation), ports and bunkering services and vessel operators.

Bunker suppliers are involved in the distribution of marine fuels from production facilities or import/export hubs to in-port storage facilities or directly to the vessel via truck, bunker vessel, or fixed infrastructure. Alternative marine fuels such as hydrogen, ammonia, and methanol each present distinct challenges to their safe and efficient storage, distribution and transfer that will require new infrastructure and equipment to safely deliver the fuels to vessels; this may include storage facilities, pipelines, landside vehicles, and bunker vessels. It is likely that the fuel producers may undertake some or all of the bunker supply activities.

Ports sit at the intersection of the supply and demand of marine fuels

Ports will play a vital facilitating role in the transition of shipping to zero emission fuels. As a minimum, ports can be expected to facilitate port visits from vessels using alternative fuels. However, there is an opportunity to support movement of fuels into their site and facilitate bunkering activities, requiring the appropriate knowledge and procedures to manage this safely. Development of fuel storage facilities within the port boundary will require significant investment. It should be noted that bunkering of several different fuels in a single port, each with distinct handling requirements, is likely to be commonplace in the future.

Sharing the cost of the fuels across the supply chain

Increased operational costs associated with the high cost of low carbon marine fuels will be faced by vessel owners and operators. They will additionally require significant capital investment for new or upgraded ships and supporting technologies. Collaborating with other value chain actors on offtake agreements, port fee incentives, or premium cargo rates can help to mitigate this. Significant technical and regulatory challenges remain to the uptake of some fuel's onboard vessels and collaboration with regulators, shipbuilders, and equipment suppliers will be required to overcome them.

Cargo owners bridge the gap between the shipping industry and consumer ambition

Cargo owners will play a key role in the development of green shipping corridors. Ambitious decarbonisation targets have been set by cargo owners in response to government and consumer pressures and this is driving these businesses to seek low carbon shipping options. For example, the Cargo Owners for Zero Emission Vessels (coZEV) network, which includes major retailers like Amazon and Ikea, is working to accelerate maritime decarbonisation by sending demand signals for zero emission shipping services and supporting green shipping corridor development [25].

Governments will play a central role in the decarbonisation of shipping at local, regional, national, and international levels

The nature of the marine fuel production value chain will require involvement from a range of government departments. By setting top-level, Paris-aligned decarbonisation policies for the energy and transport sectors, governments can ensure the shipping industry is clear on the targets that need to be achieved. Governments may also seek to regulate the greenhouse gas intensity of fuels used by domestic shipping, in a similar approach to the existing Clean Fuel Regulations [26] put in place in Canada to help drive development and uptake of low emission fuels in transportation sector.

Government also has a central role in the development of enabling regulations and provision of any direct grant funding to support bridging the cost gap in the short to medium term. Creating decarbonisation policies with clear targets and embedding them across taxation, development planning and regulations sends opportunities signals to the market. This will need to take place at a local, regional, national, and international level and work across the value chain.

The substantial investment opportunity needs to be unlocked

Decarbonisation of the global shipping industry by 2050 has been estimated to require investment of up to USD$1.6 trillion [3]. This presents new opportunities for the investor community around ship building and retrofits, energy and fuel production infrastructure as well as associated supply chains. Internalising the wider value opportunities means investors moving outside the traditional, narrow lending criteria which views uncertainty as risk, rather than a steppingstone to a bigger opportunity.

4. The Total Value Case

4.1 A Total Value approach could illuminate the potential co-benefits of green shipping corridors

Substantial capital and operational investment is required in new infrastructure to supply low and zero emission fuels to first mover green shipping corridors. These projects could have significant positive impacts on Canada's economy, at both national and local levels, as well as on the natural environment and communities living nearby. Considering the 'Total Value' case for green shipping corridors and supporting fuel supply projects can help to shape, capture, and leverage their wider value and therefore improve their investment case.

The Total Value of infrastructure is the "perception of worth, or benefit, that accrues to stakeholders, communities and other beneficiaries over time" [27]. It is the sum of the financial, economic, social, and natural value delivered by the project. A Total Value assessment should identify the positive value outcomes that could be realised, helping to embed these as objectives from an early stage of the project. However, it should also identify and explore the risk of negative value outcomes, such that they can be mitigated and minimised wherever possible.

This section explores how a Total Value framing approach can be applied to green shipping corridor projects in Canada, the areas that value could be delivered in, as well as some of the potential risks and negative outcomes that should be mitigated. A 'Total Value story from 2040' has been developed for each of the case studies in sections 6 and 7 to illustrate the value outcomes that could be delivered and the approaches to realising them.

Figure 6 – Total value for green shipping corridors

(Adapted from Arup [27])

4.2 Benefits that green corridors and broader maritime decarbonisation could bring to Canada

Figure 6 shows a range of areas where green shipping corridors and their associated fuel production infrastructure could – if shaped and implemented in the right way – deliver broad value to diverse stakeholders. Although presented separately, many of the value areas are inter-linked or overlapping, underlining the importance of considering the full value profile together. Each individual project will have a greater or lesser impact on each value category and there may be additional categories to be considered that are not shown here. Each of these value categories is described in more detail below.

Economic value

Economic value is the value delivered to the public purse, for example by supporting jobs, facilitating trade, or increasing tax revenue.

Shipping has been estimated to directly contribute CAD$3 billion to Canada's GDP [1] while the energy sector makes up a further 9% of the economy, or CAD$175billion [28]. However, both of these sectors will undergo significant change in the coming decades as the world transitions to a net-zero economy meaning that continuing in business-as-usual will not be an option. Green shipping corridors present opportunities to address risks associated with this transition, realise first mover advantages, create green jobs, and support sustained economic growth in these sectors while delivering on policy ambitions.

These economic value considerations could be grouped under the following four categories:

Sustainable Growth

Delivery of new zero emission fuel production infrastructure can help to minimise climate transition risk in Canada's energy and transport sectors; future proofing jobs in these sectors and enabling sustained economic activity and as the world transitions to net zero emissions. More broadly, shipping decarbonisation will help to secure a long-term future for competitive international trade.

Timely

There are already numerous low and zero emission fuel infrastructure projects underway globally, but production still needs to scale significantly in the coming decades to meet global climate targets. Entering the market at an early stage can help to realise first mover advantages and lock-in economic benefits over the long term. Uncertainties in the rate that demand will scale presents risks which can be mitigated through the green shipping corridor model.

Innovation

Participation in green shipping corridors and other first mover projects can support development and demonstration of innovative technologies across the fuel production chain. Fostering this innovation in Canada can help to maximise the economic potential of the maritime fuel transition while supporting a broader technology and innovation sector.

Policy Alignment

Projects should align with stakeholders' strategies and broader policy while delivering value for money. In Canada, supporting green shipping corridors will help the government deliver on its international commitments and national emissions reductions targets. There are also opportunities to consider how energy policy aligns with the decarbonisation of road transport, rail, shipping, aviation, and other fuel consuming sectors can help identify demand aggregation opportunities, unlocking economies of scale and maximising economic benefit.

Social value

Social value is the value delivered to individuals, local communities and wider society that ultimately improves quality of life.

While maritime industries can bring significant benefits to port and coastal communities, in terms of employment and economic growth, these same communities also often experience the worst of the negative impacts of shipping such as air, water, and noise pollution. Maritime activity can have a particularly acute impact on low-income communities, who may live in the most polluted areas, as well as Indigenous people who have a strong ancestral connection to the sea and coastal lands.

Green shipping corridors, and the longer-term decarbonisation of shipping, presents an opportunity to reduce pollution and pursue broader social benefits. These may include the generation of new employment opportunities, skills development for existing workers, improved health and wellbeing, enhanced community cohesion, and increasing inclusion of Indigenous groups.

These social value considerations could be grouped under the following four categories:

Quality Jobs & Opportunity

The creation of well paid, inclusive, and meaningful jobs in innovative industries - such as zero emission fuel production - can provide more and better employment opportunities for local communities with the net effect of an improved quality of life. Providing training and improving skills will provide broader opportunities over the long term and contribute to realising economic benefits.

Community Cohesion

Port communities often have a strong connection to the port’s activities with the port forming part of local identity. Ensuring the future success of the port and positioning it as a front runner can enhance this connection and provide positive community uplift benefits.

Inclusion & Diversity

Developing new energy and fuel infrastructure is an opportunity to ensure Indigenous communities are included and the full benefits are shared equally. Early and comprehensive engagement and involvement with community groups, particularly indigenous communities, is key to project success and to advancing reconciliation and self-determination.

Health & Wellbeing

Reducing air pollution from shipping will avoid negative health impacts on port and coastal communities but can also have indirect positive effects such as encouraging increased outdoor recreational and community activities. However, there are also health and safety challenges that must be addressed in the transition to these new fuels.

Natural value

Natural value is the value delivered for the environment.

Vessels operating in Canadian waters produced more than more than 13 million tonnes of CO_2 emissions in 2019 [2] as well as hundreds of thousands of tonnes of air pollutants that impact the health of port and coastal communities, pollute oceans and can themselves have a significant climate impact. There are also risks associated with accidental fuel oil spills as well as ongoing loss habitats and natural resource depletion.

Green shipping corridors are an opportunity to collaborate across the energy, fuel, and shipping value chains to address these environmental impacts while exploring opportunities to deliver net benefits to biodiversity and support the development of circular economy principles in any new projects.

These natural value considerations could be grouped under the following categories:

Water Quality

Combustion of fossil fuels contributes to ongoing environmental damage through processes such as ocean acidification and eutrophication. The transition to alternative fuels can help to slow these processes. However, care must still be taken when handling these new fuels to avoid accidental leaks or spills, particularly in areas with vulnerable ecologies.

Air Quality

Poor air quality in ports and coastal areas caused by shipping contributes to negative health impacts and causes millions of premature deaths globally every year. Reducing combustion of carbon-based fuels will reduce emissions of particulate matter and associated health impacts. However, adverse impacts of combustion of alternative fuels must be understood and managed.

Climate

The importance and urgency of reducing greenhouse gas emissions in order to protect people and the planet has never been clearer. Climate impacts will be felt at a local level, impacting coastal communities as well as stakeholders across the port and shipping sectors. Transitioning to low and zero emission shipping fuels will address greenhouse gas emissions and hence help to prevent the worst climate outcomes.

Biodiversity

The need to produce develop new energy and fuel production infrastructure at scale, which can occupy large areas of land or seabed, must be balanced with the need to protect sensitive environmental areas and enhance biodiversity. Maximising the use of brownfield sites and repurposing existing infrastructure wherever possible can help to achieve this aim and deliver the fuel transition with as little environmental impact as possible.

Resources & Circular Economy

Many of the fuel production pathways explored in this report require significant quantities of feedstocks, from biomass to fresh water, and also produce waste streams, such as oxygen or carbon dioxide. Effective use of these resources should be prioritised to avoid adverse environmental impacts. Meanwhile, any opportunities to use waste products from other industries or provide by-products for secondary use should be explored.

Financial value

Financial value is the direct financial benefit delivered to stakeholders through the delivery and operation of new infrastructure.

Decarbonisation of the global shipping industry will require significant investment in land side energy and fuel production infrastructure [3]. Green shipping corridors can help to attract this investment to Canada where available natural resources, a skilled workforce and available land can be leveraged to produce cost competitive zero emission shipping fuels. The development of this infrastructure raises opportunities to explore how its financial benefit can be distributed among a broader range of stakeholders such as local communities and indigenous groups.

These financial value considerations could be grouped under the following categories:

Profit

The shipping industry consumes billions of dollars' worth of fuel every year; there is a significant opportunity for stakeholders across the shipping and fuel supply value chain to realise new revenue streams and profit from the transition away from fossil fuels. This could include energy companies, fuel producers, bunker suppliers, ports and first mover shipping companies. Exploring different ownership structures may raise the potential for greater public or community wealth building.

De-Risk

Although there is inherent risk in first mover projects involving innovative and emerging technologies, by mobilising supply and demand simultaneously, green shipping corridor initiatives are an opportunity for stakeholders de-risk investments in new fuel infrastructure. This infrastructure is also an opportunity for investors to de-risk existing portfolios by reducing exposure to legacy fossil fuel infrastructure and potential of stranded assets.

Ownership

Considering how to structure the ownership of new infrastructure alongside the broader value aims of a project can help to ensure the intended outcomes are achieved and benefits maximised. These projects provide an opportunity to increase ownership stakes in projects for public bodies, local groups, and indigenous communities.

ESG

Good governance in new infrastructure projects is crucial to ensuring value is delivered across all areas and to all stakeholders. Work should be done to ensure stakeholders, including investors, have strong Environmental, Social and Governance (ESG) performance and values that align with the broader aims of the project.

4.3 Delivering the value

As explored in the preceding section, there are a broad range of positive value outcomes that could be delivered for Canada through green shipping corridors and longer-term maritime decarbonisation. However, the type of value that can be delivered - and the benefactors of it - depends as much on the approach taken to implementing the infrastructure projects as it does to the type of infrastructure delivered.

Considering the impact at a local, national, and global scale

As identified in the Canadian Green Shipping Corridor Framework, actions to tackle emissions at a local level can support positive outcomes at a national or global scale. This is applicable across the Total Value framework, where supplying zero emission shipping fuels in Canada could also realise economic, social, and financial benefits at a global scale. Figure 7 sets out example benefits that could be delivered by at a local, national, and global scale.

Applying a place-based approach

A place-based approach recognises that a one-size-fits-all attitude to project delivery will not capture the importance of local context and how this shapes the uniqueness of place. The impact of creating green shipping corridors on the local communities will be unique to Halifax, Vancouver, Prince Rupert, and indeed any port in Canada. Ensuring that evidence-based knowledge of local need and context feeds into decision-making processes within the project allows for sustainable and relevant long-term value creation.

Identifying the target value outcomes from a project and embedding them in its delivery

Undertaking a value assessment at the start of any project can enable stakeholders to identify the potential value that could be delivered and embed this as specific objectives in the project's delivery. The objectives should be revisited at all key stages of the project to ensure they are delivered. This approach can help to make sure all stakeholders are aligned on the outcomes and working together towards them.

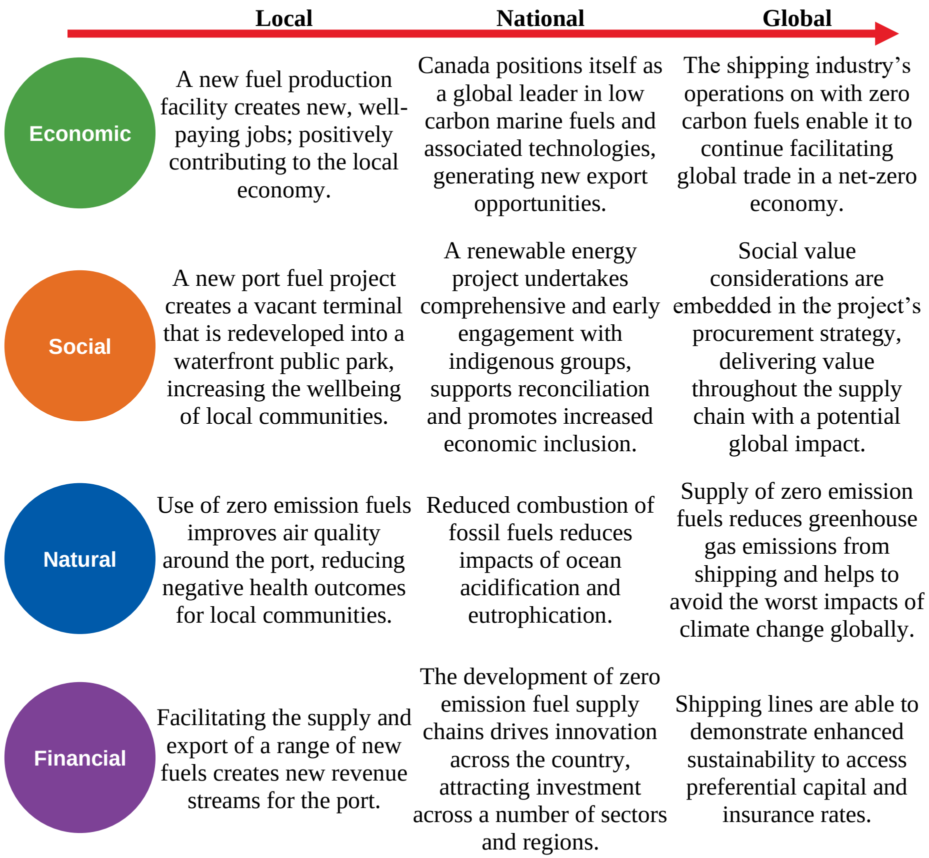

Figure 7 – Example benefits that could be realised at a local, national and global scale

5. Case study: British Columbia, the Port of Vancouver, and the Port of Prince Rupert

This report uses two Canadian case studies to illustrate the potential impact that green shipping corridors and the longer term decarbonisation of shipping could have in Canada. These case studies examines the Port of Vancouver and Port of Prince Rupert in British Columbia. These explores the region's energy and resource setting, the local context of each port, and how these factors can influence the feasibility of different fuel production pathways.

Using an estimate of the potential future low and zero emission fuel, produced by the Lloyd's Register Maritime Decarbonisation Hub, an example fuel production and supply typology is developed for each port to illustrate the type, scale and cost of the infrastructure required to meet potential future demand for low and zero emission shipping fuels. The cost estimates provide an order of magnitude indication of the investment required to deliver the infrastructure for each typology and are based on assumptions and benchmarks taken from publicly available sources and similar projects.

A Total Value story has been developed for each of the illustrative fuel supply typologies to demonstrate possible value outcomes that could be delivered for each location, including some of the approaches taken to doing so. Considering the 'Total Value' case can help to shape, capture, and leverage the wider value of the corridor and therefore improve their investment case.

5.1 Regional energy and resources

British Columbia has a high renewable energy mix with excess generation capacity

In British Columbia, hydroelectric power generates about 87% of the region's electricity followed by Biomass (5%) which primarily uses waste from the province's large forestry sector [29]. A further 4% of electricity is generated from wind power and the remaining 4% is generated from combustion of natural gas generation. This high renewable energy mix means that the province has one of the lowest carbon intensity grids in the world, as shown in Figure 8.

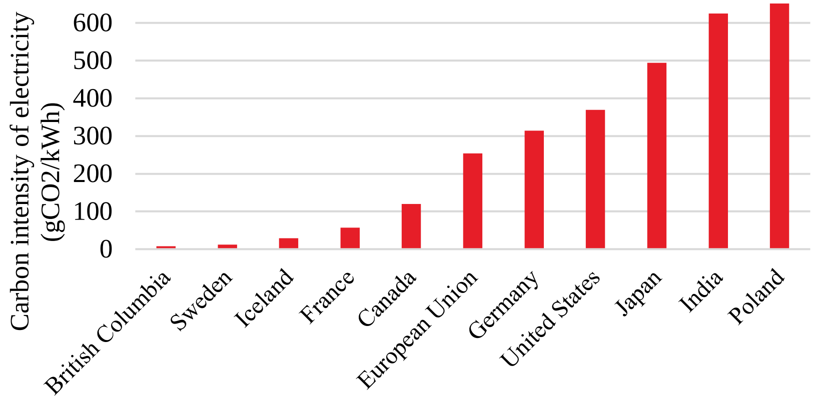

Figure 8 – Carbon intensity of electricity in British Columbia compared to a selection of global economies in 2020

Data source: British Columbia [29], all other countries [30]

Most of the hydroelectric generation plants are situated on the Peace River in the northeast and the Columbia River in the southeast of British Columbia. A major, 1,100 MW hydroelectric project called Site C is currently being built on the Peace River and is anticipated to be finished in 2025 aiming to provide additional low-cost renewable energy.

There is a currently an energy and capacity surplus in British Columbia which is forecast to persist until around 2030 [31]. Given the large quantities of renewable energy in the grid, the province has the opportunity to produce low carbon fuels such as hydrogen and its derivatives.

The province has significant natural gas resources

British Columbia is a major producer and supplier of natural gas; accounting for 35% of total Canada's total natural gas production in 2020 [29]. An established pipeline network supports the distribution of natural gas within the province as well as its export elsewhere in Canada and to the US. The Province has recently released a New Energy Framework that sets requirements for new LNG facilities to set out plans to reduce production emissions to net zero by 2030. The framework commits to putting in place a regulatory cap on production emissions from the oil and gas industry to ensure British Columbia meets its 2030 emissions-reduction target for the sector. The utilization of renewable energy to lower the greenhouse gas emissions from the production and liquefaction of natural gas, would help to minimise the lifecycle emissions where the gas is used as a feedstock in production of CCS-enabled hydrogen and its derivatives.

Some parts of the electricity grid are constrained

There is a push to electrify buildings and vehicles to curb climate-warming emissions. However, in the northwest of British Columbia there is limited grid capacity and lower security of supply which has impacted the rate of decarbonisation in the area. These constraints could impact the viability of any e-fuel production facility in the area, including Prince Rupert. However, the commitment in the New Energy Framework to accelerate the industrial electrification with renewable electricity could help to alleviate this concern.

There is government support for transport electrification and hydrogen production

Despite British Columbia having a low carbon electricity grid and surplus generation capacity, around 70% of the region's total energy demand is met through fossil fuels such as gasoline and domestic natural gas. In 2021, BC Hydro, the electric utility that generates most of the region's electricity, launched a 5-year 'Electrification Plan' [32], which includes plans to invest CAD$260 million to promote energy studies, energy incentives and other programs to encourage customers to switch to electricity. This plan covers customers across industry, transportation, and homes and buildings. For the Transportation sector, BC Hydro are providing incentive support around customer specific electrification roadmaps, studies, fleet conversations and demo projects. There is potentially an opportunity to further extend this programme to support e-fuel production for vessels that cannot be directly electrified.

The province's government has published Hydrogen Strategy [21] to support its aim to reach net zero emission by 2050 and ambition to become a world leading hydrogen economy. The strategy outlines government's actions to accelerate the development of British Columbia's hydrogen sector, identifying potential for green and CCS-Enabled hydrogen production given the clean grid, natural gas reserves, and significant CCS potentials with favourable geology. This hydrogen can be used directly in fuel cells or combustion engines of some marine vessels or used in the production of e-fuels such as methane, methanol, or ammonia to fuel larger ocean going vessels.

Favourable geology creates a potential market for carbon sequestration

The geological formations that provide the province's abundant natural gas reserves also present a significant opportunity for the geological storage of carbon dioxide. Neighbouring Alberta has already committed $1.24 billion of funding for two commercial-scale carbon capture, utilisation and storage projects in the region where carbon will be collected from industrial activities and injected into secure geological formations. The potential for significant long-term sequestration of captured carbon, as well as the availability of natural gas with low production emissions, could lend itself to production of CCS-enabled hydrogen and derivatives such as ammonia at commercially competitive cost.

There is also the potential to develop further economic activity around the capture, handling, and storage of carbon, potentially importing captured carbon from other regions or countries, or becoming a leading region in the technology development required to develop this industry. For example, local company Carbon Engineering is already operating a pilot Direct Air Capture (DAC) plant in Squamish which has the potential to produce feedstock to produce low emission e-fuels.

5.2 Estimated demand for low and zero emission fuels

The Lloyd's Register Maritime Decarbonisation Hub conducted an analysis of vessel traffic operating on the West Coast of Canada during a baseline year of 2021 to estimate zero emission demand under different scenarios. The applied methodology for this analysis is described in full at Appendix B.

Port of Vancouver

The analysis identified 3,300 vessels that entered the region covering the western coastline of Canada and the US, extending to the southern point of Oregon. Of these, 830 vessels entered the Strait of Georgia and Vancouver area. However, as shown in Figure 9, many of these vessels spend a significant proportion of the year operating internationally and therefore have greater options to bunker elsewhere. To account for this, the analysis assumes that vessels would be unlikely to bunker in the port if less than 20% of their total port calls are in Vancouver or they spend more than 50% of the year outside the region; these vessels are therefore considered out of scope and excluded from the estimate of fuel demand. Applying these thresholds to the first mover segments - bulk carriers, container ships and Ro-Ro vessels - Lloyd's Register identified 144 vessels as being in-scope. The estimated total annual fuel demand of the in-scope fleet is in the region of 820 thousand tonnes per annum (ktpa) of HFO equivalent fuel (HFO[e]), of which around

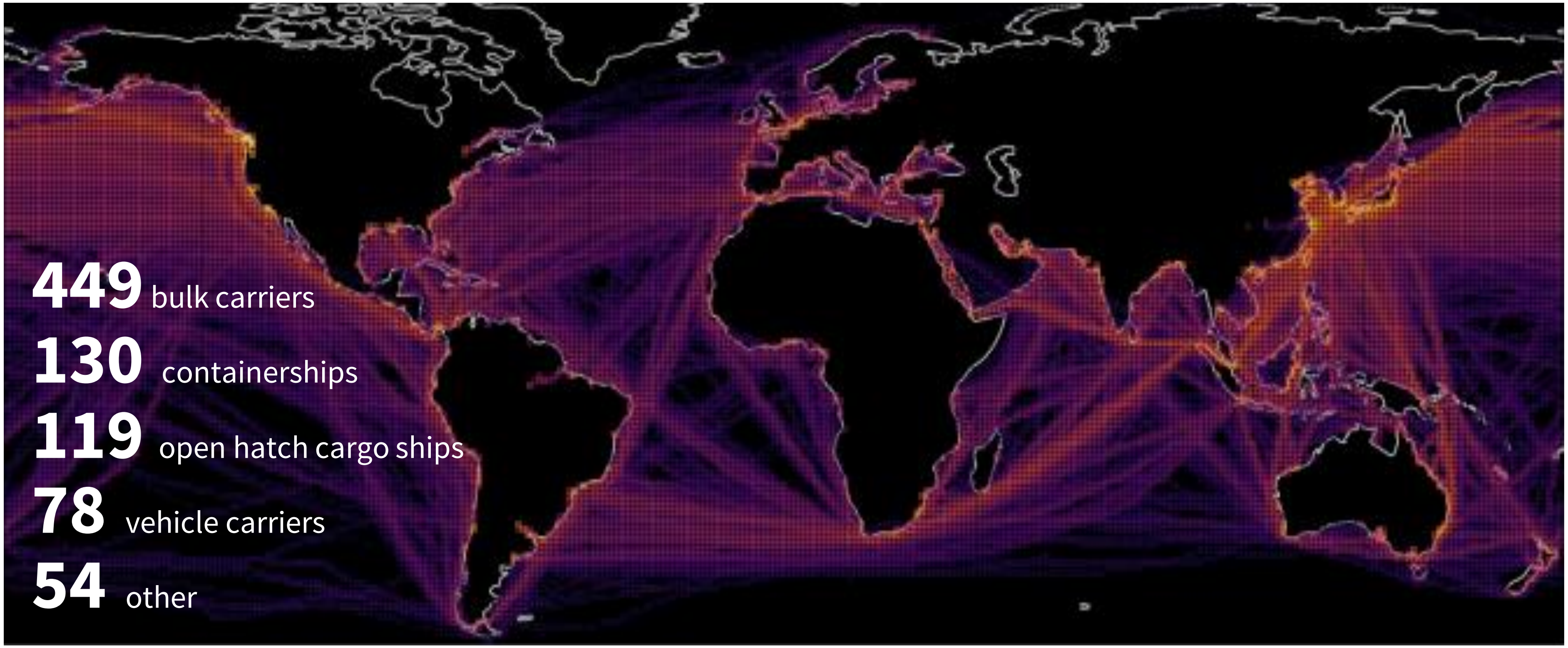

Figure 9 - Heatmap of global activity of vessels that ever called in Vancouver during 2021

(Source: Lloyd's Register Maritime Decarbonisation Hub)

230ktpa is estimated to be attributable to Vancouver based on the time the vessels spend in the region.

The analysis applies a number of assumptions to project the uptake of zero emission fuels to 2030 including estimates for transport demand growth, alternative fuel uptake versus other options, level of decarbonisation ambition, and refuelling frequency/feasibility which are described in more detail at Appendix B. The analysis predicted a zero emission fuel demand at the Port of Vancouver of approximately 11ktpa HFO[e] in 2030, which is equivalent in energy terms to 24ktpa of ammonia or 22ktpa of methanol.

Figure 10 shows how this demand could develop if uptake were to follow a decarbonization trajectory aligned to 1.5°C Paris Agreement goal. If uptake follows this projection, the demand for zero emission marine fuels in Vancouver could warrant dedicated production facilities.

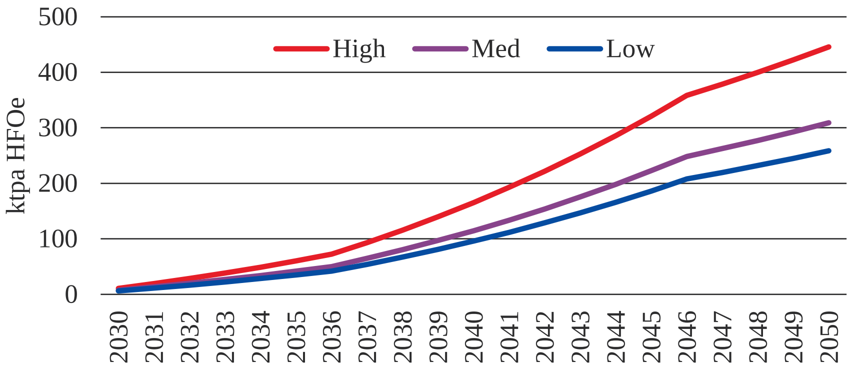

Figure 10 – Projected zero carbon fuel demand in thousands of tonnes per year of HFO equivalent in Port of Vancouver

(Source: Lloyd's Register Maritime Decarbonisation Hub)

Port of Prince Rupert

In the case of the Port of Prince Rupert, the analysis identified 72 vessels that made a collective 239 port calls in the baseline year. As shown in Figure 12, these vessels operate globally throughout the year and as such the annual fuel demand that is likely to be attributable to the Port of Prince Rupert is low. Projecting this to 2030 results in a low fuel demand that is unlikely to make dedicated production infrastructure economically viable in the short to mid-term, as shown in Figure 11.

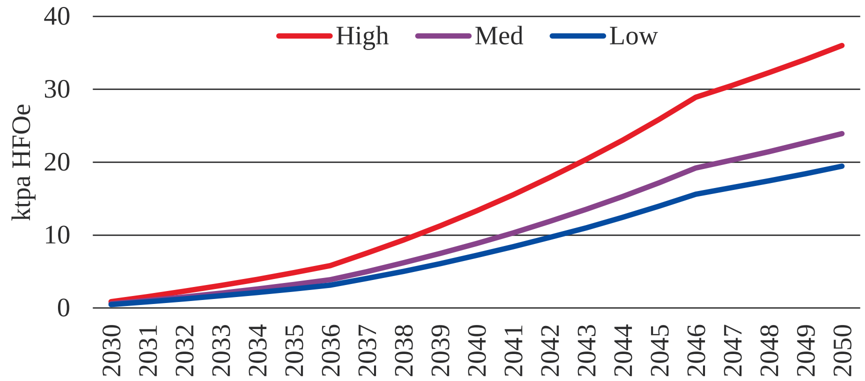

Figure 11 – Projected zero carbon fuel demand in thousands of tonnes per year of HFO equivalent in Port of Prince Rupert

(Source: Lloyd's Register Maritime Decarbonisation Hub)

As identified above, using vessel traffic data analysis to estimate fuel demand at a port level is a first step to explore opportunities for green shipping corridor and other initiatives. However, another important activity is engagement with stakeholders; examining port calls of vessels to establish routes, and therefore potential partner ports, is one way of doing this.

Table 1 shows the most common port calls for the container vessels identified in the analysis immediately before they arrive in Prince Rupert and immediately afterwards. For example, Lloyd's Register identified that of the 239 port calls identified in 2021, 48 were container arrivals from Okpo, South Korea and Zhoushan, China. This indicates potential links to two international locations that could be leveraged in the establishment of international green shipping corridors.

Table 1 - Top port calls by container vessels before and after Prince Rupert

(Source: Lloyd's Register Maritime Decarbonisation Hub)

Previous port call	Next port call
Okpo, South Korea	Vancouver, Canada
Zhoushan, China	Masset, Canada
Masset, Canada	Wilmington, USA
Port Edward, Canada	Port Orchard, USA
Yokohama, Japan	El Segundo, USA
	Yantian, China

West Coast Demand

Lloyd's Register also identified several ports along the west coast of Canada and the USA, including Vancouver, which create a network of ports servicing containerships that have designated service lines. By aggregating zero emission fuel demand across multiple ports, greater economies of scale can be achieved in the production plants serving first mover initiatives. It will also allow the burden of investing in new refuelling infrastructure to be shared across the ports.

For these reasons, a combined demand for these two port locations has been considered for the purposes of estimating the size of the infrastructure required in the example fuel supply typologies explored later in this section.

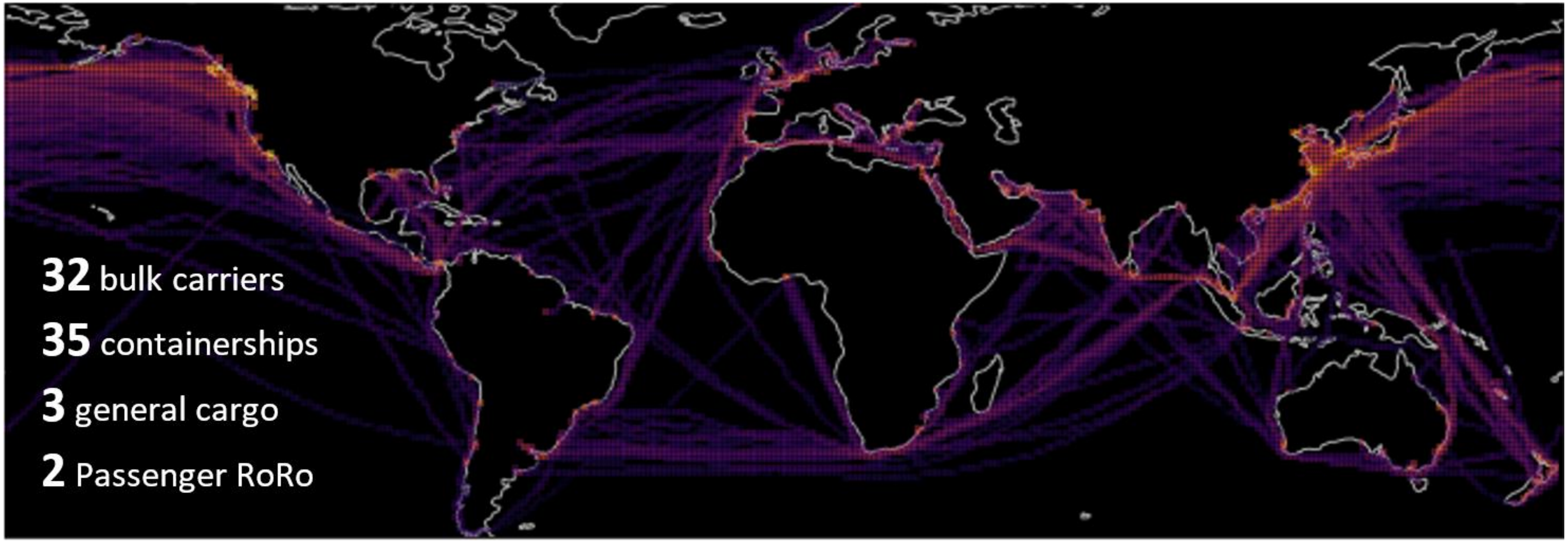

Figure 12 - Heatmap of global activity of vessels that called in Prince Rupert during 2021

(Source: Lloyd's Register Maritime Decarbonisation Hub)

5.3 Port of Vancouver

The Port of Vancouver is Canada's largest and most diversified port, situated in the south west of British Columbia. Managed by Vancouver Fraser Port Authority, the port is a major gateway for trade between Canada and Asia and handles a wide variety of cargo. By value, Vancouver handles CAD$1 of every CAD$3 of Canada's trade outside of North America, with over 75% of cargo handled at Vancouver exported to or imported from China, Japan, and South Korea. The Port has 29 multimodal terminals and borders 16 municipalities, intersecting several Coast Salish First Nation lands. In 2021 the terminals handled a total combined throughput of 146m tonnes worth ~CAD$275bn [33]. As the largest Port in Canada Vancouver has the opportunity to drive the shift in decarbonising ships operating in the region.

Port activities directly interface with the city of Vancouver

The Port of Vancouver covers a large area with numerous direct interfaces with the city of Vancouver. The majority of operations take place in Vancouver Harbour, in close proximity to densely populated areas such as Downtown and North Vancouver, potentially resulting in barriers or challenges to future development, especially for the storage, production, and transfer of alternative fuels which in many cases present new risks due to their flammability or toxicity. However, the city location also raises the importance of improving air quality from the vessels in port, through electrification or the use of alternative fuels, to reduce the negative impacts shipping emissions can have on local communities.

There is a wide variety of cargo handled in Vancouver

The Port of Vancouver handles a wide variety of cargo, in 2021 the terminals handled a total combined throughput of 146m tonnes worth ~CAD$275bn. The chart across shows the volume of cargo shipped through Port of Vancouver, over the past three years the tonnage through the port has increased at a rate of 1m per year. In 2021 Bulk accounted for the majority (69%) of the annual tonnage throughput followed by Container (17%) and Breakbulk (14%) [34].

Table 2 - Port of Vancouver cargo type overview

Cargo Type	Overview
Bulk (Dry and Liquid)	There are 21 Bulk Terminals in Vancouver, this cargo type makes up the majority of Vancouver's annual tonnage, handling 102m tonnes in 2021. A number of these service the petroleum industry, providing potential opportunities for re-development in future fuel transitions.
Container	There are four large container terminals located across the Port of Vancouver, in 2021 these had a combined throughput of 25m tonnes or around 3.6 million TEU.
Breakbulk	In 2021 around 20m tonnes of Breakbulk Cargo was handled over two terminals, each having road and rail connections.
Automobiles	There are two Automobile terminals, both located in the Fraser River. They provide import services from Asian markets, handling 350,000 cars in 2021.
Cruise	Due to Covid-19 the Port of Vancouver's Cruise berth was not open to the public over recent years. Previously in 2019, around 1m passengers arrived at Vancouver.

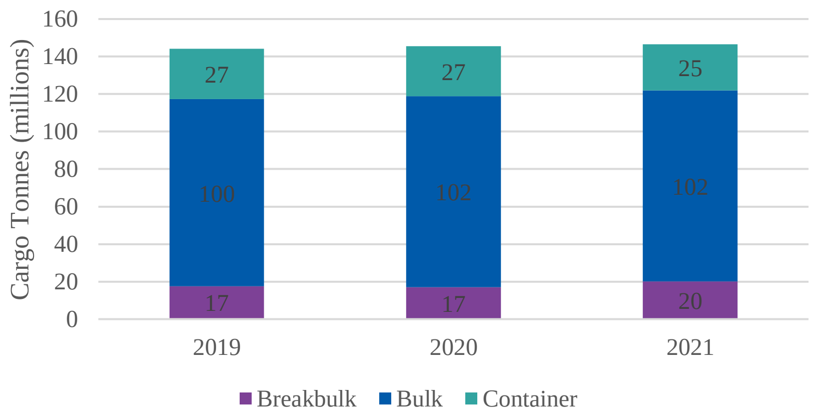

Figure 13 – Vancouver Cargo Throughput (2019-2021)

Source: Port of Vancouver [34]

The port is working to deliver its vision to become the world's most sustainable port

The Port of Vancouver has a vision to become the world's most sustainable port which is demonstrated through a number of ongoing initiatives:

- The port has developed a framework, summarised in Figure 14, that describes their interlinking sustainable objectives. They have developed performance indicators which they report against. The framework includes 10 areas of focus and 22 statements of success.
- It was the first port authority to join the Sustainable Shipping Initiative (SSI), an initiative connecting stakeholders committed to improving sustainability within the shipping industry.
- In 2017 the Port formed the Northwest Ports Clean Air Strategy, which in 2020 was updated committing to eliminate all port-related emissions by the year 2050, through shifting port operations toward technologies and fuels with lower emissions.
- Currently the Port offers shorepower at the cruise and container terminals, allowing ships to shut off their diesel-powered auxiliary engines when docked and take power from British Columbia's low-carbon grid.
- Through the Low-Emission Technology Initiative, the port authority and the province of British Columbia have each committed US$1.1 million in funding to support the port community's transition to low-emission energy. This includes the testing of battery-electric terminal tractors, 100% biodiesel on commercial ferries, a hydrogen-powered crane, and 100% renewable diesel on port vehicles [35]
- Finally, the Port of Vancouver is a partner in the Pacific Northwest to Alaska Green Corridor Project which aims to accelerate decarbonisation of cruise ships operating in the region.

Economic prosperity through trade	**Healthy environment**	**Thriving communities**
Competitive business	Healthy ecosystems	Good neighbour
Effective workforce	Climate action	Community connections
Strategic investment and asset management	Responsible practices	Indigenous relationships
		Safety and security

Figure 14 - Port of Vancouver sustainability framework: ten areas of focus to be the world's most sustainable port

Source: Vancouver Fraser Port Authority [36]

Example Fuel Typology: production of e-methanol at the Port of Vancouver

To illustrate the scale of infrastructure potentially required, and to feed into the consideration of the broad value that this could deliver, we have shaped an illustrative fuel supply typology for the Port of Vancouver, based on the production of e-methanol.

The production of e-methanol could be well suited to the province of British Columbia and Vancouver area specifically for the following reasons:

- The surplus low carbon renewable energy generation capacity, predominantly from hydro-dams, in the region.
- The relative ease with which it can be handled safely in bulk, particularly in proximity to populated areas such as in Vancouver.
- The opportunity it represents to develop and demonstrate emergent Direct Air Capture (DAC) technologies as a source of the carbon feedstock required in methanol synthesis.

As discussed elsewhere in this report, there are multiple possible fuel pathways that could be used to decarbonise shipping. The mix of fuels available at a port will be dependent on local conditions as well as policies and regulations. The typology presented here is provided as an illustration of a possible pathway for Vancouver based on its context and resources but is not intended to be prescriptive to select this fuel rather than others. It is therefore not intended as a recommendation on the most economical or technically viable fuel production pathway.

Demand evolution

Based on the demand scenarios explored by Lloyd's Register Maritime Decarbonisation Hub (see Appendix B) for Vancouver and Prince Rupert, demand in a methanol fuel transition scenario would range between 14 and 24 ktpa by 2030. If the fuel uptake in these segments tracks a Paris Agreement aligned trajectory, this could scale to between 560 to 980 ktpa by 2050 as shown in Figure 15.

For the purposes of estimating the size and cost of the infrastructure requirements, it is assumed that a commercial production facility completed towards the end of this decade would be designed with the ability to produce 200ktpa of methanol. This plant would be adequate to meet the projected the zero-emission shipping fuel demand projected in 2040, in a 'low' bunkering occurrence scenario as indicated in Figure 15. Using the lower projected demand recognises that the demand is unlikely to be exclusively for methanol. Further study to explore the size and evolution of the demand would be required to develop the strategy and design of fuel production infrastructure. This scale of production would compare with relatively large commercial e-methanol plants being developed around the world [37].

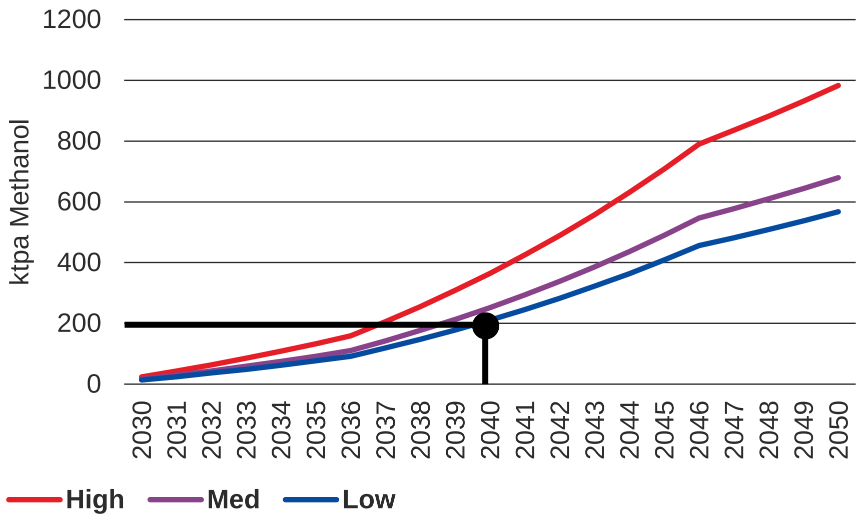

Figure 15 – Projected zero carbon fuel demand in thousands of tonnes per year of methanol for vessels calling at Vancouver and Prince Rupert

(Source: Lloyd's Register Maritime Decarbonisation Hub)

Scale of investment

Delivering the fuel production facility described on the following page is estimated to potentially attract in the region of CAD$3-4 billion of capital investment. This estimate assumes that there is sufficient surplus renewable energy capacity in the grid. Where additional hydro-electric generating capacity required then this could double the amount of investment required to deliver the project. As covered in more detail below, there is uncertainty around the cost of some key technologies in this typology that could impact this cost estimate in both either a positive or negative direction.

Size and type of infrastructure required

Energy source

An e-methanol plant with production capacity of 200ktpa would require approximately 370MW of renewable power to operate at full capacity. An estimated 25% of this power would be consumed by the Direct Air Capture (DAC) process, a described below.

This typology assumes that the renewable energy is generated from the hydro-dams located around British Columbia which are anticipated to provide a surplus capacity of more than 1GW in 2026.

Carbon feedstock

An estimated 320,000 tonnes of CO_2 feedstock would be required per year to synthesise 200,000 tonnes of methanol. This typology assumes that a Direct Air Capture (DAC) plant would produce this CO_2 and be co-located with the fuel production infrastructure to minimise CO_2 transport and storge costs.

A DAC plant of this size is estimated to occupy around 30 acres; however this could vary depending on the technology development. Sourcing this CO_2 from biogenic feedstocks such as municipal or agricultural waste would likely reduce costs if an appropriate supply can be established in the required quantities.

Fuel production & storage

The methanol production facility is assumed to be located in the Vancouver area, potentially on the Fraser River. The facility would include PEM electrolysers rated to 400MW with supporting desalination plant, hydrogen storage, compression, and supporting auxiliary infrastructure and a methanol synthesis plant to combine the H_2 and CO_2. Sufficient product storage would be required onsite to manage variations in demand and offtake frequency. Such a plant, including the DAC plant, would occupy an estimated footprint in the region of 70 acres.

In-port handling & delivery

It is assumed that the production facility would have waterfront access allowing delivery directly to vessels via a jetty. However, in practice a methanol bunker barge would be expected to deliver most of the fuel to vessels around the Port of Vancouver or further afield. The fuel facility could also provide truck loading facilities or pipeline connections for supply of methanol or hydrogen to secondary users.

Key feasibility challenges & opportunities

This typology presents several key feasibility challenges and opportunities that should be considered in its development. For the production and distribution of the fuel, these include:

- *Exploring circular economy opportunities* – The methanol production plant will require significant amounts of fresh water for the electrolysers and produce oxygen and waste heat as a by-product. Seeking out opportunities to integrate the electrolysers with the local water system without negatively impacting the environment, rather than employ desalination units, or use waste heat or oxygen in other industrial processes locally would support reduced costs.

- *Addressing renewable generation capacity and transmission constraints* – Surplus renewable energy generation capacity in the province of British Columbia could support low carbon e-fuel production without the need to develop new, dedicated renewable energy infrastructure. BC Hydro's Integrated Resource Plan [31] forecasts a surplus generating capacity of at least 500MW until the middle of the next decade, with as much as 1.5GW surplus available when the new generating station on the Peace River is completed. This is sufficient to power the e-fuel plant as described by this example typology in the until around 2035, as shown in Figure 16. In the longer term, if the region is to become a significant e-fuel producer, additional renewable generating capacity is likely to be required, particularly in the context of increased electrification across other sectors. Furthermore, the power demand of the described e-methanol plant is unlikely to be met by the existing electrical transmission infrastructure in the area and, as such, significant investment could be required for new substations and transmission lines.

- *Technology risk and cost* – Two key technologies in this typology are electrolysers to produce hydrogen and Direct Air Capture (DAC) units to extract carbon from the air for use in the fuel synthesis process. Although widely demonstrated, electrolysers are still a high-cost technology albeit with significant cost reductions forecast in the coming years. Availability

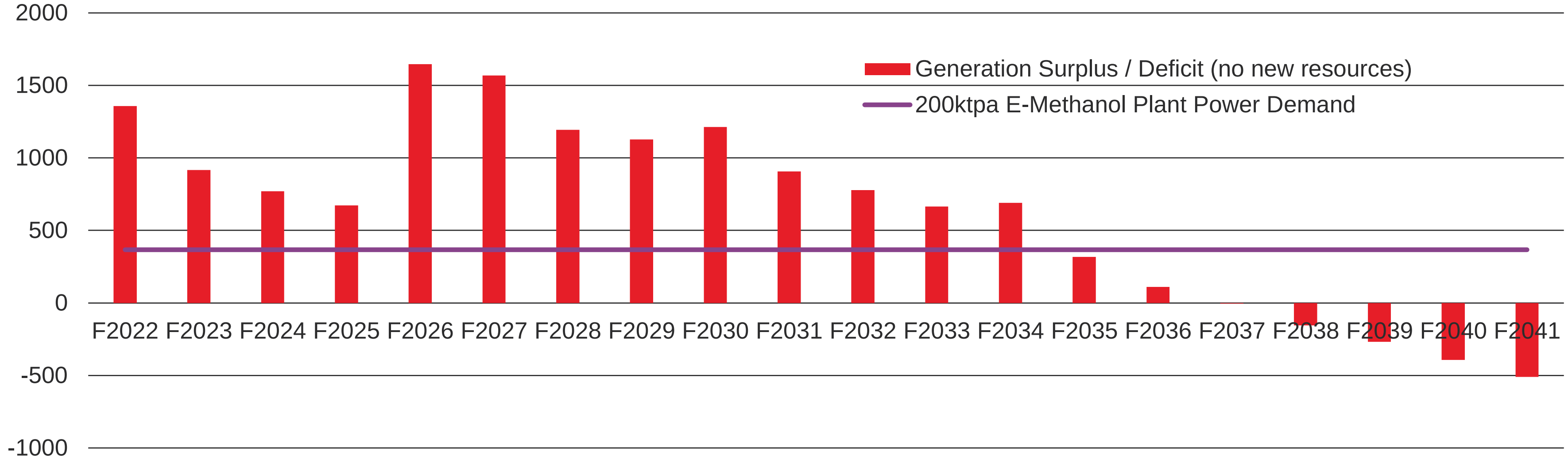

Figure 16 - BC Hydro forecasted electricity grid surplus/deficit generating capacity with no new generation sources compared to estimated power demand of 200kpta e-methanol production facility

Data source: BC Hydro Integrated Resource Plan [31] of electrolysers can also be a challenge. Meanwhile, DAC is still relatively a relatively nascent technology that has not been demonstrated at the scale required to support full-scale fuel production, presenting a risk to any first mover fuel producers looking to implement it.

For the port itself, key challenges and opportunities include:

- *Aggregating demand across different sectors* – The demand estimate is based on assumed uptake of methanol among first mover shipping segments. Aggregating this demand with other users of low carbon fuel can help to support economies of scale as well as de-risk the investment. As Vancouver is home to the largest port in Canada, as well as 50% of the province's population, there are numerous potential users of hydrogen or its derivatives. Working with a range of stakeholders can help to build certainty around the fuel's demand, this could include different shipping segments, other transport modes, industrial processes, domestic energy supply or even export markets.

- *Managing fuel demand evolution* – The demand of low and zero emission shipping fuels will need to scale rapidly in order to align the sector with Paris Agreement goals. For this typology, the modular nature of the electrolysers and DAC technologies could allow for a progressive scaling of the plant to meet growing demand, thereby de-risking the investment. However, developing technology and limited available industrial land in the port may warrant developing a separate facility to meet full-scale demand in the future.

- *Available development land* – As per the Port of Vancouver's Land Use Plan [38] and the Metro Vancouver Industrial Land Inventory [39], there are some potential opportunities for developments to support port activities, with key sites for new developments being located in Planning Area 5 in the Fraser River. There are also 5 existing petroleum terminals, located in the Burrard Inlet, that present an opportunity to expand or re-purpose in the longer term as the energy and shipping fuel transition progresses. With a total footprint in the region of 70 acres, it is potentially feasible to locate the example fuel production plant in close proximity to the port, reducing transport costs for the produced fuel, however, further scaling of the production facility beyond this level may be challenging and warrant a more remote location with the fuel transported to the port via pipeline, rail, or ship.

- *Leveraging existing experience in methanol handling* - Methanol presents a different risk profile to conventional fuel oils due to it toxicity and flammability, requiring new safety procedures to be put in place for bunkering. This is particularly applicable in Vancouver harbour, a congested waterway with a direct interface between the city and the port operations, where potential barriers could arise from regulators or local opposition. Experience gained through handling methanol as a cargo within the port of Vancouver could be leveraged to support the development of safe methanol bunkering. Methanex, is a Vancouver based producer and supplier of methanol, and owns Waterfront Shipping, the world's largest methanol tanker fleet and has ordered a number methanol fuelled ships as well as taking part in bunkering studies elsewhere in the world [40].

'Total Value' story from 2040

Vancouver's clean energy advantage and dynamic maritime sector has allowed the region to be a first mover on shipping decarbonisation, initially establishing green shipping corridors with several international partners and developing a burgeoning domestic zero emission fuel production sector.

Social

One green corridor partnership undertook a Local Needs Analysis early on. The Local Needs Analysis allowed the partnership, through data analysis and stakeholder engagement, to understand the needs, challenges, and opportunities within the community surrounding the port. The Local Needs Analysis identified improved air quality and improvements to human health as a key strategic aim for their partnerships in Vancouver. This shaped decisions around fuel choices, on-board technologies, and fuel supply logistics.

Due to the high density population that surrounds the Port of Vancouver, the green corridor partnerships collaborated with other transport operators in the region, working together to monitor and report their collective impact on air quality improvements and the knock-on benefits to human health and wellbeing. Through this work, the green shipping corridor partnerships formed a strong connection with local healthcare stakeholders and community groups, easing the development process for future infrastructure projects.

Natural

The rapid uptake of zero emission fuels in the 2030s led to significant reductions in carbon emissions linked to the port traffic. The shipping sector globally is demonstrating significant action on decarbonisation - protecting and enhancing its position as an energy efficient and sustainable form of goods movement.

The growing role of the port as a bunkering hub has increased the frequency and volume of ship-to-ship fuel transfers. There were initially concerns that spills could lead to adverse impacts on the sensitive local ecosystems, but innovations in technology and operational processes developed through the green corridor partnerships meant that these risks were managed. The partnerships shared lessons with the global maritime community on the approaches developed, enhancing their reputation as environmental leaders.

Economic

Development and construction of the new e-methanol plant in Vancouver attracted several billion dollars of investment, directly supporting over a thousand jobs in the region and delivering more than CAD$600 million in RVA (refer to Appendix A for methodology) for the Canadian economy. Furthermore, focus on the e-methanol supply chain positioned British Colombia as a leading innovator on Direct Air Capture (DAC) technology and the hydrogen economy. Additionally, the strategic emphasis on air quality catalysed local research and development into large-scale fuel cell technology, with successful demonstration projects influencing global thinking about the next generation of ocean-going vessels.

This bolstered the R&D investment in the region and its reputation as a hub for innovation. In turn, this induced value-added gains to the regional economy beyond the ports and shipping sector, creating a clean technology ecosystem and green maritime sector that reinforce each other's competitive positions.

Financial

The demands from the local shipping market resulted in significant investment in fuel production facilities, port infrastructure and connecting transport systems. This investment had a catalytic effect on the local energy system, helping to realise additional investment in energy and transport infrastructure and action on decarbonisation.

The additional cost of zero emission fuels warranted concerns about higher transport costs and knock-on effects for cargo-owners and consumers. A core focus of the green shipping corridor partnerships was to develop new commercial models that shared costs across supply chain actors and between the public and private sector. Additionally, the partnerships focussed on adapting existing infrastructure which helped reduce the cost gap with traditional marine fuels.

5.4 Port of Prince Rupert

The Port of Prince Rupert is located on Kaien Island in the north west of British Columbia. Managed by the Prince Rupert Port Authority, the Port handles coal, wood, propane, agribulk and containerised cargo; it also has a cruise ship facility. While the port is in a rural setting, especially when compared with Port of Halifax and Port of Vancouver, a majority of the operations are within the city of Prince Rupert, with a population of approximately 12,000.

Prince Rupert's location make it a key gateway to East Asian ports

The Port of Prince Rupert is one of the fastest growing ports in North America, which can be in-part attributed to it having the shortest sailing time to key East Asian ports such as Shanghai, Busan and Tokyo (circa 8 days) [41] when compared to any other major North American ports. The six terminals at Prince Rupert Port therefore provide a gateway for the North American market to international trade, particularly with the Asian Pacific markets. Limited navigational restrictions allow the port to accommodate the largest vessels within the trans-Pacific trade lines. Furthermore, the Port has strong rail connections: all freight terminals at the port have direct, on-dock rail-connecting into the CN mainline. The network connects Prince Rupert to locations across North America.

Ongoing growth of the port is facilitated by available development land

Prince Rupert Port Authority has a range of tenants and activities operating on its property, it has a long-term vision to make Prince Rupert a sustainable and economically resilient port centred around growth and diversification. This ongoing growth is evidenced in a number of major ongoing projects, including the expansion of the Fairview container terminal that will increase capacity from 1.6 to 1.8 million TEUs per year and a feasibility study exploring the potential of a second container terminal at the port.

The Port has identified an opportunity to develop operations on Ridley Island that could support the production, storage or bunkering of low and zero emission fuels. Currently there is an operational propane export facility on the island as well as an ongoing project to potentially develop a new bulk liquids storage facility by Vopak Pacific Canada. There have also been several potential LNG export facilities explored in the area, although none of these have reached a final investment decision to date.

The port has committed to carbon neutrality and environmental protection

The PRPA is committed to becoming carbon neutral by 2050, with an initial goal of reduction of 30% carbon emissions by 2030. As part of its strategy to achieve these aims, the port:

- Has built shore power infrastructure at Fairview Container Terminal, allowing cargo ships to use hydroelectric power while docked, considerably reducing local air pollution alongside greenhouse gas emissions.
- Is incentivising its customers, through reduced port fee discounts, to invest in sustainable practices, such as emissions reduction technology or the use of clean fuels, through its 'Green Wave Program'.
- Undertakes continues air quality monitoring to track performance on a continuous basis.

Alongside carbon and air pollution reductions, the port also supports broader environmental protection initiatives such as marine mammal monitoring programs, progressive land use planning, and habitat enhancement programs

New bunkering infrastructure is under construction

Bunkering is not currently provided at the Prince Rupert Port. However, there is a project underway to provide conventional marine fuels at the port, led by Wolverine Terminals [42]. Trains from the CN Mainline will board a 'rail barge' at the existing Aquatrain terminal. The barge will be moved to the Wolverine Marine Fuels mooring site where the fuel will be discharged onto a distribution barge. The distribution barge, once loaded, will move between marine berth and fuelling locations within port, delivering up to 1,000 tonnes per day. Wolverine Terminals have signed a transportation agreement with CN Rail and they expect this service will be operational in the near future.

The port handles a wide variety of cargo

The Port of Price Rupert handles a wide variety of cargo, summarised in Table 3. In 2021 Container cargo accounted for the majority of annual tonnage (42%), followed by Coal (22%) and Grain (14%). Figure 17 shows the volume of cargo shipped through Port of Prince Rupert over the past four years. The volume of Cargo at the Port fell in 2021 compared to 2020 by c.23% due to the pandemic and supply chain constraints resulting in a drop of major cargo (container and bulk) lines [43].

Table 3 - Port of Prince Rupert cargo type overview

Cargo	Overview
Coal (bulk)	In 2021 coal accounted for 5.6m tonnes of cargo throughput. The Trigon Pacific Terminal handles bulk exports, it has a deep berth and has the capacity to handle 18m tonnes.
Wood Pellets	Wood pellets are exported for use as a biofuel overseas. In 2021 wood pellets accounted for 1.4m of cargo.
Propane	The Ridley Island Propane terminal primarily exports to the Asian market. In 2021 the terminal handled a 1.9m tonne of LPG, the most it has handled at the island.
Grain	In 2021, 3.6m tonnes of grain were handled at Prince Rupert Grain terminal, Canada's largest West Coast grain terminal. The facility has an annual export capacity of approximately 7 million tonnes.
Container	In 2021 container cargo accounted for the majority of throughout through the Fairview Container Terminal, accounting for 10.6m tonnes of cargo in over 1m TEUs. The terminal is the first North American port of call for weekly services from Shanghai, Yokohama, and Busan.
Cruise	Prince Rupert has a 330m berth for cruise vessels. The number of passengers passing through the terminal increased from 49.1k in 2021 to c.76.6k in 2022.

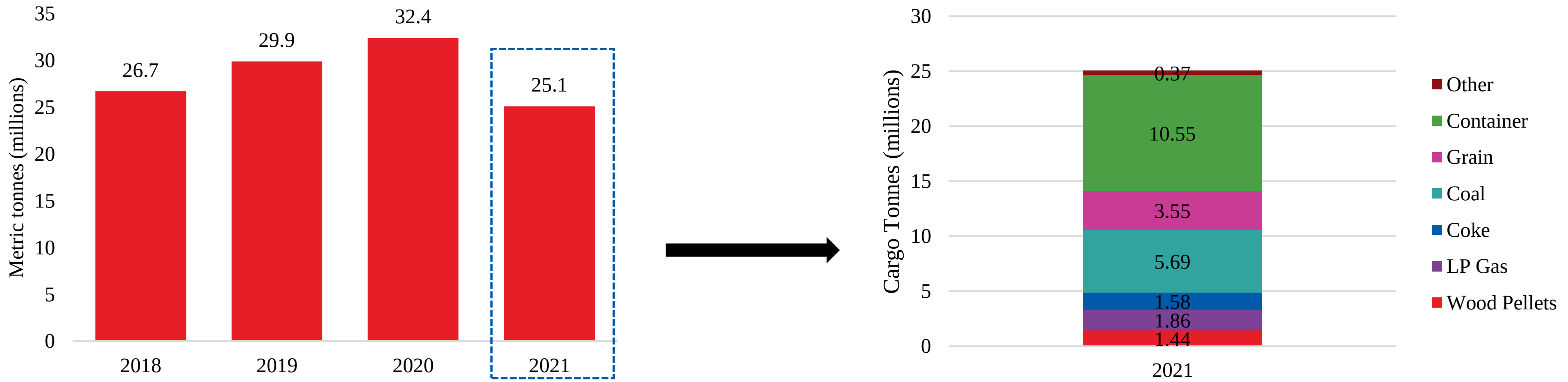

Figure 17- Prince Rupert Port cargo throughput (2018-2021)

Source: Prince Rupert Port Authority [41]

Example Typology: CCS-enabled ammonia supply to the Port of Prince Rupert

To illustrate the scale of infrastructure potentially required, and to feed into the consideration of the broad value that this could deliver, we have shaped an illustrative fuel supply typology for the Port of Prince Rupert, based on CCS-enabled ammonia.

This typology leverages the natural gas reserves of northern British Columbia and the associated industry for its production and supply around the province. It also makes use of the carbon sequestration presented by the Western Sedimentary Basin. Since the electrical power demand in CCS-enabled fuel production relatively is relatively low, the challenges around transmission capacity and resilience to more remote areas of the province will be less of a limiting factor on the typology. This typology is for a remote production facility where the produced fuel is transported to the port for use as a shipping fuel.

As discussed elsewhere in this report, there are multiple possible fuel pathways that could be used to decarbonise shipping. The mix of fuels available at a port will be dependent on local conditions as well as policies and regulations. The typology presented here is provided as an illustration of a possible pathway for Prince Rupert based on its context and resources but is not intended to be prescriptive to select this fuel rather than others. It is therefore not intended as a recommendation on the most economical or technically viable fuel production pathway.

Demand evolution

Based on the demand scenarios explored by Lloyd's Register Maritime Decarbonisation Hub (see Appendix B) for Vancouver and Prince Rupert, if all first mover segments currently using these ports transitioned to ammonia fuel by 2030, the combined estimated demand in 2030 would be between 15 and 25 ktpa. If the fuel uptake in these segments tracks a Paris Agreement aligned trajectory, this could scale to between 600 and 1050 ktpa by 2050.

Considering that a multi-fuel future is the most likely outcome, for the purposes of estimating the size and cost of the infrastructure requirements, it is assumed that a commercial production facility completed towards the end of this decade would be designed with the ability to produce 225 ktpa of ammonia.

This plant would be adequate to meet the projected the zero-emission shipping fuel demand projected in 2040, in a 'low' bunkering occurrence scenario as indicated in Figure 18. Using the lower projected demand recognises that the demand is unlikely to be exclusively for ammonia. Further study to explore the size and evolution of the demand would be required before proceeding with design and construction of any fuel production infrastructure. This scale of production would compare is relatively small compared with commercial CCS-enabled ammonia projects announced globally, however there is scope to serve other sectors, to achieve greater economies of scale.

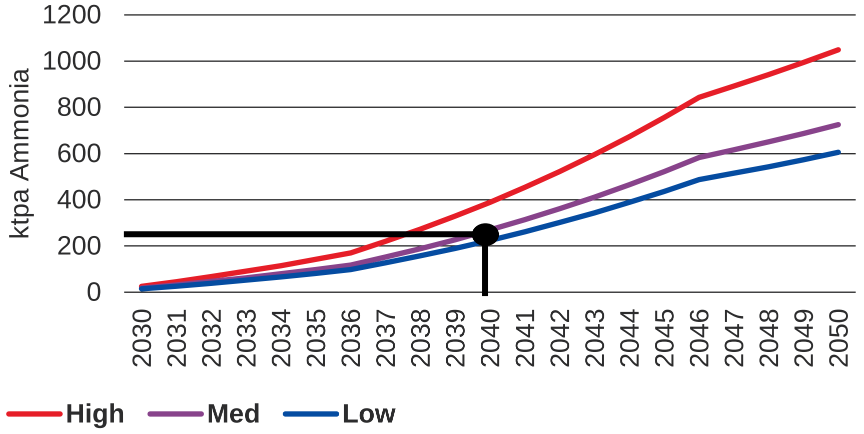

Figure 18 – Projected zero emission fuel demand in thousands of tonnes per year of ammonia for vessels calling at Vancouver and Prince Rupert

(Source: Lloyd's Register Maritime Decarbonisation Hub)

Scale of investment

Delivering the fuel production and supply infrastructure described on the following page could attract capital investment in the region of CAD$750-1,000m, assuming there is little new investment required in the natural gas production infrastructure, rail connections, or for transporting the captured carbon over long distances.

Size and type of infrastructure required

Natural Gas Feedstock

Natural gas produced from existing fossil fuel production infrastructure in northern British Columbia is the main feedstock for use in the fuel production Almost 6 tonnes of natural gas is required for each tonne of CCS-enabled ammonia produced, so a plant producing 225ktpa of CCS-enabled ammonia would consume more than a million tonnes of natural gas per year, which is equivalent to approximately one day of British Columbia's natural gas production.

Fuel Production

The CCS-enabled ammonia production plant in this typology is assumed to be located in proximity to natural gas production and carbon sequestration opportunities in northern British Columbia, several hundred miles from the port. The fuel production plant will include a Steam Methane Reformer (SMR), air separation unit for nitrogen generation, and ammonia synthesis via a Haber Bosch plant. An integrated carbon capture process would capture the resulting carbon for compression and injection into a geological sequestration site.

Carbon Sequestration

A typical SMR process produces around 10 tonnes of CO_2 for every tonne of hydrogen resulting in up to approximately 400,000 tonnes per year that would need to be sequestered. This typology assumes that the fuel production plant is situated close to the carbon sequestration site to limit the costs associated with transporting the carbon dioxide.

Transport

Based on the estimated demand, transport of the produced fuel to the port via the existing rail connections is expected to represent an attractive option with little capital investment. If demand scales significantly beyond the estimated quantities, or an export market for the fuel is developed, then distribution by pipeline may become a preferred solution.

In-port handling & delivery

Delivery to vessels around the port and more widely in the region would be via a bunker barge. If possible, making use of existing infrastructure, such as the proposed new bunkering terminal, to transfer the fuel from rail cars to the bunkering barge.

Key feasibility challenges & opportunities for this typology

This typology presents several key feasibility challenges and opportunities that should be considered in its development. For the production and distribution of the fuel, these include:

- *Making use of existing infrastructure* – This typology maximises the use of existing infrastructure to deliver low carbon shipping fuel to shipping in Prince Rupert and potentially more widely. This includes the existing natural gas production, rail links and potentially the port's new bunkering infrastructure. In doing so, the capital investment required is significantly lower than other fuel production pathway options and the environmental and social impacts of constructing major new infrastructure can be minimised.

- *Natural gas feedstocks exposing the fuel to price fluctuations* – As a globally traded commodity, natural gas can be subject to significant and unpredictable price fluctuations. Given the large quantities of natural gas required to produce CCS-enabled ammonia, any price fluctuations could have a significant impact on the cost of the produced fuel and therefore the price paid by the end-user.

- *Challenges to achieving truly low lifecycle greenhouse gas emissions* – Steam Methane Reforming (SMR) is already a mature technology however, in order to qualify as a low carbon process and achieve an emissions intensity below 20gCO_2e/MJ, as described at Section 3.1, it requires the addition of Carbon Capture and Storage (CCS) technologies with high capture rates as well as secure, permanent sequestering of the captured carbon, which are both processes that will need to scale up and mature further to become cost effective. Furthermore, fugitive methane emissions throughout the process must be tightly controlled. Robustly demonstrating that CCS-enabled ammonia from a particular production facility has a low associated emissions will be key to its acceptance as a fuel with low lifecycle greenhouse gas emissions.

- *Transmissions constraints* – Although the primary feedstock required for CCS-enabled ammonia production is natural gas, several processes require electrical energy. In order to minimise lifecycle emissions of the produced fuel, this electricity should come from low or zero carbon sources. A constrained and unreliable grid in northern British Columbia may necessitate the use of electricity generated locally using fossil fuels, negatively impacting the carbon intensity of the produced fuel, or the construction of new, high-cost renewable generation sources or transmission infrastructure.

- *Managing demand evolution* – Reformers are non-modular in nature, increasing the challenge of scaling the plant to future demand. This challenge may be compounded by variations in the demand for ammonia fuel throughout the year. Aggregating the shipping fuel demand with other ammonia consumers, such as agriculture, or seeking export opportunities would help to address this challenge as well as increase revenues. In the longer term, the appropriateness of CCS-enabled fuel production in a net-zero economy may warrant replacement of the reformers with electrolysers to produce green ammonia.

For the port itself, key challenges and opportunities include:

- *Delivering the fuel to the port* – This typology assumes the CCS-enabled ammonia fuel production facility will be located inland, closer to natural gas fields and carbon sequestration sites, to avoid transport of the feedstock and resulting CO_2 to and from the port. While this reduces the amount of new infrastructure required, transporting the fuel product, potentially over several hundred miles, could be costly and may introduce resilience challenges. Existing rail links could be leveraged to deliver the fuel to the port; a 100-car freight train could be capable of delivering around 6000 tonnes of ammonia. However, loading and unloading several hundred rail cars of ammonia will introduce additional operational costs when compared to a pipeline.

- *New bunkering infrastructure* – Ammonia presents a significantly different risk profile to conventional fuels so there are safety and logistics challenges to be addressed for its bunkering and use onboard vessels. The new bunkering terminal in development at the port is designed for use with conventional marine fuels and, although some aspects may be re-purposed for ammonia bunkering, it is likely that significant modifications or completely new infrastructure would be required.

- *Export potential* – Ammonia has a wide range of uses, including as a fertiliser, industrial processes, or as a fuel for power generation. If CCS-enabled ammonia can be produced at a commercially competitive cost in the region, then there is an opportunity for exporting the product by sea to other countries that lack the same level of resources. Given the available land around Prince Rupert, the port could capitalise on the opportunity with a new export terminal.

- *Carbon import opportunities* – The production of CCS-enabled ammonia at these scales will require significant carbon sequestration facilities which are not universally available elsewhere. There is potential to import CO_2, captured in industrial processes elsewhere, through the Port of Prince Rupert for sequestration at the same site. This would help to achieve economies of scale for the fuel production facility as well as represent a new revenue stream for the port and other stakeholders along the supply chain.

Total Value Story from 2040

Prince Rupert's location, as a shipping gateway to east Asia, allowed the port to position itself as a key bunkering hub in a first mover green shipping corridor partnership involving a network major North American and Asian container ports. Leveraging northern British Columbia's rich natural gas reserves and carbon sequestration potential, the region became a key global producer of CCS-enabled ammonia which is delivered to the port for use as a shipping fuel by container ships operating on the green corridor network.

Economic

Capital investment in new CCS-enabled ammonia production and supply infrastructure directly supported over three hundred jobs in the region while delivering more than CAD$100 million of RVA to the Canadian economy. The ongoing operation of a zero-carbon marine fuelling service in Prince Rupert continued to support dozens of future proofed jobs in the city.

The availability of cost competitive zero emission fuel at the Port of Prince Rupert helped the port to maximise the number of vessel calls from the growing Asia to North America container trade. An increase in the number of container vessel calls and the continued growth of the port supported further terminal expansions and associated ongoing economic growth of the city.

Natural

Delivery of the fuel to the port by existing rail connections helped to maximise the use of existing infrastructure and minimise habitat loss in the port area Embedding environmental values within the project's development realised funding for ongoing habitat restoration work in the Prince Rupert area to deliver an overall biodiversity net gain.

An emissions monitoring programme was co-funded by the port and its green shipping corridor partners to track the impact of any increase in NOx emissions from combustion of ammonia fuel onboard vessels. Results of the monitoring were made publicly available, supporting acceptance of the new fuels among local communities and environmental groups.

Social

Participation in the green corridor partnership with other major port cities around the pacific helped to position Prince Rupert on the world stage as a leader on climate and sustainability. The development of the port presented opportunities to involve the local community in plans to enhance the public realm, providing access to the waterfront and supporting enhanced wellbeing and community cohesion. This community uplift as a result of the zero-carbon fuel project strengthened the connection between the city, local indigenous communities, and the port, which is a key part of Prince Rupert's cultural identity.

Financial

The Prince Rupert Port Authority and City of Prince Rupert secured federal development funding to support the establishment of the new fuelling infrastructure in the port, allowing the new service to remain in public ownership. The ownership structure supported ongoing reinvestment of revenues in new infrastructure as well as social and environmental programmes, helping to keep the generated wealth within the community.

6. Case study: Nova Scotia and the Port of Halifax

This case study uses the Port of Halifax in Nova Scotia as an example to illustrate the potential impact that green shipping corridors and the longer-term decarbonisation of shipping could have in Canada. It explores the region's energy and resource setting, the local context of the port, and how these factors can influence the feasibility of different fuel production pathways.

Using an estimate of the potential future low and zero emission fuel, produced by the Lloyd's Register Maritime Decarbonisation Hub, an example fuel production and supply typology is developed for the Port of Halifax to illustrate the type, scale and cost of the infrastructure required to meet potential future demand for low and zero emission shipping fuels. The cost estimates provide an order of magnitude indication of the investment required to deliver the infrastructure for the typology and are based on assumptions and benchmarks taken from publicly available sources and similar projects.

A Total Value story has been developed for the illustrative fuel supply typology to demonstrate possible value outcomes that could be delivered, including some of the approaches taken to doing so. Considering the 'Total Value' case can help to shape, capture and leverage the wider value of the corridor and therefore improve their investment case.

6.1 Regional energy and resources

Existing electricity generation is carbon intensive but there are plans to address this

In Nova Scotia the electricity grid has a high emissions intensity; over 76% of NS's energy mix comes from non-renewable fossil fuel sources including coal and coke (52%) and natural gas (22%) – contributing to the second highest grid emissions intensity in Canada, at 670 g CO_2e/kWh [44]. However, the province has some of the most ambitious greenhouse gas reductions targets in the country – targeting 53 per cent below 2005 levels by 2030 and is committed to net-zero by 2050 [45]. A significant proportion of the reduction up to 2030 is expected to come from a planned phase out of coal-fired electricity generation and a planned increase in the share of renewable energy generation sources from around 25% today to 80% by 2030.

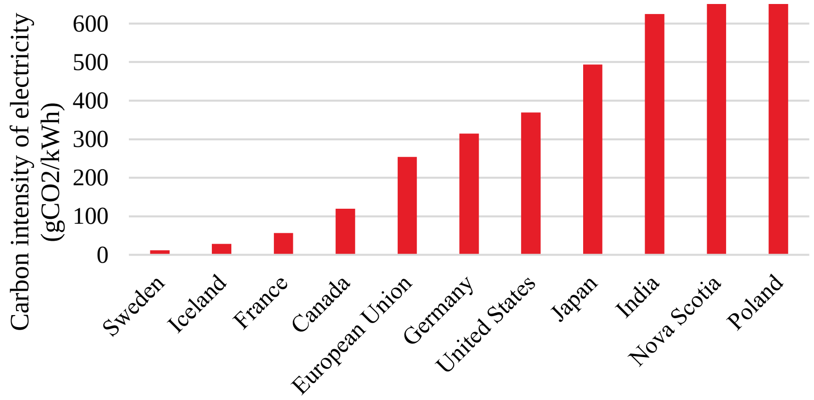

Figure 19 – Carbon intensity of electricity in Nova Scotia compared to a selection of global economies in 2020

Data source: Nova Scotia [29], all other countries [30]

The Maritime Link connects the province to neighbouring Newfoundland and Labrador, helping to stabilise the grid and provide access to clean hydroelectricity, the province imported 7% of all electricity in 2019. The Maritime Link is expected to play a key role in reducing Nova Scotia's grid electricity emissions by 2030.

Production of natural gas ceased in 2018 and the energy focus is now on developing offshore renewable generating capacity

Historically Nova Scotia has been a producer and exporter of fossil fuels from the Sable Offshore Energy Project but production stopped in 2018 and the Imperial Oil's Dartmouth refinery closed in 2013. Now natural gas is imported for consumption through the Maritimes & Northeast Pipeline (M&NP).

Recent years has seen the development of onshore renewables, in particular hydro-electric power and onshore wind farms. The provincial government has committed to the delivery of at least 500MW of new, local renewable energy by 2026 with an additional 50MW of community solar projects, which aim to increase participation of community groups in the energy transition.

The province has identified significant potential for development of renewable energy generation sources including solar, wave, tidal and offshore wind. There have been a number of pilot scale tidal and wave energy projects in the province, but the most significant contribution is expected to come from offshore wind. The province has committed to leasing 5GW of offshore wind development sites by 2030, which will help support the green hydrogen industry.

Significant hydrogen and ammonia projects are planned with large export potential

EverWind a private developer of green hydrogen and ammonia production in Nova Scotia announced in 2022 the signing of a Memorandum of Understanding ("MOU") under which Uniper will purchase green ammonia from EverWind's initial production facility in Point Tupper, Nova Scotia. They intend to extend and develop the NuStar storage terminal into a regional green hydrogen hub for Eastern Canada, complete with new green hydrogen and ammonia production facilities. The production of green ammonia is forecast to begin in 2025. The plant has plans to produce up to 10mtpa of green ammonia with 1mtpa of offtake agreements for export to Germany.

Another ongoing project at Point Tupper Industrial Park area is being driven by Bear Head Energy. They are planning to develop, construct and operate a large-scale green hydrogen and ammonia production, storage and loading facility at the site of the previously approved for an LNG export facility.

6.2 Estimated demand for low and zero emission fuels

The Lloyd's Register Maritime Decarbonisation Hub conducted an analysis of vessel traffic operating on the East Coast of Canada during a baseline year of 2021 to estimate zero emission fuel demand under different scenarios. The applied methodology for this analysis is described in full at Appendix B.

The analysis identified 239 vessels that called at the Port of Halifax during the baseline year. These vessels had a high concentration of activity along the east coast of North America and on trans-Atlantic routes to the Mediterranean and Northwest Europe as shown in Figure 21, increasing the number of bunkering options for the vessels at ports along these longer voyages. To account for this, the analysis applies assumptions that vessels would be unlikely to bunker in the port if less than 20% of their total port calls are in Halifax or they spend more than 50% of the year outside the region; these vessels are therefore considered out of scope and excluded from the estimate of fuel demand. Applying these thresholds, only 43 vessels of this fleet fall "in-scope", the activity of which is shown in Figure 22. The analysis predicted a zero-emission fuel demand at the Port of Vancouver of approximately 1ktpa HFO[e] in 2030, which is projected to scale to between 13 and 19ktpa by 2040 and 30 to 50ktpa by 2050.

Similarly to the Port of Prince Rupert, established and operational service lines connecting the port to other locations across the globe could be one way of initiating collaboration discussions with ports along the route and associated shipowners where there are limitations to identifying a purely regional fleet that is likely to bunker in a specific location. These service lines include connections with ports in North West Europe, the Mediterranean, the Middle East and Asia [46].

A fuel supply typology for the Port of Halifax is explored later in this report where vessels operating on these service lines are secondary offtakers from a large-scale hydrogen export facility in Nova Scotia.

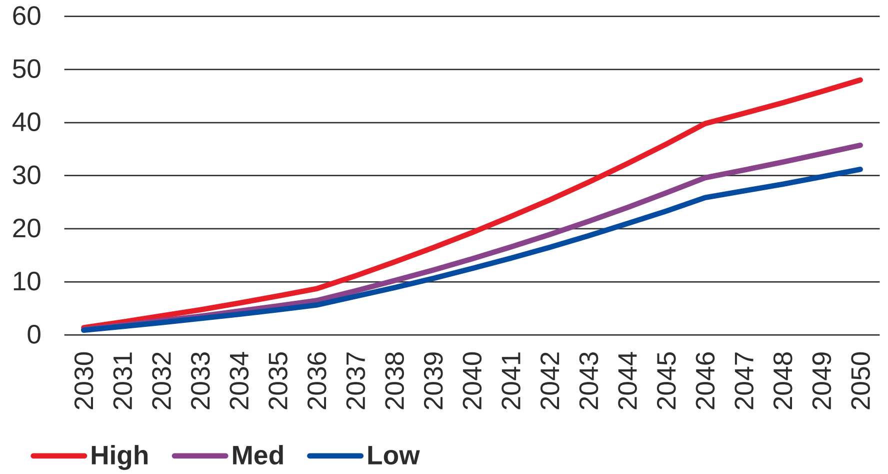

Figure 20 – Projected zero emission fuel demand in thousands of tonnes per year of HFO equivalent in Port of Halifax

(Source: Lloyd's Register Maritime Decarbonisation Hub)

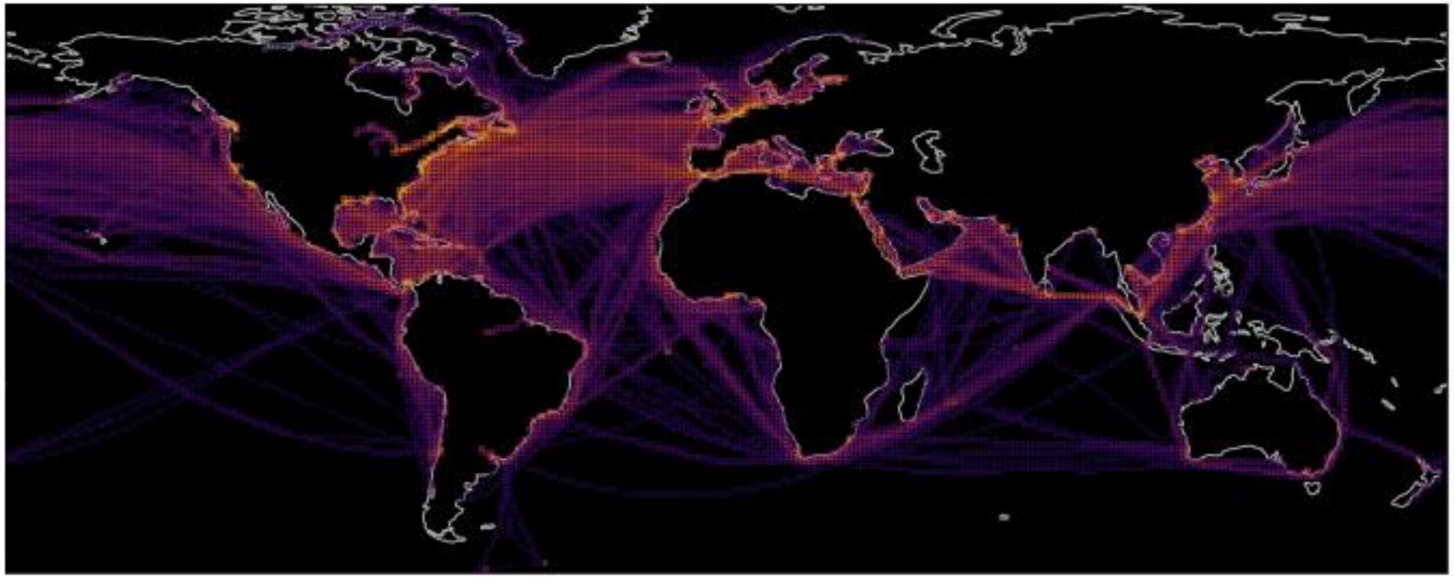

Figure 21 - Heatmap of global activity of the 239 vessels that called in Halifax during 2021

Source: Lloyd's Register Maritime Decarbonisation Hub

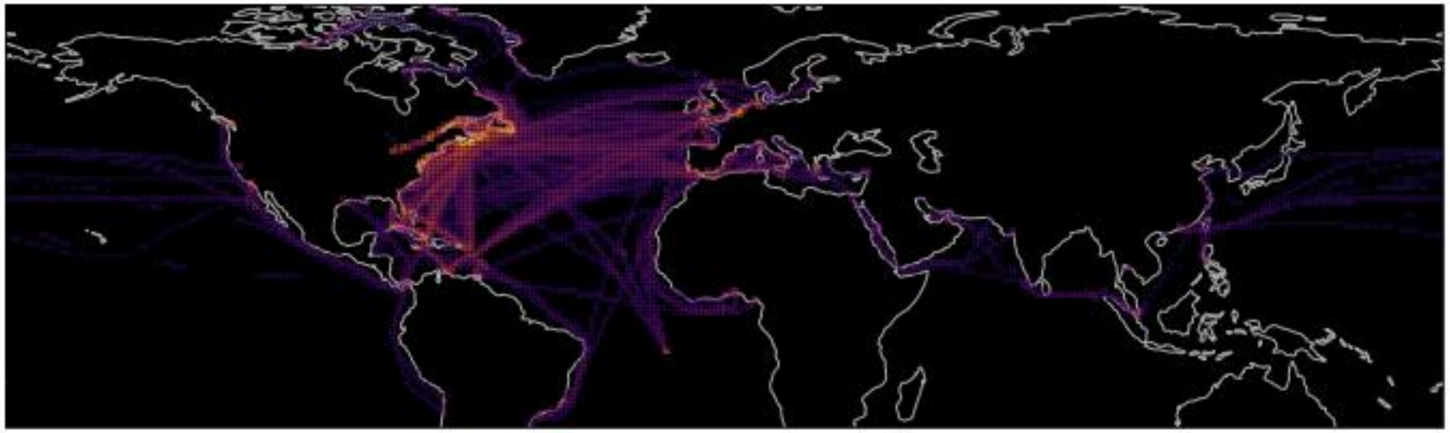

Figure 22 - Heatmap of global activity of the 43 'in-scope' vessels that called in Halifax during 2021

Source: Lloyd's Register Maritime Decarbonisation Hub

6.3 Port of Halifax

Port of Halifax is located in the province of Nova Scotia and the city of Halifax. Managed by the Halifax Port Authority (HPA), the port is one of the deepest and largest natural ice-free harbours in the world covering 15,000ha of water and 1,000ha of land.

As a Gateway, Port Halifax offers alternative fuel bunkering opportunity

Historically Halifax has benefited from its strategic geographic location as the closest main-land North American Port to Europe (its principal trading partner) and serving as a significant gateway for trade to and from Southeast Asia, a route made easier by the Suez Canal's ongoing renovation and enlargement. Acting as a gateway raises a potential opportunity to bunker alternative fuelled vessels before vessel onwards legs to other ports.

There is a direct interface between the port and the city

Most of Halifax's Port operations are in Halifax Harbour, therefore there is a direct interface between the city and the port operations. Due to the proximity of the port operations to the city, there may be barriers to storing and bunkering alternative fuels which could be more volatile within the port boundary. This could result in barriers to future development, especially for the handling and storage of alternative fuels such as hydrogen and ammonia which present additional risks that must be considered.

Identified availability of development land

The Port of Halifax has a varied range of tenants and activities operating on its property. As described above, the majority of the these are based in the city of Halifax where it is unlikely that there will be sufficient land available to develop new fuel infrastructure, nor would such a development represent the most appropriate land use.

However, a large 475-acre plot of land with waterside access recently became available [47]. This land was previously used for industrial purposes and is could therefore be as a potential viable location for an alternative fuel production and storage site to support ship-to-ship bunkering.

The port has set its targets for reduction of its own emissions

The Halifax Port Authority has set targets for reduction of its Scope 1 and 2 emissions, covering its own operations, of 40% by 2030 and 100% by 2050 [48]. It has also committed to measuring and reducing scope 3 greenhouse gas emissions. It is setting out to achieve these in a number of ways, including the provision of shore power to visiting vessels, with the first system developed as part of a partnership with the Government of Canada and the province of Nova Scotia.

The port is supporting the export of hydrogen from Nova Scotia

The Port of Halifax is a member of the Atlantic Hydrogen Alliance, that is looking into the development of a viable clean hydrogen value chain. The alliance aims to build on the East Coast's opportunity to leverage their wind resources, and other renewable energy sources, to create new jobs in renewable energy and to attract new investments in innovation and clean technology.

In 2022, the Halifax Port Authority and Hamburg Port Authority signed a memorandum of understanding committing to work together to decarbonise the shipping corridor between the two ports [49]. The focus of the collaboration is on the development of port infrastructure for the bunkering and trading of green hydrogen and its derivatives as well as the fostering of collaboration between key value chain partners to advance the use of green energy on the corridor. Exploring the energy and fuel production infrastructure needed to supply the shipping traffic is critical for successful wider implementation.

Port of Halifax specialises in handling containerised cargo

The Port of Halifax primarily handles Containerised Cargo, in 2021 the total cargo handled by the port was 4.9m tonnes. Containerised Cargo accounted for 89% of the cargo, with the remaining 11% non-containerised. The cargo types handled in the Port of Halifax are summarised in Table 4 and Figure 23.

Table 4 - Port of Halifax cargo type overview

Cargo Type	Overview
Container	In 2021, 89% of cargo moving through HPA facilities was containerised with a total throughput of 434 thousand TEU.
Non-containerised	In 2021 5.5m of non-containerised material was handled by HPA. The majority of which was grain, steel rail, steel coils, nickel sulphide, wood pellets, and Ro-Ro. [50]
Cruise	The Halifax Seaport can receive the world's largest cruise ships. In 2020 and 2021 there were no cruise passengers due to Covid-19, however, previously in 2019 there were 323k passengers.

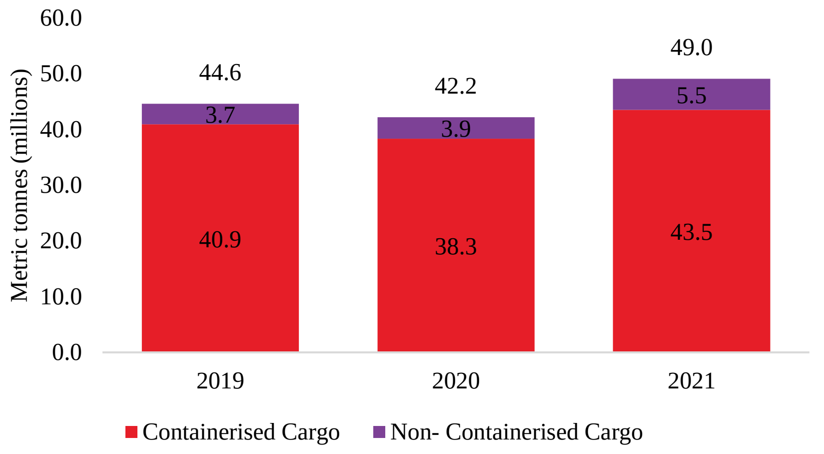

Figure 23- Port of Halifax Cargo Throughput (2018-2021)

Source: Port of Halifax [51]

Example Typology: Port of Halifax as a secondary offtaker of e-ammonia

To illustrate the scale of infrastructure potentially required, and to feed into the consideration of the broad value that this could deliver, we have shaped an illustrative fuel supply typology for the Port of Halifax, based on the supply of e-ammonia.

Nova Scotia as a net energy exporter

As detailed in Section 7.3, the estimated demand for low carbon fuel in 2030 from shipping currently using the Port of Halifax is relatively low and is unlikely to trigger development of significant renewable energy or a large-scale production facility.

More broadly, there are a number of factors that make the province of Nova Scotia well positioned to become a significant producer and exporter of green hydrogen and ammonia. This includes the province's significant potential for low carbon renewable energy generation, in particular the provinces target to offer leases for 5GW of offshore wind development by 2030. A number of projects are already in the pipeline to fulfil this potential.

Shipping as a secondary demand

This typology considers a scenario in which the Port of Halifax, through close collaboration with its customers and broader stakeholders, establishes itself as a bunkering hub in a number of first mover green shipping corridor partnerships. It considers the feasibility challenges and opportunities for the Port of Halifax to deliver a portion of the e-ammonia produced in Nova Scotia to shipping traffic using the port as well as the potential of developing a zero emission fuels hub to supply port equipment and other users in and around the Halifax area, such as the transport and industrial sectors.

Scale of investment for fuel supply typology

The estimated capital cost for an ammonia bunkering vessel, fuel storage facility and loading jetty is between CAD$250-500 million. However, this does not include any marine works such as breakwaters or dredging which could add a significant cost but is highly dependent on the specifics of the site selected.

World-scale hydrogen & ammonia production facility

This typology assumes a separate hydrogen and ammonia production plant is constructed to supply domestic and international demand and that shipping using the Port of Halifax would be a minor offtaker from this plant.

If this plant were to produce 1 million tonnes of green ammonia per year, it would require around 3GW of offshore wind power capacity to be available. This scale of offshore wind generation would likely be made up of several separate wind farms and cover several hundred square miles of sea area.

The ammonia production plant itself would require electrolysers with rated capacity of around 2GW, an air separation unit producing 175 tonnes of nitrogen per hour, and a significant Haber Bosch plant. The electrolysis process will consume more than 2 million tonnes of water per year which could be met by a desalination plant to avoid negative impacts on nearby natural water systems.

Given the scale of the facility, which could occupy an area of hundreds of acres, this typology assumes that it is be located some distance from the port and would have its own dedicated loading jetty for the export of the ammonia by gas carrier.

Delivering an 1Mtpa e-ammonia production facility with 3GW of offshore wind power generation would attract capital investment in the region of CAD$20 billion. Approximately 50% of this investment would be made in the build out of the offshore wind farms with most of the remaining cost for the fuel production facility.

Size and type of infrastructure

Fuel Source

As described above, ammonia is produced at a world-scale production plant located elsewhere in Nova Scotia, being supplied by the developing offshore wind generation capacity. Given the relatively limited shipping demand in comparison to the scale of the plant, shipping is not considered as a primary trigger for the development of this infrastructure.

Distribution

Delivery of ammonia fuel from the production plant to the port is via a gas carrier loaded at the production facility's marine loading jetty. Due the relatively limited rail network in Nova Scotia this isn't considered a suitable solution. Furthermore, the relatively low anticipated fuel demand in the short- to mid-term is unlikely to warrant the high capital cost of a pipeline.

In the short term, while the uptake of ammonia fuel scales up, the relatively infrequent bunkering activities could be met by a bunker vessel that acts as in-port storage as well as delivering the fuel directly to the receiving ships. Assuming a days' transit time from fuel production plant to the port, a 20,000m^3 ammonia bunkering vessel could potentially be capable of delivering up to a million tonnes of fuel to vessels each year. However, as demand scales and bunkering become more frequent, it may be necessary to develop in-port storage facilities to ensure more consistent fuel availability. In this case a dedicated in-port bunker vessel would serve ships in the port and a separate shuttle tanker would resupply the facility.

In-Port Handling & Delivery

In-port storage and handling facility, delivering to vessels via bunker barge and to secondary users via truck or pipeline. This facility would consist of storage tanks, a liquid transfer jetty and associated plant. The size of the storage tanks would depend on the demand evolution, however, is likely to be matched to the size of typical shuttle tanker capacities in the region of 40,000 to 60,000m^3.

Key feasibility challenges & opportunities for this typology

This typology presents several key feasibility challenges and opportunities that should be considered in its development. For the production and distribution of the fuel, these include:

- *Competition for a scaling renewable energy capacity* - As renewable generation capacity is expanded in Nova Scotia; any fuel production facility will be competing for the produced energy with existing consumers. Since Nova Scotia's electrical grid is currently highly carbon intensive, it would be preferable from a climate impact perspective to divert the energy to more efficient electrified onshore consumers such as industry, domestic and transport uses. This challenge may be mitigated by increasing the import excess hydro-electric power from neighbouring provinces in the shorter term. In the longer term, the province's offshore wind generation capacity could out-grow its forecast peak power demand of 2-3GW [52]; low carbon fuel production will be an effective means of utilising this excess generation capacity.

- *Circular economy opportunities* – Production of hydrogen and ammonia at the anticipated scale will require large quantities of fresh water as a feedstock and produce significant amounts of oxygen and heat. Careful consideration must be given to where fresh water is sourced from to avoid negative impacts on natural water systems and associated ecosystems. For large scale plants, a desalination plant is typically required to provide the necessary quantities of water, however this also increases energy consumption. Significant value can be unlocked by investigating the potential integration of the plant with other industries that might provide a water supply or make use of the by-products.

For the port itself, these include:

- *Available development land* – There is available development land along the shoreline of Halifax Harbour that was previously utilised in fossil fuel refining and distribution. This presents an opportunity for the development of dedicated, in-port fuel infrastructure that would enable the efficient delivery of fuels to vessels in the harbour. This infrastructure may include ammonia storage, for supply as a shipping fuel, as well as small scale production of green hydrogen or other fuels for supply to harbour vessels, port equipment, trucks and other shoreside consumers.

- *Potential to drive shipping fuel demand evolution* – The proximity of commercial scale fuel low and zero emission fuel production facilities and the location of the Port of Halifax as the closest major North American port to Europe to has an opportunity to location makes it well placed to drive demand for bunkering in the port. Engaging with stakeholders across the fuel value chain to establish demand and supply will help to unlock the opportunities this presents.

- *Scaling infrastructure to match demand evolution* - Demand for low and zero emission shipping fuel is expected to scale rapidly over the coming decades as the shipping industry decarbonises. It may be challenging to scale the in-port infrastructure to meet growing demand. In the short term, while demand is low, a bunker vessel delivering fuel directly from the remote production plants is likely the most cost-effective solution however it will impact overall efficiency of the fuel supply chain. In the longer term, increased bunkering frequency is likely to make in-port storage preferable.

- *Handling of ammonia in a city environment* – All industrial zones in Halifax Harbour are in close proximity to residential properties and no more than a few miles from the city centre. This raises potential challenges with the storage and transfer of ammonia in the port from a safety perspective as well as potentially presenting a nuisance to local communities. Similar considerations will also apply during bunkering operations at terminals and anchorages elsewhere in the area. Demonstrating the safety of these operations and engaging effectively with local stakeholders will be critical to successful implementation.

Total Value story from 2040

Offshore renewable energy generating capacity was rapidly scaled up in Nova Scotia, decarbonising its grid electricity and supplying world-scale hydrogen production plants, making the province a significant energy exporter. The Port of Halifax developed an in-port marine fuel storage and bunkering facility to supply ammonia to container shipping using the port as well as other secondary users in and around the city.

Economic

Through the development of bunkering infrastructure, the Port of Halifax has capitalised on the local availability of zero emission fuels and supported the decarbonisation of shipping using the port securing the long term future of the port as a key gateway to European and Asian markets.

The region has maximised the economic benefits by setting requirements for local content in the procurement strategies of these projects, fostering a thriving regional supply chain, and by investing in education and training programmes to ensure local workers have the required skills to operate and maintain the new infrastructure.

Involvement of local First Nations as partners in the fuel production projects' development has ensured their inclusion in the opportunities that these projects present and advanced the cause of economic reconciliation in the region.

Natural

The Nova Scotian electrical grid now has one of the lowest carbon intensities in the world. In Halifax the fossil fuel generating stations are closed, all ships use shore power, and truck, port handling equipment, ferries and harbour craft are powered by hydrogen fuel cells, slashing air pollutant emissions in the city with benefits realised for the local population and environment.

The new energy, fuel and port infrastructure has maximised the use of existing industrial land wherever possible to minimise the impact on Nova Scotia's natural habitats and biodiversity.

Social

The energy and fuel production infrastructure projects undertook comprehensive engagement with all relevant First Nation communities from the outset. By gathering traditional knowledge on the sea and land uses, the project not only avoided any major negative impacts, but also actively enhanced biodiverse and culturally important sites highlighted during engagement. This early engagement process allowed potential positive outcomes for these groups to be identified and embedded into the project's objectives from the outset.

The port worked with the fuel producers, bunker suppliers, and partner shipping lines to undertake safety assessments to demonstrate the safe handling of ammonia. Transparency and public engagement around these activities helped to allay concerns from local communities around the safety of handling of ammonia in the Port of Halifax during engagement. This presented an additional opportunity to communicate the benefits of the marine energy transition to local schools and community groups to increase the community's sense of stewardship around local environmental issues in Halifax.

Financial

The port engaged with a number of first mover container lines and the fuel producers to demonstrate the scale of demand that could be generated from shipping using the Port of Halifax. This higher level of certainty supported the completion of agreements between the container lines and fuel producers to purchase ammonia fuel. The port partnered with the fuel producer to co-invest in new in-port fuel storage and bunkering infrastructure which now leased to a third party operator, generating a key new revenue stream for the port.

7. Summary

This report provides an overview of the potential benefits that green shipping corridors – and maritime decarbonisation in general – could deliver for Canada. It sets out an illustrative fuel supply typology for three different ports to explore the size, type and capital cost of the infrastructure needed to meet the potential zero emission fuel demand, as estimated by Lloyd's Register, and describes the 'Total Value' that these could deliver.

Canada has already identified green shipping corridors as an effective means of accelerating maritime decarbonisation

Green shipping corridors have emerged over the past two years as a means of mobilising cross-value chain stakeholders to address the technical, regulatory, and commercial barriers that have hampered the uptake of zero emission shipping fuels. Stakeholders in the Canadian maritime industry have recognised the potential of these initiatives as evidenced by several green shipping corridors involving Canadian ports. The Canadian government has also backed the initiatives, as well as indicating its ambition to see net zero emissions in the shipping industry by 2050, through a number of declarations.

There is a significant opportunity presented by maritime decarbonisation and Canada could be well positioned to realise it

The development of new energy and fuel production infrastructure to meet the projected demand for zero emission shipping fuels represents a significant opportunity for Canada to achieve its environmental objectives while fuelling economic prosperity, realising social co-benefits, and protecting themselves from the impact of divestment from fossil fuel industries.

As an existing energy producer with a skilled workforce and significant land and natural resource availability, Canada is well placed to seize the opportunity to become a producer, and potentially exporter, of low carbon fuels. This report has described three example fuel supply typologies to illustrate how these advantages can be leveraged:

- E-methanol production in Vancouver, making use of the existing surplus hydro-power generating capacity and local expertise in Direct Air Capture (DAC) technologies.
- CCS-enabled ammonia production complying with stringent lifecycle emissions standards to supply shipping from the Port of Prince Rupert, making use of British Columbia's significant natural gas reserves and geology suitable for long term carbon sequestration.
- Supply of ammonia to shipping in the Port of Halifax as a secondary consumer of fuels from the world-scale hydrogen production facilities planned in the region.

To support the decarbonisation of shipping on a trajectory aligned with a 1.5°C Paris Agreement goal the fuel production pathways in each of these typologies must be demonstrated to comply with stringent standards for lifecycle emissions of low carbon fuels.

Green shipping corridors could help to drive demand for zero emission fuels produced in Canada

Analysis of historical shipping traffic data conducted by Lloyd's Register Maritime Decarbonisation Hub has demonstrated the potential evolution of fuel demand in the Port of Vancouver, Port of Prince Rupert, and Port of Halifax. In Vancouver, first-mover shipping could generate significant zero emission fuel demand in the port, potentially warranting dedicated fuel production infrastructure. Whereas, in Prince Rupert and Halifax, the relatively lower shipping traffic volumes result in lower projected bunkering demand. Developing multi-stakeholder green shipping corridor initiatives using these ports could help to drive demand for fuels in these two ports and support investment in the land side infrastructure to produce them.

The total value of opportunity from green shipping corridors includes a broad range of potential co-benefits

Considering the ‘total value’ case for green shipping corridors and supporting fuel supply projects can help to shape, capture and leverage their wider value and therefore improve their investment case. the total value opportunity from green shipping corridors and maritime decarbonisation is broad and diverse, covering financial, economic, environmental, and social benefits at a local, national, and global scale.

A Total Value assessment should identify the positive value outcomes that could be realised, helping to embed these as objectives from an early stage of the project. However, it should also identify and explore the risk of negative value outcomes, such that they can be mitigated and minimised wherever possible.

The type of value that can be delivered - and the benefactors of it - depends upon the type and scale of infrastructure realised but also the approach taken to strategizing, implementing the infrastructure projects that should ensure value objectives are delivered on.

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Appendix A

Quantifying the economic value of the fuel supply typologies

A high-level analysis has been made, based on the estimated capital cost of each typology, to assess the impacts in terms of temporary jobs during the development and construction phase and the Real Value Added (RVA) from the employment that is generated. RVA reflects the value generated by producing goods and services and is measured as the value of output minus the value of intermediate consumption. RVA includes:

- Direct employment directly generated through the construction and day-to-day operation of the new plant.
- Indirect employment created and/or sustained in suppliers to the plant. These jobs represent the cumulative effect through the supply chain as initial suppliers make purchases from their suppliers and so on.
- Induced employment supported by the wages and salaries of workers employed both directly by the plant, and indirectly by suppliers to the plant.

The analysis also takes into consideration other additionality factors, with assumptions made for:

- Leakage – the number or proportion of outputs that benefit those outside of the intervention’s target area or group.
- Displacement/substitution – the number or proportion of outputs accounted for by reduced outputs elsewhere in the target area.
- Deadweight – output that would have occurred without the intervention.
- Multipliers - Further economic activity (jobs, expenditure, or income) associated with additional local income, local supplier purchases and longer term effects. For this assessment employment multipliers published by the Canadian Government have been used.

Appendix B

Lloyd's Register Maritime Decarbonisation Hub fuel demand estimation methodology

To assess the scale of energy and fuel production infrastructure required to supply green shipping corridors in Canada, the refuelling quantities and frequencies must first be estimated. The Lloyd's Register Maritime Decarbonisation Hub have conducted a separate analysis to estimate the potential future demand for low and zero emission shipping fuels at the three ports considered by this study.

The Lloyd's Register analysis applies a methodology first developed as part of a joint study by The Resilience Shift, Lloyd's Register and Arup entitled "Port energy supply for Green Shipping Corridors" [53] and further developed for the specific case studies of the Port of Prince Rupert, Port of Vancouver, and Port of Halifax. The methodology allows Lloyd's Register to consider alternative fuel demand evolution, at the port level, and can also be applied to uncovering green shipping corridor opportunities. The approach is based on three steps:

1. **Identification –** involves identifying shipping routes or ports as a starting point for the assessment.
2. **Calibration and categorisation –** involves examining Automatic Identification System (AIS) data to study ships calling at the key ports along the shipping traffic route; understanding ship fuel demand patterns for a base year; and then breaking down this estimated fuel demand into categories for more granularity.
3. **Projection –** involves applying a number of assumptions to project the potential demand for alternative fuels in the future, based on activity in the baseline year. This includes estimates for transport demand growth, alternative fuel uptake versus other options, level of decarbonisation ambition, and refuelling frequency/feasibility.

Identification

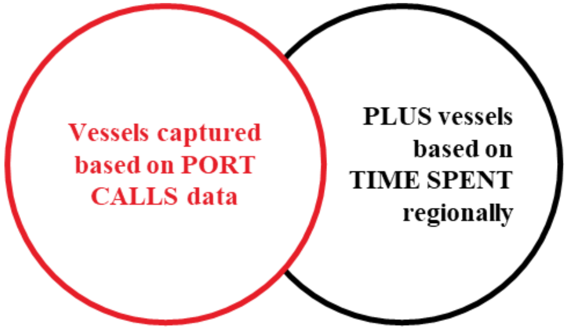
Ports are integral to the entire shipping system, at the node of intermodal networks while also facilitating and housing connections between various shipping functions and resilient energy systems. With ports at the heart of shipping activity, it is important to understand how the role of ports, port users and its engagements will evolve to facilitate and advance the wider industry's energy transition.

In the case of this report, three individual ports were pre-identified as case studies, however the demand estimation methodology can be deployed to various applications, including multi-port shipping corridors and across domestic and international trading zones.

Calibration and Categorisation

2021 was taken as the baseline year for each of the case studies in which to study the activity and profile of vessels calling at the ports. To account for the uncertainty around future bunkering activities, the identified fleet is split into three categories based on the vessel's likelihood to refuel in the location of interest: primary, secondary, and tertiary. The likelihood of refuelling is a function of the number of port calls made in the port and nearby ports as well as the time spent by the fleet in the region, as defined in Figure 24. For instance, in the cases of the Port of Vancouver and Port of Prince Rupert, the region was defined as the western coastline of Canada and the US, extending to the southern point of Oregon.

The Lloyd's Register Maritime Decarbonisation Hub analysis assumes that vessels would be unlikely to bunker in the port if they rarely call at the port and spend most of the year outside the region; these vessels are therefore considered out of scope and excluded from the estimate of fuel demand. This concept of regionality is also employed by the Silk Alliance green shipping corridor cluster, which focuses on a regional fleet that predominantly bunkers in Singapore [54], extending beyond a point-to-point corridor concept to drive scale and stronger region-specific partnerships.



Vessels captured in each categorisation	% port calls at selected port	TSR %
Primary	>30%	70%
Secondary	>25%	60%
Tertiary	>20%	50%

Figure 24 - Thresholds for identifying vessels within scope of the analysis
(Source: Lloyd's Register Maritime Decarbonisation Hub)

Projection

The Lloyd's Register Maritime Decarbonisation Hub analysis considers the outlook for the fleet which can vary between the vessel types and is based on trade flow dynamics both domestically and internationally. For this analysis, low and zero emission fuel demand uptake in 2030 is projected for the in-scope vessels based on the following:

- Percentage of time spent in the region.
- Market growth projections for each vessel type, taken from the 4th IMO greenhouse gas study [55].
- Identification of likely "first mover", or high ambition, fleet segments, for example containerships, bulk carriers, and Ro-Ro vehicle carriers in the context of a green corridor initiative. These are ship types where end-consumer pressure is increasingly pushing for action to decarbonise and those that usually operate regular routes, allowing fuel strategies to be planned with more certainty. This analysis has only considered these first mover segments.
- Alternative fuel uptake pace based on ambition of fleet segment, for example an assumption is made that first mover segments will track the 5% fuel uptake target by 2030 [56] and subsequently follow a decarbonization trajectory aligned to 1.5°C Paris Agreement goal.

The fuel demand estimates also take into consideration potential changes in refuelling occurrence of vessels operating on low and zero emission fuels, considering their lower energy densities, resulting in low, medium, and high estimates for different scenarios.

Further considerations

The Lloyd's Register analysis conducted follows the above methodology to provide an estimate of the potential demand for low and zero carbon fuels in the identified ports. This estimate should be considered in the context of the following points:

- The analysis uses historical data, taking 2021 as the baseline year, but cargo trade patterns may change in future, which need to be accounted for. Estimates of fuel demand to identify potential first mover initiatives and green corridors is a first step to explore opportunities. Engagement with the fuel consumers is crucial to validate and supplement the analysis carried out to estimation future fuel demand. Studying port calls is also a way of uncovering natural port collaborations by seeing where vessels regularly call before or afterwards.
- Feasibility of a bunker hub also extends to safety. The local characteristics of the port, which is not studied in this report need to be factored. For example, the proximity to local communities and populated areas become meaningful constraints as handling alternative fuels poses greater risks than conventional fossil fuels. These considerations are explored in more detail elsewhere in this report, but dedicated safety studies and hazard risk assessments are necessary steps to evaluating bunkering feasibility and preparing for a port's decarbonisation transition.
- Pre-selected port case studies are used as examples by this study to estimate potential fuel demand and the infrastructure required to meet it. Applying a similar methodology in a more holistic Canada-wide approach could help to pinpoint to narrow down green corridor opportunities and potential collaborator ports.