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GREEN SHIPPING CORRIDORS:
LEVERAGING SYNERGIES

TABLE OF CONTENTS

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1.0 INTRODUCTION — WHAT IS A GREEN CORRIDOR AND WHAT ARE THE CURRENT DEVELOPMENTS?

In 2021, as part of the United Nations Climate Change Conference (COP26), 19 countries, including the United States (U.S.), United Kingdom (U.K.), Chile and Australia, signed the Clydebank Declaration, which aims to support the establishment of at least six green corridors by the middle of this decade, intending to scale up over the decade. In April 2022, the U.S. Department of State (DOS) announced its objective to help set up green shipping corridors and provided high-level guidance on the building blocks for green shipping corridors.

Maritime decarbonization is a particularly complex challenge with multiple pathways that are at various levels of technological and operational readiness. Conceptually, the vast majority of the decarbonization pathways involve accelerating operational efficiencies and deploying alternative low- and zero- carbon fuels at scale. One of the unique issues with shipping decarbonization is the numerous moving parts since the industry is diverse, disaggregated and globally regulated. To solve this issue, green shipping corridors will help shrink the challenge of coordination between fuel infrastructure and vessels, in the value chain and between countries, down to a more manageable size while retaining scale. Green shipping corridors bring all these varied stakeholders to the same table to create a net-positive impact on emission reduction and, simultaneously, help provide a business proposition for each member of the value chain.

The creation of green shipping corridors, defined as a shipping route between two major port hubs (including intermediary stopovers) on which the technological, economic and regulatory feasibility of the operation of zero-emission ships are catalysed through public and private actions, offers the opportunity to accelerate progress in tackling the challenges of decarbonizing shipping.

The U.S. DOS has provided additional guidance with a Green Shipping Corridors Framework. The framework adds further context to the concept of green shipping corridors. The U.S. envisions green shipping corridors as maritime routes that showcase low- and zero-emission life-cycle fuels and technologies with the ambition to achieve zero greenhouse gas (GHG) emissions across all aspects of the corridor in support of sector-wide decarbonization no later than 2050.

Green shipping corridors can spur early and rapid adoption of fuels and technologies that, on a life-cycle basis, deliver low- and zero-emissions across the maritime sector, placing the sector on a pathway to full decarbonization. There are multiple pathways through which a fully decarbonized corridor can be achieved; and the aim of a green shipping corridor framework is to provide maritime stakeholders the flexibility to choose the path that best suits their needs.

A broad range of green shipping corridor definitions (i.e., more than just shipments between two major port hubs) are developing among stakeholders with common decarbonization goals for flexibly defined shipping value chains of cargoes and/or passengers. Each corridor will have different development paths and timelines for achieving various levels of maturity while working toward an overall goal of decarbonized shipping for a specific scope/segment of maritime operations, including vessel/barge movements, assist vessels, port and terminal operations, and even intermodal transportation connections.

In this broader context, green shipping corridors become critical organizing frameworks for regional and international stakeholders to work collaboratively on maritime decarbonization goals and to connect low/zero-carbon shipping to broader regional, national and international decarbonization initiatives (Fit for 55 legislation, which includes the revised European Union Emissions Trading System [EU ETS], new fuel EU maritime regulation, revised energy taxation directive, alternative fuel infrastructure regulation, renewable energy directive, U.S. Department of Energy's [DOE's] Hydrogen Hubs, National Science Foundation Innovation Engines, Inflation Reduction Act's [IRA] Port Electrification initiatives, and Infrastructure Investment and Jobs Acts' [IIJA] programs on marine highways, etc.).

As such, the all-encompassing view may incorporate multiple connection points of more narrowly defined green shipping routes for specific cargoes and/or passengers. For example, a Gulf of Mexico green shipping corridor is under development for flow of cargoes along the intracoastal waterway and the Lower Mississippi River system and will encompass many different commodity flows and other cargoes along this waterway and the many associated ports. Similar initiatives will be valuable in other locations such as the Great Lakes, traffic to/from Hawaii, traffic across the Caribbean, designated MARAD marine highway routes and coastwise traffic in the Northeast and the mid-Atlantic. Numerous other conceptual green corridors have been announced and are at various stages of progress; some of them include the LA-Shanghai Green Shipping Corridor, the Australia- Japan iron ore green corridor, Rotterdam-Singapore green corridor, European Green Corridor Network and Chilean Green Corridors Network. There have been a few others announced which are listed at the end of the paper.

In many ways, stakeholders can leverage green shipping corridors to create multiyear development plans that provide common focus and objectives so that their individual and government-funded (e.g., grants) projects work toward common objectives rather than a series of one-off, disconnected projects. Thus, green shipping corridor initiatives can drive the fundamental change that both government and industry are seeking for decarbonization of maritime operations. They also provide the mechanism for providing shippers, charterers and the public with a verifiable understanding of the carbon footprint associated with the cargo and passenger flows along various routes.

Currently, there are numerous green corridors initiatives in various stages of discussion and, based on the level of interest seen in this space over the past few months, it is clear that many stakeholders view green corridors as a powerful tool in helping decarbonize the maritime shipping industry. Green corridors are currently conceptual, but as one green shipping corridor operationalizes even on a pilot scale, it is only a matter of time before this idea takes off to re-wire the entire industry.

The figure below depicts how these green corridors will look when fully developed. Any permutation and combination of these fuels and technologies could apply based on the techno-economic feasibility of the corridor in question.

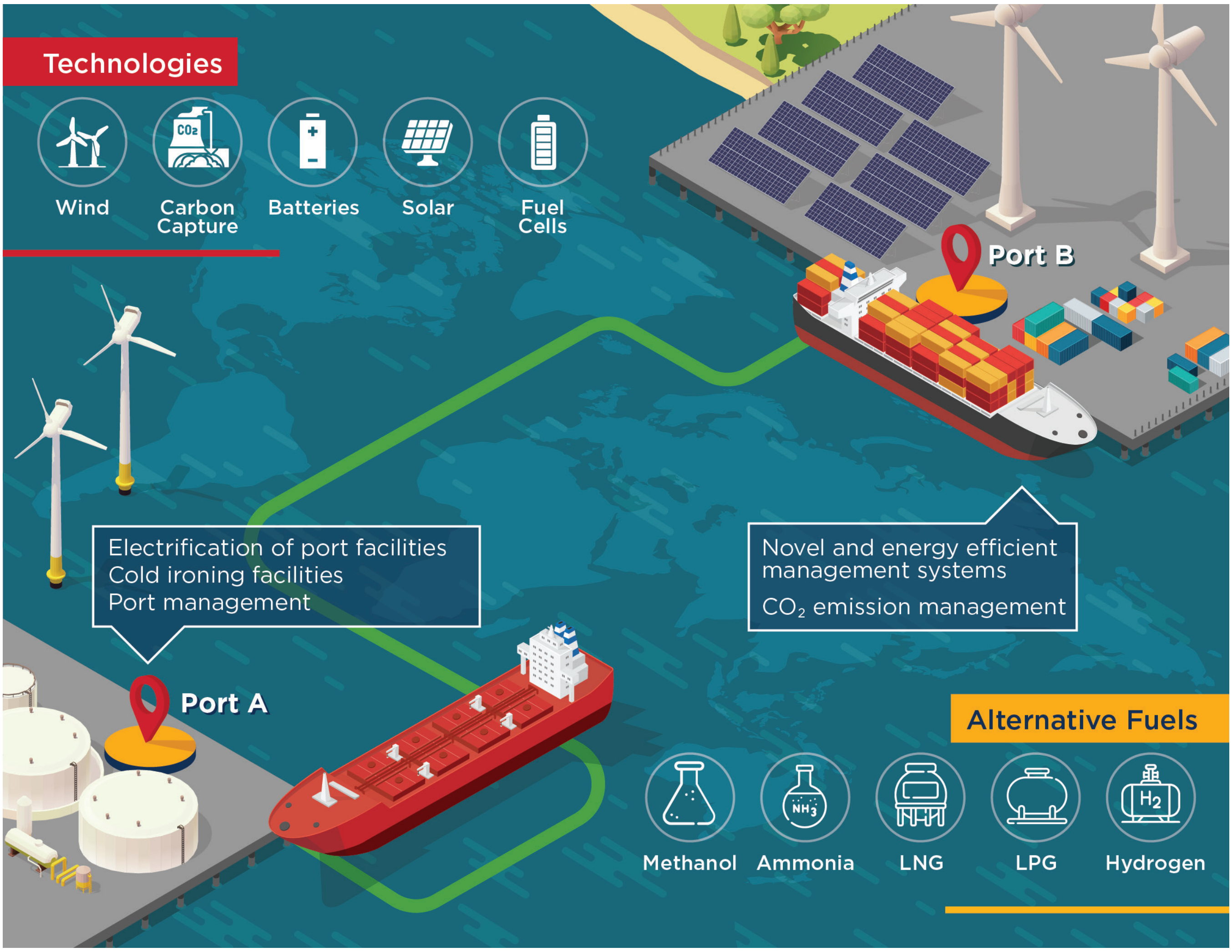


Figure 1: Vision of a Green Corridor.

1.1 WHAT DOES "GREEN" MEAN?

"Green" indicates that the foundational focus of the corridor is emission reduction. According to the Clydebank Declaration, the focus is on zero-emission maritime routes between two or more ports while, in the case of the U.S. DOS initiative, both low- and zero-carbon maritime routes are considered within the ambit of the definition of a green corridor.

Keeping emissions as the north star, different proposed corridors may focus on different elements of decarbonization. Certain green corridors may be fuel and technology agnostic (i.e., they take the most liberal interpretation of a green corridor). In some other cases, green corridors may be driven by the existing presence or potential development of fuel and bunkering infrastructure. Finally, there would be cases where certain green corridors may choose to clearly indicate that their corridor needs to have a technology demonstration aspect and may specify fuels that they will rely on to achieve emissions reduction.

Since the end goal is emission reduction, it makes little sense at this point to have clearly defined prescriptive definitions. The approach should be technology agnostic to allow for all the ideas to germinate and then it is a matter of execution. The definition will keep evolving and eventually, market forces and success of these corridors will clarify and solidify the definition.

1.2 HOW IS "CORRIDOR" DEFINED?

In the context of green corridors, this specifically indicates the geographical connection between two locations (could be specific maritime routes or it could be multiple ports between two regions) and the enabling environment that helps reduce emissions. A corridor, apart from being a geographical reality, can also serve as an enabling environment for new business cases and policies which help organizations achieve low or zero-carbon emissions.

A corridor should be bottom up, created based on a detailed pre-feasibility and feasibility assessment that clearly answers the following:

- What is the business case?
- What are the alternative fuels available and infrastructure present and ease of development of new infrastructure?
- What are the policies and governmental support that help enable the development of a green corridor?

A corridor should not be randomly announced and developed based on existing popular maritime routes. There should be a framework for filtering and rating the potential of a maritime route before being transformed into a green corridor. A corridor could be described as the equivalent of a "grouping" that expects all members within the physical reality to agree and operate within some commonly-accepted standards that help reduce emissions.

1.3 PORT-CENTRIC VS TECH-CENTRIC CORRIDOR

Port-centric corridors are those that keep ports at the center of decarbonization efforts. Typically, most corridors announced are between two ports, but there are more being developed which focus on a business case that is at the center of the corridor development, for e.g., the Australia-Japan Iron Ore Corridor and the Chile Green Corridors focus on green hydrogen.

A tech-centric green corridor is like a port-centric corridor but with a shift of the focus more towards technology demonstrations. A green corridor may prescribe in its objectives' document that certain fuels or technologies need to be considered (for technical and non-technical reasons) and provide a scope for future scaling.

There could be green corridors that are technology agnostic and want to encourage emission reduction with currently available technology (e.g., port decarbonization by electrification followed by liquefied natural gas [LNG] fueled vessels). All these technologies are currently available and do not require any demonstration aspect.

All types of green corridors are equally valid and if the end-goal of emission reduction is achieved, one should not take any positions that either encourage or discourage a certain pathway. Even a "low-ambition" green corridor is still a net positive for the environment and should be encouraged.

1.4 FRAMEWORKS FOR GREEN CORRIDORS

1.4.1 CLYDEBANK DECLARATION

In November 2021, the Clydebank Declaration was signed by several countries on the sidelines of COP26. whose aim is to support the establishment of at least six green corridors by the middle of this decade, with the goal of scaling up over the decade.

"It is our collective aim to support the establishment of at least six green corridors by the middle of this decade while aiming to scale activity up in the following years, by inter alia supporting the establishment of more routes, longer routes, and/or having more ships on the same routes. It is our aspiration to see many more corridors in operation by 2030. We will assess these goals by the middle of this decade, with a view to increasing the number of green corridors."

The signatories aim to support the establishment of green shipping corridors and specifically use the term "zero-emission maritime routes". The term zero emission route sounds prescriptive, but the declaration text does not specify fuels or dictates individual jurisdictions to decide on decarbonization pathway. The declaration provides the following additional directives:

- Facilitate the establishment of partnerships between ports, operators, and the entire value chain to help with accelerated decarbonization of the sector
- Identify barriers and take steps to prevent them for the development of these green corridors, which include regulatory frameworks, incentives, information sharing, or infrastructure
- Recommends steps to include green corridor development as part of their national action plan to align with the U.N. Sustainable Development Goals (SDGs)
- Complete a wide-ranging review of these green corridors to reduce environmental impacts and focus on sustainability

Voluntary participation is at the foundation of this declaration and has clarified that not all vessels transiting the corridor would be required to produce zero emissions or to participate in the collaboration. The declaration also recognizes that a life-cycle (well-to-wake) approach is followed for carbon accounting including production, transport or consumption of these decarbonized fuels and propulsion technologies.

1.4.2 US DEPARTMENT OF STATE (DOS)

After the Clydebank Declaration, the U.S. DOS provided some additional follow-up guidance on how they envision the development of these green corridors. The definition and guidance are mentioned below.

"The United States envisions green shipping corridors as 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."

As one can see, the definition is rather open-ended which indicates the need to develop a corridor that specifically focuses on low- and zero-emission life-cycle fuels which cover a wide range of alternative fuels. In addition, the focus is on specific routes where the availability of these fuels is guaranteed between the ports and/or transshipment stopping points.

The development of a green corridor will be a multidecadal project that aims to create not only physical infrastructure for the deployment of alternate fuels, and develop vessels that can operate efficiently using them, but also a regulatory and stakeholder framework to align all of the varied stakeholders.

The conceptual framework provided by the U.S. DOS aims to provide a level of flexibility that can either start with a small, conceptual, pilot project before being expanded in scale. Initial ambitions for these green corridors are to accelerate the adoption phase using a pilot project and act as a signal for the seriousness of the decarbonization effort of the stakeholders. The pilot project will have a demand-signaling effect for alternate fuels and zero/low-emission vessels. As mentioned previously, green corridor developments are long-term projects, but initial project implementation is crucial for these corridors to take off as a powerful tool for sector-wide decarbonization.

1.4.3 CARGO OWNERS FOR ZERO EMISSION VESSELS (COZEV) INITIATIVE

Cargo Owners for Zero Emission Vessels (coZEV) is a group of cargo-owners' companies that have joined hands to specifically focus on using only zero-carbon ocean freight by 2040. The group has larger goals toward maritime decarbonization and have recently made strides toward establishing a Los Angeles-Shanghai green corridor. This initiative focuses on zero-carbon emission vessels and, at the same time, brings several major cargo owners who have ambitious goals toward their supply chain decarbonization. Further, this initiative specifically defines zero-carbon fuels as follows:

> ***"By zero-carbon fuels, we mean fuels that have zero greenhouse gas emissions on a lifecycle basis, are sufficiently scalable to decarbonize the entire shipping industry, and for which safety and land use concerns have been addressed. Liquified Natural Gas does not meet these criteria. Leading analysts have determined that our goals are most likely to be accomplished with hydrogen-based fuels. Global fuel standards that address environmental and social impacts and promote ethical/responsible sourcing of zero-carbon fuels are needed to support informed decision making."***

The initiative is the most prescriptive in terms of its definition of "green" (zero-carbon fuel) and "corridor" (cargo owner supply chain). While the definitions are in place, questions remain around what fuels they will finally choose, what certification standards will be utilized and how fuels will be sourced or even if there is enough supply of hydrogen-based fuels. Based on the current information, they are looking at a 100 percent reduction in GHG emissions with minimal scope for low-carbon fuels, which may be a large swathe of the fuel supply. For example, not considering LNG as a fuel, even with responsible low-carbon sourcing, is a challenge this initiative could face over the short-term.

1.4.4 CHILEAN GREEN CORRIDOR

The Chilean government, which was one of the signatories of the Clydebank Declaration, has announced a formal agreement to establish a network of green corridors to facilitate green maritime transportation of goods in and out of Chile. The announcement included some initial direction on next steps which will involve mapping and assessment of the most promising corridors based on emission intensity, distance to ports, vessel segments, routes and cargo types. It is apparent from this announcement that public-private collaboration will be at the foundation of decarbonization of the maritime sector. This corridor is a case study for how the government is taking the lead and enabling the formation of a green corridor. Not much is known about the results of the feasibility assessment at this time, but the results of this corridor will be an interesting case study of a public/private partnership at the national scale leading to the formation of a corridor.

2.0 WHAT ARE THE FOUNDATIONAL ELEMENTS?

A robust green corridor should have well-defined foundational elements. The successful development of a green corridor and the continued sustenance of it, will require a set of elements to be clearly and methodically addressed. These elements will ensure the successful launch of any green corridor and mitigate any associated risk. For any green corridor to succeed, the following elements are critical and need to be clearly laid out during the pre-feasibility and feasibility assessment. There are numerous ways to define the foundational elements and the details could vary based on the specifics of the green corridor, but the broad emphasis should be on the four points listed below.

- Collaboration across the value chain
- Development of alternative fuel pathways and port infrastructure
- Shipping impact/logistical case
- Policy and regulatory support

This section will discuss each of the critical foundational elements in detail and their interdependencies and the figure below shows the conceptual framework.

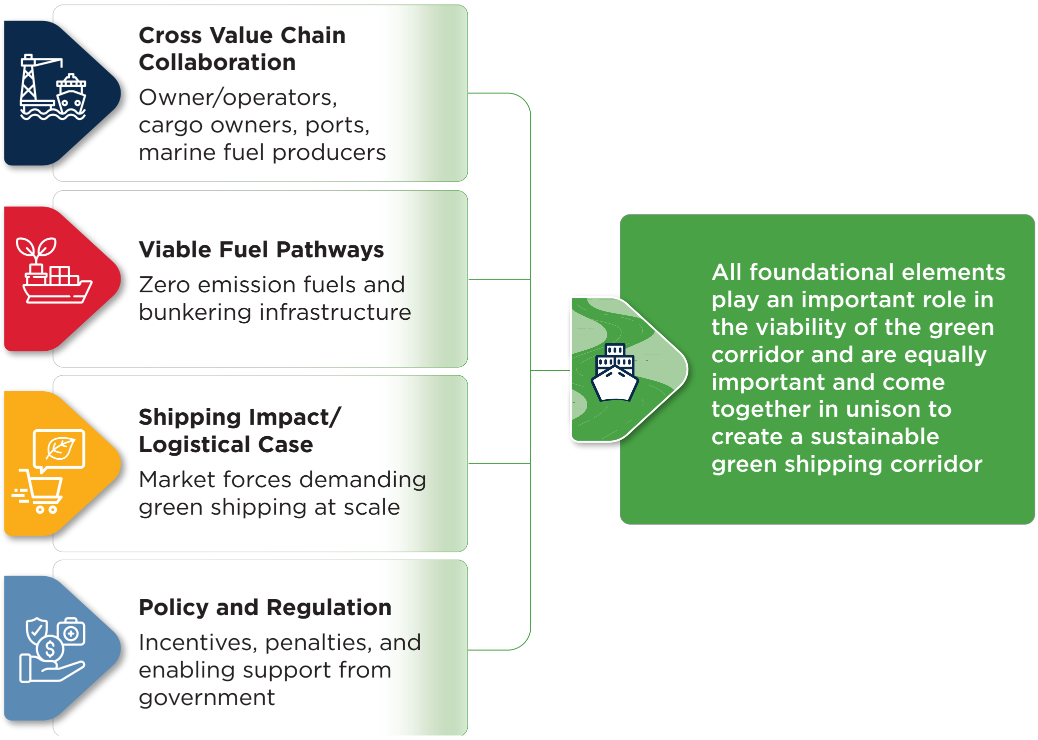


Figure 2: Enabling Environment for Green Shipping Corridors.

2.1 FOUNDATIONAL ELEMENT #1 — COLLABORATION ACROSS THE VALUE CHAIN

Commitment across the value chain is an integral aspect of any green corridor since fundamentally, a green corridor is a value chain decarbonization initiative bringing together stakeholder groups that are solving the same problem. For a green corridor to succeed, each of the members of the value chain need to collaborate, particularly at the intersection of their operational boundaries. This interaction will improve interoperability and may initially lead to boundaries blurring, but over a period, the entire corridor will operate as a system, that not only helps in maritime decarbonization, but also leads to economic opportunity that was not previously envisioned. The collaboration should be built on a foundation of open dialogue among the stakeholders in a trusting environment with well-defined contracts to prevent any issues at the interface between the stakeholders.

Every member of the value chain will have different decision-making criteria which align with the needs of their business model. The table below summarizes some of the key points each member of the value chain should consider before investing in a green corridor.

Value Chain Member	Description	Value Proposition (Why be a part of a Green Corridor?)	Decision-making Criteria
Vessel owners	The entity that has financial control of the vessel. This entity may also be the vessel operator	Vessel owners can get ahead of the curve in terms of investment in green technology deployment and testing of vessels. Being involved in a green corridor will allow for an “ecosystem” where the costs are spread across the various stakeholders interested in the implementation. In addition, green financing options make these investments attractive.	• Future Fleet Size Requirement • Total cost of ownership (TCO) of decarbonized options • Vessel Decarbonization pathway • Number of Newbuilds and retrofit vessels • Capital expenditures (CAPEX) requirements for converting existing vessels and new vessels and financing options
Vessel operators/ charterer	The entity that has operational control of the vessel. This entity may also be the vessel owner.	For vessel operators and charterers who have operational control, these investments will help them meet their net-zero goals and reduce their carbon footprint. In addition, will help them get ahead of the curve from an operational experience perspective.	• Understand downstream financial and non-financial impact of vessel fleet changes i.e., operating with new and retrofitted vessels and costs premiums related to alternative fuels • Identify commercial mechanisms that allow passing off some of the cost to the charterers or cargo owners • Forecast future demand for alternative fuels and ability to quickly obtain them
Cargo owners/ charterer	The entity that enlists the operator to transport their products.	Cargo owners aiming to reduce produce life cycle emissions can take advantage of low carbon/ zero carbon emission vessels that operate as part of the green corridor. Costs for eco-friendly/ green labeled products can be passed to downstream consumers who may be willing to pay a “green premium”.	• Cargo’s sensitivity to shipping and transport cost • Assess customer willingness to pay for the “green premium” • Identify commercial mechanisms that allow for spreading the costs using long term offtake agreements, green credits etc. • Identify efficiencies in the supply chain to offset the costs
Ports	The entity that assists the vessel in loading and unloading cargo.	Ports that are first movers can use the green corridor framework to upgrade their infrastructure and scale up from a regional hub to an international one.	• Estimate current demand and capacity for handling alternate fuels based on expected demand growth, existing and planned infrastructure, and regulatory framework in place for ports • Estimate required investments for storage and bunkering infrastructure
Marine fuel producers	The entity that produces and supplies marine fuel	Marine fuel producers are guaranteed long-term demand and can make plans to re-wire their production process. These green corridors and associated funding available will help many traditional fuels manufacturers transition to alternate fuels.	• Estimate growth in Alternative fuel demand • Identify possible production centers and identify supply-gap • Estimate CAPEX and operating expenditures (OPEX) required to be ready for demand explosion and alignment with their business realities

Table 1: Green Corridor Decision Making Criteria – Value Chain Members.

The first step of the process of considering a green corridor will involve the establishment of a consortium of stakeholders with a neutral body, such as a classification society playing the role of a facilitator. Any consortium should include members of the value chain that are aligned on the goals of corridor. Once the value chain consortium is setup, a pre-feasibility assessment which answers some of the questions, indicated in the table below, will provide the foundational decision-making points for further detailed analysis. The output from this assessment should rank the considered corridors from high to low and a benchmark should be setup based on hard, quantitative metrics to allow for the formation of the corridor.

2.1.1 CONDITIONS THAT ENABLE THE FORMATION OF GREEN CORRIDORS

Although the areas of collaboration above were described linearly, between one party and the other, the holistic view of green corridor collaboration is much more complex. Each of these issues, such as alternative fuel selection, bunkering procedure development, alternative fuel storage, vessel retrofits and logistics, all require multistakeholder collaboration. The initial selection process for green corridors is crucial. For a route to be selected as a candidate for a green corridor, it needs to have potential for decarbonization, thereby creating the necessary impact to help the shipping sector achieve its decarbonization goals. This also needs to be feasible from an implementation viewpoint.

The selection of a green corridor is a very complex process and needs to be based on real-world data that has undergone rigorous review. Each green corridor needs to undergo a detailed pre-feasibility study that answers the following questions described in the table below.

	What are the Important Questions Corridor Developers need to think about?
Screening Considerations	What is the vision and objective of the green corridor? A well-defined end goal is a primary requirement, i.e., what are the corridor's key performance indicators (KPIs), which help understand metrics of interest to be tracked.
	What is the timeline for the formation of the green corridor?
	Is a regulatory framework in place at a country/province/port/city level to support a green corridor? If not, what advocacy needs to be done to create an enabling environment?
	What is the business case for these green corridors? What is the timeline for return on investment (ROI)
	What are the funding sources? How much governmental support is available? Green corridors are massive undertakings, and governmental support is paramount, particularly in the port and bunkering infrastructure-green corridor interface.
	Who are the members of the consortia? Ports, vessel owners/charterers, shipyards, alternate fuel producers, class societies, OEMs, regulatory and governmental bodies.
	What are the low/zero-emission fuel options and the potential for scalability for the green corridor?
	What are the trade routes, vessel segments, and cargo types that operate between ports which are part of the green corridor?

Table 2: High Level Screening Considerations.

When the above listed questions are answered rigorously, the identity of a viable green corridor will reveal itself, which will include the following: location, business case, consortium members and funding sources.

2.1.2 VESSEL OWNERS AND VESSEL OPERATORS

For vessel owners/operators, being a part of a green corridor in many cases, will involve making massive capital expenditure (CAPEX) investments and could fundamentally change their fleet composition. Owners who have already moved ahead in their decarbonization pathway may be well positioned to participate in a green corridor initiative. Changes to their fleet composition will depend on their estimation of the future demand for their new upgraded fleet, current utilization of vessels, presence of nearby green corridors, operational optimization and nearby alternative fuel bunkering capabilities. Certain vessel owners, depending on the age of their fleet, may be better positioned to be a part of the evolution. For example, if a large part of their current fleet is reaching its end of life and is getting ready to be scrapped, they may find that investments in vessels that can operate on green corridors are a great opportunity. The current fleet average age and utilization will be a critical metric for these owners and operators.

Additionally, the total cost of ownership (TCO) will need to be analyzed, taking into consideration changed costing assumptions such as CAPEX requirements (newer vessels with new technologies), operating expenditure (OPEX) requirements (operating with alternative fuels), and cost of alternative fuel logistics (storage and bunkering). Carbon pricing is an evolving variable, but it has the potential to fundamentally shift many of the current financially unviable projects into viable ones. Currently, regulatory carbon credits are available in a few jurisdictions in the U.S. and are expected to be a part of the European Union Emissions Trading System (EU ETS) program. Additionally, speculative revenue streams in the voluntary carbon markets could motivate owners/operators to invest in new technologies without negatively impacting their profitability.

The next step would be to understand the emission reduction potential for each of the options in alignment with the TCO (i.e., what is the option that provides the greatest reduction potential per dollar spent). Analyzing these types of data points, the owner can decide on the path to take in terms of newbuilds and retrofits. Based on the data points available, the owner can also plan the scrapping schedule and possibly obtain favorable sustainable financial terms while investing in newbuilds.

Fundamentally, vessel decarbonization pathways are a technological challenge. The engine manufacturers, shipbuilders and other members of the shipbuilding value chain need to ready themselves for the fleet evolution to take place. Apart from the owner focusing inward, they also need to focus outward on the current state of the shipbuilding value chain to align with their plans.

2.1.3 CARGO OWNERS

The next layer of collaboration between value chain partners is the relationship between vessel operators and cargo owners. Cargo owners are consistently looking to mitigate their scope three emissions and therefore need to manage expectations with vessel owners and operators. This may include revising contract terms to commit to emission reductions over time. Foresight from vessel operators is essential for a smooth transition and mitigation of risk associated with not meeting cargo owner requirements on emission reduction.

The cargo owner being closest to the consumer will need to assess the consumer's willingness to pay a green premium which will evolve over time. They should assess the cargo's elasticity of demand based on market research reports, historic shipping service sales data. Additionally, trade fluctuations, relative weight of shipping costs to retail value of cargo, contribution of shipping emissions to total emissions of the cargo and abatement opportunities for non-shipping emissions. The analysis will help understand the cargo's ability to carry a green premium.

Once the cargo's potential for decarbonization is assessed, assessing alternative transportation options/routes will help in understanding the feasibility of the cargo using other options which will prevent the cargo from utilizing the corridor. The next step would be to estimate the customer's willingness to pay for decarbonized shipping services and clearly map out the drivers (i.e., is it consumer behavior or scope three emission targets of owners?). Some of the steps that the cargo owner would need to take is to engage with their consumers using surveys, align their scope three targets with that of the corridor and assess contract/charter dynamics.

2.1.4 VESSEL OPERATORS AND PORTS

The relationship between vessel operators and ports is one that requires constant communication throughout the development of a green corridor. During the development phase, operators and ports need to discuss compatibility and safety requirements associated with the potential solutions being implemented. This may be unique bunkering arrangements for varying alternative fuels, cold-ironing arrangements while at berth or emission capture arrangements at berth. Other collaborators will be involved in the process, but these two entities will be the ones executing the procedures. Therefore, their discussions will be oriented toward operational safety and success compared to some of the overarching philosophical discussions being had on developing the corridor.

2.1.5 PORTS AND MARINE FUEL PRODUCERS

Ports play a key role in the green corridor development as they require access to an alternative fuel supply, logistics in place to procure and store the alternative fuel and the infrastructure to safely bunker the alternative fuels.

The ports and fuel producers need to come together to detail the green corridor's storage and bunkering demand profile based on vessel type, voyage and fuel characteristics. Ports need to focus on the storage requirements based on the fuel volume and the physical state of the fuel (does it need to be pressurized or refrigerated?). Additionally, they will need to map the current and expected storage and bunkering ports/regions and their infrastructure capacity and understand the regulatory requirements for handling alternative fuels, permitting processes and safety standards. Focusing on the above data points, will clarify for the port operators and fuel producers, the level of challenge when deciding on a port-centric green corridor.

The challenge will be the inherent storage and safety concerns with new fuels. These will need to be discussed and engineered for, with input from the other value chain partners.

2.2 FOUNDATIONAL ELEMENT #2 — DEVELOPMENT OF ALTERNATIVE FUEL PATHWAYS AND PORT INFRASTRUCTURE

An important decision-making criterion for a green corridor will be quantifying the energy demand for the corridor based on the evolution of the route, vessel utilization, vessel engine type and size. Additionally, the fuel producers in the consortium of project developers will need to calculate the alternative fuel demand based on the fuel characteristics (heat content, efficiently transport and utilize). Decarbonization is economy wide and hence, the shipping industry will need to assess the availability of these fuels for the shipping industry. The green corridor consortium should help fuel producers by guaranteeing long-term demand to allow for capacity development and to corner the supply. This could be the most critical part of the development of the corridor, since fuel supply is at the underlying foundation of a green corridor.

Deep analysis of the fuel availability should include a gap-analysis between expected demand for the corridor and the available supply to estimate the import requirements. The corridor developers will need to identify the production capacity over time by focusing on announced projects, market estimates of alternative fuel capacities and policy incentives (such as the Inflation Reduction act [IRA], Infrastructure Investment and Jobs Act [IIJA], EU ETS Marine Provisions) for supply growth. Scaling the supply of one alternative fuel is difficult enough but managing the availability across two regions can exasperate the issue and hence, a green corridor will help spur growth and provide the demand side push that will aid in development of fuel production pathways and port infrastructure. There may also be major variances in the price of the selected alternative fuel based upon regional supply and policy incentives. For example, a country such as Australia that has large scale alternative energy production will be more capable of producing green hydrogen. In turn, the availability of alternative energy will alleviate some of the price challenges. On top of availability of supply, the maritime industry will have to compete with demand from other industries to procure the limited supply. This will certainly be true of biofuels, which will have high cross-sector demand that will likely keep prices elevated, even as supply increases.

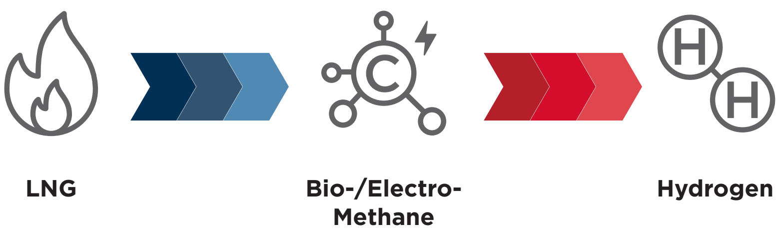
The fuel costs will be a moving target and evolve over time with deployment. Since the fuel cost trajectory is not clear among the considered alternative fuels (ammonia, methanol, hydrogen, biofuels, LNG), the consortium should diversify their risk to allow for a multipathway approach. Fuel producers particularly will need to estimate their CAPEX and OPEX investments, considering governmental support such as green investment subsidies and other nascent tailwinds such as a carbon credit revenue stream. Fuel producers, particularly being a part of a green corridor, will allow them to guarantee offtake and help them invest with a high degree of confidence.

2.2.1 FUTURE FUEL MIX AND AVAILABILITY OF THE FUEL (CROSS-SECTOR DEMAND, SUPPLY)

The industry is aware that the International Maritime Organization (IMO) mandated technical and operational measures, such as Energy Efficiency Design Index (EEDI), Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII), are steps towards decarbonization over the short term, but there will be the need for a fundamental rewiring of the industry for achieving net zero and IMO's decarbonization goal by 2050. Substantive decarbonization requires the large-scale adoption of alternative fuels. This is a huge challenge for vessel owners and operators since, apart from the technical challenges of identifying the optimum fuel specification for the vessel, the cost of fuel inflates every aspect of their operations and gets passed down the value chain. The current set of technologies and fuels can be divided into the following three pathways.

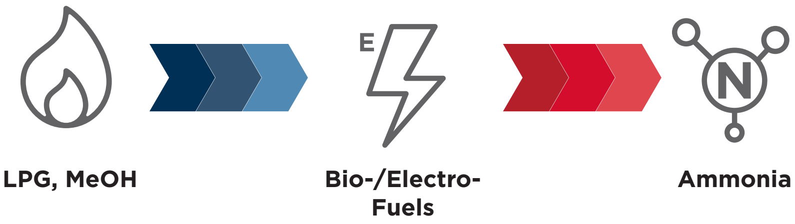
The Light Gas Pathway (From Setting the Course to Low Carbon Shipping: Pathways to Sustainable Shipping. ABS, 2020)

This category includes fuels comprised of small molecules with low carbon/hydrogen (C/H) ratios, which can help to reduce carbon emissions, and in the case of methane (CH_4), provide comparatively high energy content. However, these fuels require cryogenic storage and more demanding delivery systems. This pathway includes LNG, bio-LNG, and synthetic natural gas (SNG) or renewable natural gas (RNG), which can be produced from biomass and/or by using renewable energy.



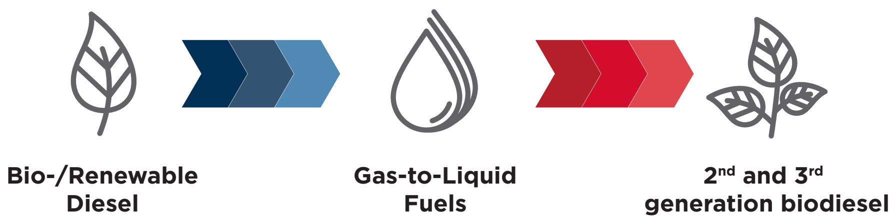
The Heavy Gas and Alcohol Pathways

This category includes fuels – such as LPG, methanol, ethanol and ammonia – that are comprised of larger molecules than those in the light-gas group. As such, they have higher C/H ratios – therefore, lower potential to reduce carbon emissions – and lower energy content. Their fuel storage and supply requirements are less demanding.



The Bio/Synthetic Fuel Pathway

This category includes fuels that are produced from biomass, including plants, waste oils and agricultural waste. Catalytic processing and biomass upgrading can produce liquid fuels with physical and chemical properties that are comparable to diesel oil; this is desirable from a design standpoint because they can be used as drop-in biofuels with minimal or no changes to marine engines and their fuel-delivery systems.



For any green corridor to succeed, alternative fuel uptake will be on the critical path, since fundamentally, emission reduction is the controlling variable. According to Clarksons, as of February 2022, 1.4 percent of the global fleet was powered by alternative fuels. The figure below shows the existing fleet powered by alternative fuels (as of February 2022).

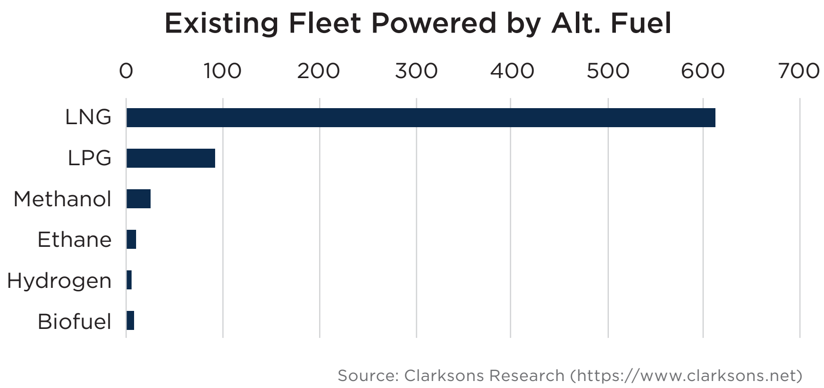


Figure 3: Existing Fleet Powered by Alternative Fuels.

In the orderbook, about 23 percent of vessels are scheduled to be powered by alternative fuels (see figure below).

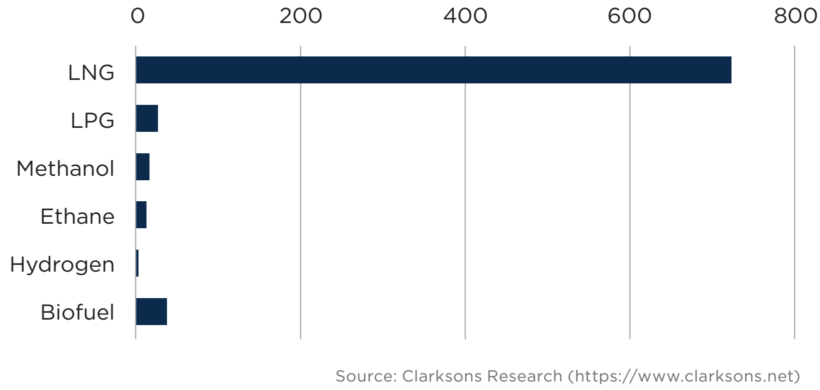


Figure 4: Orderbook of Fleet Powered by Alternative Fuels.

In terms of fuel mix, LNG, methanol and LPG have increased rapidly in recent years and ammonia as a marine fuel has seen progress too, with engine designs receiving approvals and several projects aiming to have vessels in the water by the middle of the decade. It is expected that adoption of methanol, ammonia and hydrogen will accelerate after 2030.

The latest ABS Zero Carbon Outlook indicated that significant investments had been made in new building tonnage with a particular focus on containerships and gas carriers. The trends indicated that LNG, methanol and LPG will have a starting point advantage over the other fuels currently considered, at least until the middle of the decade. Based on the vessel type and applications, the fuel uptake will vary. For example, it is expected that more large bulk carriers will adopt LNG compared to smaller vessels. The tanker sector's adoption of alternative fuels is expected to lag bulk carriers. The expected future fuel mix will inevitably involve a rapid reduction in oil-based fuels from close to 80 percent today to less than 30 percent by 2050 with LNG, methanol, ammonia and hydrogen rapidly increasing in adoption. Ammonia and hydrogen will be carbon free if they are produced by the green pathway. The uptake will depend on several factors, availability of fuel being one apart from the readiness of ports and bunkering infrastructure. See the figure below of the expected future fuel mix.

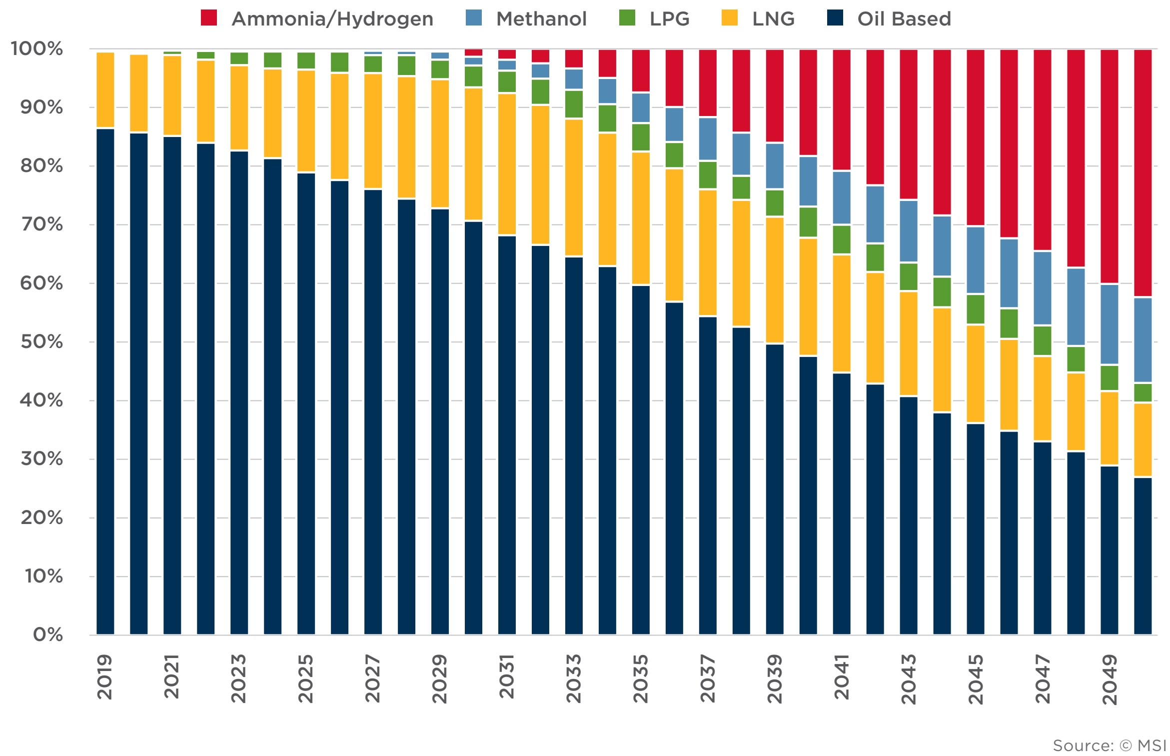


Figure 5: Forecasted Future Fuel Mix.

Around 2030, a step change in alternate fuel uptake is expected based on fleet renewals over the next decade, considering newbuilding contracts and ship demolition. LNG will be an immediate transition fuel (low-carbon variant) and its use is expected to increase steadily until 2030 and will slowly reduce when other non-carbonaceous fuels become available. Renewable forms of LNG will continue to gain demand and may create a dedicated LNG pathway. Ammonia, while being a great option, has handling and toxicity challenges which may be the biggest stumbling block to its adoption. Methanol as a shipping fuel is gaining traction particularly with industry's growing interest in green production.

2.2.2 PRODUCTION PATHWAY AND BUNKERING INFRASTRUCTURE

Discussion with the local ports will be critical to confirm that bunkering infrastructure needs are met. The challenge that is presented when scaling alternative fuels is the need for requiring distinct bunkering infrastructure for different fuel types. Many of these fuel types are new to the marine industry and hence, apart from developing shoreside infrastructure, skill development of operators will be required. As LNG bunkering infrastructure is widely built and in operation, this study will focus on the readiness and challenges of the three promising alternative fuels, ammonia, methanol and hydrogen.

2.2.2.1 Ammonia

As a promising marine alternative fuel, ammonia can be utilized in the ship internal combustion engine. Multiple pathways have been presented to refer to different energy inputs and technologies for ammonia production. The major ammonia producers are China, Eastern Europe, Southwest Asia and North America. Currently, there are no commercial applications for ammonia as a fuel in the shipping sector (IRENA, 2021). As for global shipping infrastructures, approximately 341 ports are available for the supply of ammonia in Japan, the United States, Europe and along the predominant maritime routes. Several ammonia bunkering feasibility projects are in progress in major port hubs such as Rotterdam, Singapore, etc. Moreover, because of its strategic location, Morocco has great potential to become a central bunkering hub for renewable H_2, as well as green ammonia.

ABS has awarded approval in principle (AIP) to two ammonia bunkering vessels in Singapore (ABS, 2022). The IRENA report finds that announced projects for renewable ammonia will total 17 MT of ammonia per year by 2030. This indicates momentum in the industry in moving towards scaling-up green ammonia production (IRENA, 2021). Significant ammonia project investors include Australia, Chile, Denmark, the Netherlands, and New Zealand (IRENA, 2021).

2.2.2.2 Methanol

Unlike ammonia, the methanol production industry is more prepared for green corridor needs. The methanol produced worldwide is 98 million tonnes at more than 90 methanol plants and generating $55 billion in economic activity per year (IRENA, 2021). The current uses for methanol include formaldehyde synthesis, olefins, methyl tert-butyl ether/methyl tert-amyl ether (MTBE/TAME) production, and it can be utilized as major source for fuel production, such as blending for gasoline, and dimethyl ether (DME) (IHS Markit, 2019).

One of the pinpoints of marine alternative fuels, infrastructure readiness, has been well solved for methanol as it has a well-established transportation and distribution infrastructure. Also, methanol is in liquid state at ambient pressure and temperature (IRENA, 2021) and it is compatible with fossil liquid fuels, so special storage is not required for methanol bunkering.

Methanol bunkering operations for ships are both easy and clean. Compared to the infrastructure CAPEX of LNG, ammonia or other alternative fuels, that of methanol's is quite low. So far, methanol has been available in over 100 major ports. Also, the physical properties of methanol derivative, DME, are similar to LPG, so many existing land-based LPG bunkering infrastructures could be ready to be used for DME. As a result, the pathway of methanol-DME can be a cost-effective enable for methanol fuel applications.

2.2.2.3 Hydrogen

In 2019, global consumption of hydrogen fuel reached about 75 million metric tons (Mt) according to International Energy Agency (IEA). Only 1.5 Mt of that volume was green hydrogen. To achieve net zero by 2050, the demand for hydrogen was expected to increase annually by seven to nine percent. This would lead to an estimated demand between 500 and 800 Mt of hydrogen by the year 2050 (ABS, 2022).

Currently, hydrogen is available as a final commercial product, but there is no international trading market established. As a result, there are no existing global transportation networks or standardized bunkering facilities available for the supply of hydrogen within any ports globally, but several hydrogen carriers are undergoing construction at present.

Green hydrogen would provide a cleaner source of hydrogen feedstock and fuel for many industries but realizing this prospect will require significant additional investment and infrastructure. Projects to produce green hydrogen are on the rise and this trend is expected to continue for the years to come, as the production of gray hydrogen has already started to decline (ABS, 2022). The figure below shows the overview of operational, under-construction and pending final investment decision (FID) blue and green hydrogen projects worldwide.

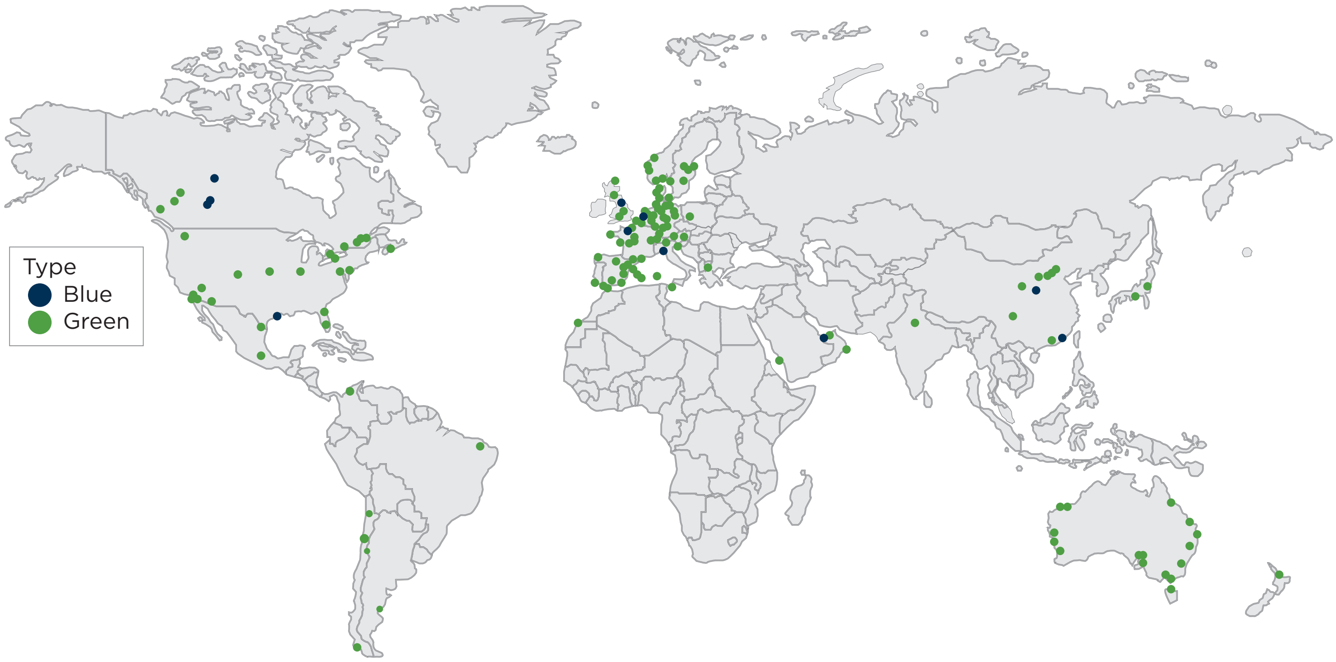


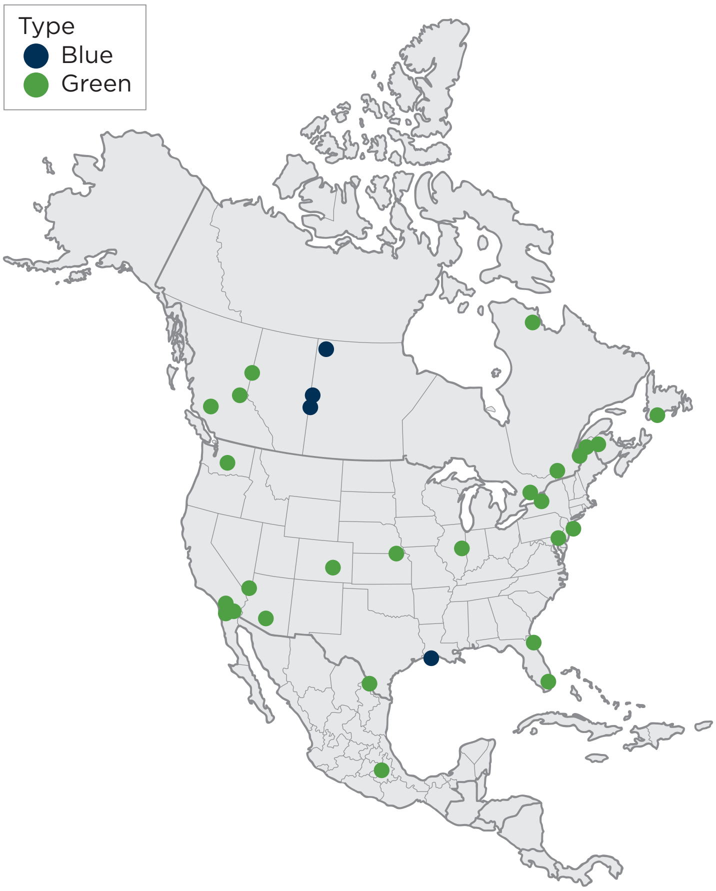
Figure 6: Overview of operational, under-construction and pending FID blue and green hydrogen projects worldwide.

Hydrogen will play a significant role in the shipping sector soon through indirect use, which enables the development of renewable fuels (methanol and ammonia) from green hydrogen. Due to the limitation of technology readiness, direct hydrogen use will not play a major role in long distance shipping, but there are opportunities to apply hydrogen in small and medium size nearshore ships (IRENA, 2021).

Moreover, infrastructure and bunkering for hydrogen has not been developed. With future demand expected to grow, there are various plans for green hydrogen developments in Australia, Chile, Morocco and Norway (IRENA, 2019).

The development of regional hydrogen hubs is critical to facilitate growth of the hydrogen value chain. These are regions in which a clean energy source can be locally scaled and refined. Hydrogen is a perfect candidate for developing hubs, considering the vast array of synthesizing hydrogen to be used as a fuel. Investments have been made by developed governments to establish these hubs, which is critical to the overall success of the global initiative (ABS, 2022).

The United States government recently approved up to $8 billion for up to four hydrogen hubs. The approval will most certainly be contingent upon geographic competitive advantages. For example, the Gulf Coast is potentially a prime location to have a hydrogen hub developed due to its commercial location. Likewise, the Great Plains have ideal geology for carbon capture and have an abundance of renewable energy in the form of solar and wind. In fact, four states (Colorado, New Mexico, Utah and Wyoming) have come together to develop a hydrogen hub and compete for the federal funding. Competitive advantages aside, scaling up of renewables will be necessary for green hydrogen to be a majority of the hydrogen mix in 2050 (ABS, 2022). The figure below shows the overview of operational, under-construction and pending FID blue and green hydrogen projects in North America.



Source: © IEA

Figure 7: Overview of operational, under-construction and pending FID blue and green hydrogen projects in North America.

Each of the three promising alternative fuels have their own strengths and weaknesses. From the perspectives of production pathways and bunkering infrastructure readiness, their status has been summarized in the table below.

Fuel	Production Pathway		Bunkering Infrastructure Status
	Strengths	Challenges	
Ammonia	• Cost of renewable NH_3 is expected to drop • Easier to store and transport • Low emission fuel with CCS production process	• Scaling up difficulties • High carbon emission in the production process • Inefficient combustion process	• Well-established worldwide distribution system, with many ships already capable of transporting ammonia • Extensive worldwide production • Green ammonia benefits from renewable H_2
Methanol	• No technical challenges in production scaling up • Commonly produced on an industrial scale • Can be used to produce many chemicals and products	• Large carbon footprint for black/brown pathways • High cost for renewable/ green pathway • Scaling up issues with green methanol • Feedstock selection for renewable methanol	• Easy to store, transport, and distribute by ship • Similar storage requirements to other common fuels • Low cost for bunkering facility modifications
Hydrogen	• Capable to be produced from renewable sources • No GHG emissions • Renewable H_2 is predicted to dominate	• High cost for H_2 production • Storage difficulties • High investment for shipping fuel application	• Infrastructure and bunkering for H_2 has not been developed • Benefit for ammonia value chain

Table 3: Production pathway and bunkering infrastructure summary of the alternative fuels.

2.3 FOUNDATIONAL ELEMENT #3 — SHIPPING IMPACT/LOGISTICAL CASE FOR A GREEN CORRIDOR

Having a solid business case transforms a green corridor from a theoretically possible action into a commercially practical solution. The business case may vary from corridor to corridor, but inevitably the driver will be demand for emission reduction from the value chain coupled with an optimal solution from an economic standpoint.

The various solutions for implementation such as methanol, LNG, ammonia or hydrogen, all have varying levels of commercial viability that are regionally dependent. Therefore, the fuel selection process will need to include a life-cycle cost analysis for the various solutions. This process will detail the emission reduction impacts of each solution, the CAPEX associated with implementation, and the OPEX associated with continuous operations. Consideration also can be made to lower prices of alternative fuels over time as supply scales.

The cost analysis will need to be corridor-wide and multistakeholder driven, in order for the corridor to be successful, each link of the corridor needs to be individually successful. The business model should aim to prevent weak links in the value chain across the corridor. If one part of the corridor fails, the entire corridor will be at risk, which is why developing a risk mitigation plan for each portion of the green corridor is critical (i.e., involve multiple fuel producers instead of depending on one fuel producer). Also, the development of port infrastructure that has multiple use cases will help prevent stranded assets for e.g., hydrogen handling capabilities are useful for industrial decarbonization too and hence, ports near chemical industries can develop infrastructure in partnership with major industrial operators in the hard to abate sectors (steel, Portland cement, petrochemicals).

In a worst-case scenario, where there is a low-price tolerance from customers and low margins, it may not be commercially viable to implement a green corridor. In that case, there needs to be an external catalyst to drive growth.

Since, none of the green corridors have been operationalized yet, a high-level data analysis of port facility readiness and shipping impact was conducted for some of the ports that have been included in the announced corridors.

2.3.1 GREEN CORRIDOR PORT FACILITY READINESS

As part of the port facility readiness analysis, 14 ports were identified as being part of potential green corridors. These are listed in the list below.

- Antwerp
- Los Angeles
- Rotterdam
- Dampier
- Montreal
- Seattle
- Houston
- New Orleans
- Shanghai
- Kashima
- Oita
- Singapore
- Port Hedland
- Vancouver

The port facility readiness for the green corridor is listed in the following table. Onshore power supply can be known as shore power or alternative maritime power. By using onshore power supply, a ship can shut down its engine without disrupting onboard operations to eliminate shipping emissions at berth. Exhaust gas cleaning systems are air quality solutions that reduce ship exhaust gas emissions. Ballast water discharge system onshore is a water quality solution which sterilizes microorganisms in ballast water to protect the nearshore ecosystem. Carbon capture and storage (CCS) systems can help ships remove and store CO_2 from the shoreside. Bunkering stations for alternative fuels ensure the fuel supply for ships, covering loading and distributing operations when ships are at berth. Windfarm support is applied to maintenance and repair duties that keep offshore wind turbines/towers in operation, which are essential for green pathway alternative fuels. The table below summarizes the port readiness of each of these selected ports.

Port Facilities	Port Name
Onshore Power Supply	Singapore, Shanghai, Rotterdam, Antwerp, Houston, Seattle, Vancouver, Los Angeles, Montreal, New Orleans
Exhaust Gas Cleaning Systems	Singapore, Rotterdam, Antwerp, Port Hedland
Ballast Water Discharge	Singapore, Shanghai, Rotterdam, Antwerp, Oita, Houston, Kashima, Port Hedland
Carbon Capture and Storage	Singapore, Shanghai, Rotterdam, Antwerp, Oita, Houston, Kashima, Port Hedland
LNG Bunkering Ready	Singapore, Shanghai, Rotterdam, Antwerp, Houston, Vancouver, Port Hedland, Dampier, Montreal, New Orleans
Ammonia Bunkering Ready	Singapore
Hydrogen Bunkering Ready	Singapore, Rotterdam, Antwerp, Los Angeles
Methanol Bunkering Ready	Singapore, Rotterdam
Biofuel Bunkering Ready	Singapore, Rotterdam, Antwerp
Windfarm Support	Shanghai

Source: © Clarkson Research Services Limited 2022

Table 4: Green Corridor Port Facility Readiness.

From the above table, Singapore port has the greatest number of port facilities available for alternative fuels and other decarbonization solutions, so Singapore is deemed as the most green-corridor-ready port, followed by Rotterdam, Antwerp, Shanghai, Port Hedland, Houston, Los Angeles, Montreal, Oita, Vancouver, Dampier, Seattle and New Orleans.

The number of times a ship has called on a port is commonly deemed as a significant indicator for the port's trading importance. The Port Calls (PC) number for the 14 ports (2021, and 2022 until September 22, 2022) were studied as part of our analysis. The figure below shows the actual number of PC in descending order.

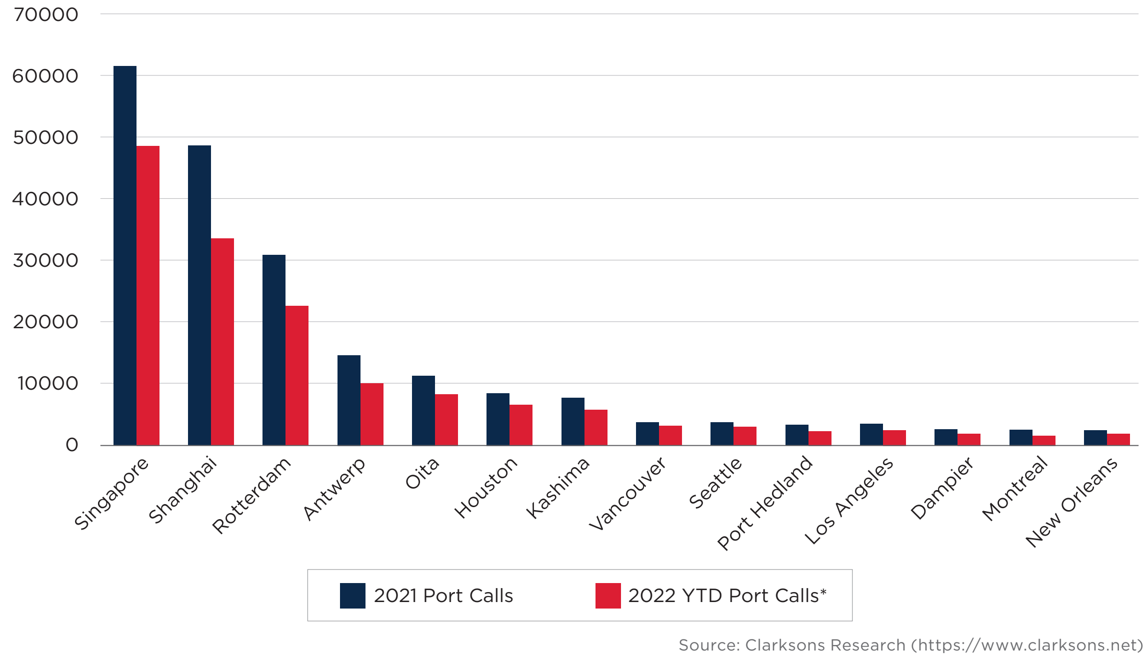


Figure 8: Port Calls for the 14 Ports.

*Note: 2022 YTD Port Calls cover Jan. 1 to Sept. 22, 2022.

The figure above illustrates that the busiest port is Singapore, and New Orleans has the least number of PC. Meanwhile, the PC number shows a consistent pattern for all the 14 ports for the two years. The Port Calls is an important metric of the business of a port and hence, should be a very important metric while choosing the initial few green corridors that are "port-centric".

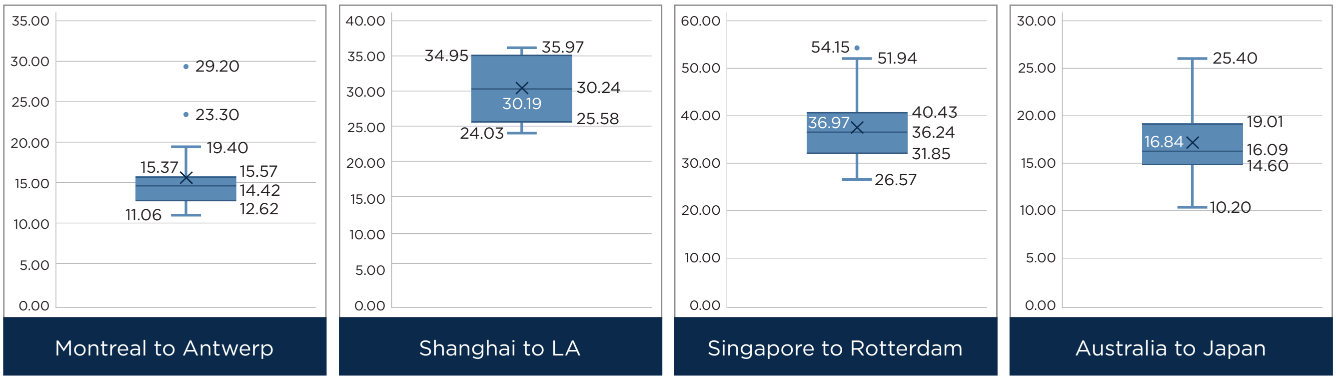
2.3.2 GREEN CORRIDOR SHIPPING IMPACT EVALUATION

Considering the trading impact and the green corridor port facility readiness, four routes for liquid tankers were selected to carry out an in-depth analysis. These are:

- Montreal to Antwerp
- Singapore to Rotterdam
- Shanghai to Los Angeles
- Australia to Japan*

*Note: Australian ports cover Dampier, Port Hedland, etc., while Japanese ports cover Oita, Kashima, etc.

The two indicators to evaluate the trading or shipping impacts are the completion days and the ton-miles of each trip, both are indicated in the tables that follow. The completion days for one single trip are determined by the time interval between the port of destination date and the port of departure date. The ton-mile is calculated by multiplying the cargoes in tons by the mileage in nautical miles, quantitatively showcasing the impact of freight or shipping activities.

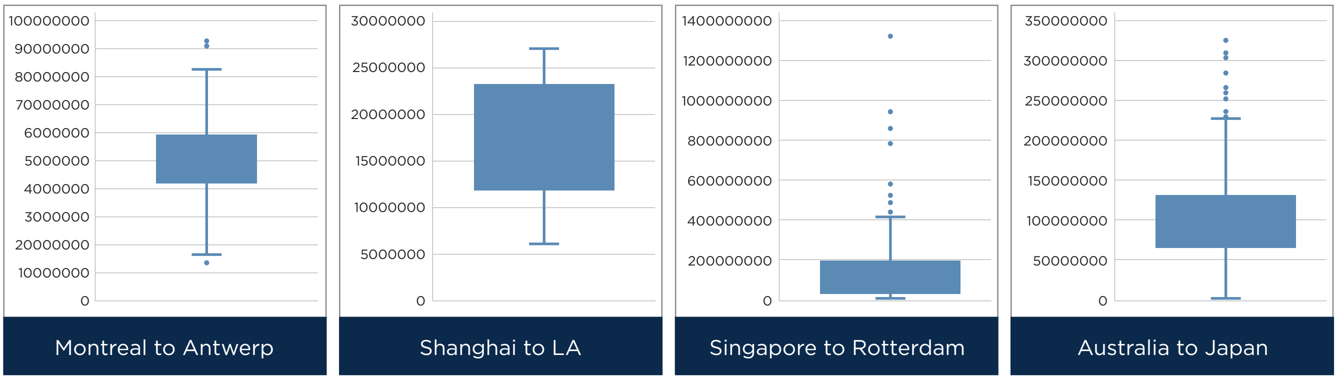


Source: Referred from Kpler database

Figure 9: Completion Days for Four Promising Green Corridor Routes (Please check supplemental data for details).

Montreal to Antwerp (with a median value of 14.42, and interquartile range [IQR] of [12.62,15.57]) Shanghai to LA (with a median value of 30.24, and IQR of [25.58, 34.95]) Singapore to Rotterdam (with a median value of 36.24, and IQR of [31.85, 40.43]) Australia to Japan (with a median value of 16.09, and IQR of [14.60, 19.01]).

As shown above, the median values of single trip completion days for the four selected green corridor routes in the order of highest to lowest, are Singapore to Rotterdam (36.24), Shanghai to LA (30.24), Australia to Japan (16.09) and Montreal to Antwerp (14.42). During one specific time period, more trips can be completed from Montreal to Antwerp than the other three selected routes.

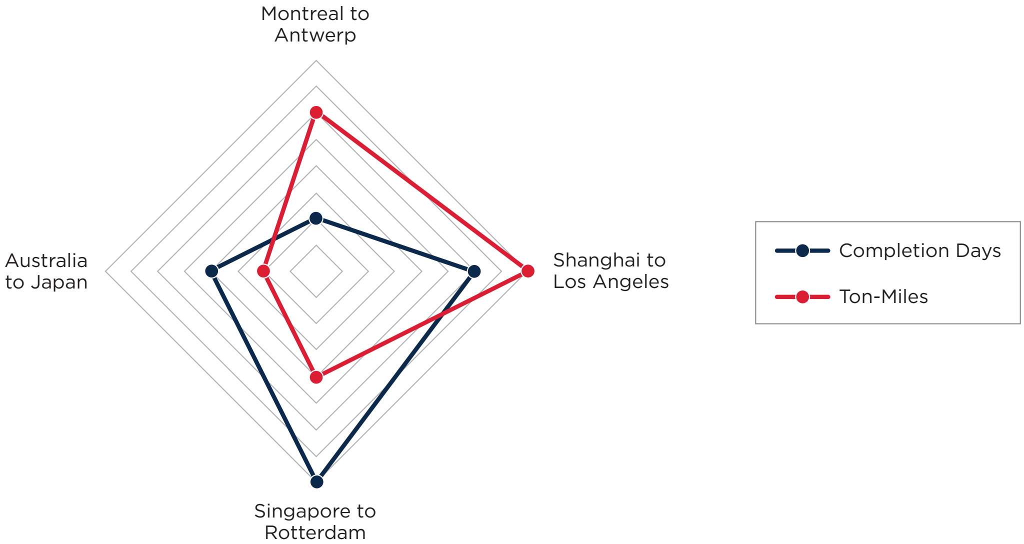


Source: Referred from Kpler database

Figure 10: Ton-Mile Analysis for Four Promising Green Corridor Routes (See supplemental data for details).

Montreal to Antwerp: Median 52567728, IQR (42182351, 59265900), Shanghai to LA: Median: 21307379, IQR: (11868671, 23221802), Singapore to Rotterdam: Median: 67997982, IQR: (26188504, 183875943), Australia to Japan: Median: 93812222, IQR: (61877874, 126154075).

The median values of ton-mile analysis for the four selected green corridor routes, in the order of highest to lowest, are Australia to Japan, Singapore to Rotterdam, Montreal to Antwerp and Shanghai to L.A.



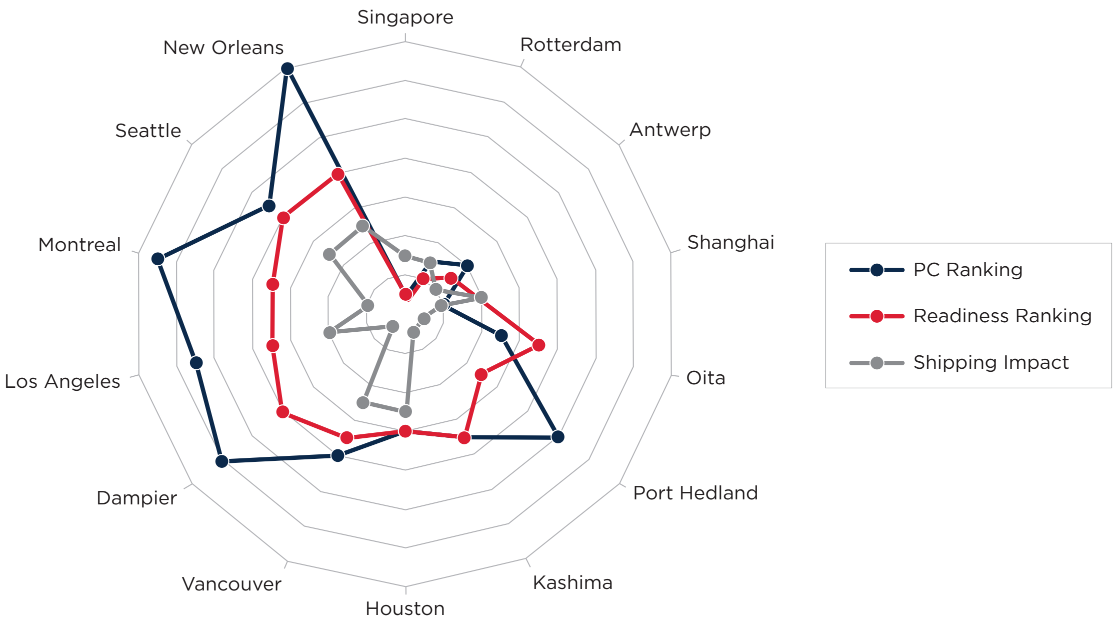
Source: Referred from Kpler database

Figure 11: Trade-off radar map for completion days and ton-miles.

By considering the trade-off effects between completion days and the ton-mile analysis, as indicated in the figure below, the shipping impact ranked from highest to lowest is Australia to Japan, Montreal to Antwerp, Singapore to Rotterdam and Shanghai to L.A.

2.3.3 SUMMARY OF PORT READINESS AND SHIPPING IMPACT

Considering both the port facility readiness and the shipping impact, this work presents a three-dimensional (3D) matrix to quantitatively determine the prioritization for liquid tankers navigating among the listed ports. The prioritization level can be summarized as shown in the figure below.



Source: Referred from Kpler database

Figure 12: Prioritization of Green Corridor Ports for Liquid Tankers.

The ranking results for the 14 ports are listed in the table below.

Port Name	PC Ranking	Readiness Ranking	Shipping Impact	Overall Ranking
Singapore	1	1	3	1
Rotterdam	3	2	3	2
Antwerp	4	3	2	3
Shanghai	2	4	4	4
Oita	5	7	1	5
Port Hedland	10	5	1	6
Kashima	7	7	1	7
Houston	6	6	5	8
Vancouver	8	7	5	9
Dampier	12	8	1	10
Los Angeles	11	7	4	11
Montreal	13	7	2	12
Seattle	9	8	5	13
New Orleans	14	8	5	14

Source: Referred from Clarkson and Kpler

Table 5: Ranking results for the 14 ports.

Note: The shipping impact is determined by the previous figure (Figure 11) with all the selected Australian and Japanese Ports ranked as one, followed by Montreal to Antwerp (rank and two), Singapore to Rotterdam (rank and three), and Shanghai to LA (ranks and four), and the ports not selected for the green corridor routes evaluation ranked as five.

Then the work determined the overall ranking by using the following formula:

$$Overall\ Ranking = W_{pc} \cdot R_{pc} + W_{Readiness} \cdot R_{Readiness} + W_{SI} \cdot R_{SI}$$

W refers to the weighted value and R refers to the ranking level. By adopting the weighted value of the three indicators of 0.2, 0.5, 0.3, respectively, the final overall ranking can be listed in the last column, illustrating the most promising green corridor port is Singapore.

2.4 FOUNDATIONAL ELEMENT #4 — POLICY AND REGULATIONS

Policy and regulations are a catalyst for enabling these large initiatives that cover multiple stakeholders across different sectors of the economy. While the green shipping corridor at the outset seems like a marine-focused initiative, it has the potential to impact multiple sectors of the economy and hence, a top-down regulatory and policy environment that is supportive is imperative.

Economic policies that help with financial barriers and regulatory policies that reduce non-financial barriers in combination are strong catalysts for solutions that are on the verge of commercial viability. Take the example of the electric vehicle (EV) industry, which has benefited greatly from tax incentives for consumers and tax credits for producers. The IRA, the IIJA, the EU fit for 55 (Maritime Industry Focused Provisions) are useful regulatory and policy support mechanisms, which heavily invest in emissions reduction and sustainable development. These, among others, cover green hydrogen production, port electrification and ocean-going vessel emissions capture while at berth. These policies are examples of how governments can spur the development of green corridors to help benefit society.

Similar to how incentivized policy pulls in new developments, regulation can help push the industry. The IMO's technical and operational regulations regarding CII, EEDI and EEXI are one such example. Through the implementation of these regulations, vessel owners are pushed towards decarbonization. The challenge becomes how to effectively implement alternative fuels on a large scale, which is where green corridor development can help ease the growing pains. Green corridors help owners and operators in reducing the CII (or FuelEU) rating of their vessels. For example, a port that offers full cold ironing facilities, will allow vessels calling into these ports to use shore power (if the vessel has this capability) and thus not operate their auxiliary engines (i.e., no emissions and no onboard fuel consumption). That will give a boost to the vessel's rating under these regulatory frameworks.

2.4.1 INFLATION REDUCTION ACT IN THE CONTEXT OF GREEN SHIPPING CORRIDORS

The IRA focuses on reducing greenhouse gas emissions by one gigaton (Gt) by 2030 which could arguably be the single largest piece of legislation focusing on climate action, giving a major fillip to the clean energy economy. Most of the financial support focuses on developing a green economy which at the outset may seem outside of the purview of a "green corridor", but there are specific programs that could align themselves perfectly with the outcomes one would want from such a corridor.

As indicated in the sections above, for any green corridor to be successful would require each of the foundational elements to be robust and have clear regulatory and funding support. The table below summarizes some of the financing and tax credits that apply directly to the development of these foundational elements.

Program	Description	Amount / Tax Credit	Green Corridor Foundational Element
Clean Ports Investments	Grants to reduce air pollution at ports	**Total = $3,000,000,000** **$2,250,000,000** • To purchase or install zero-emission port equipment or technology for use at or to serve one or more ports • To conduct any relevant planning or permitting in connection with purchase or installation of zero-emission port equipment • Develop qualified climate action plan The term "zero-emission port equipment or technology" means human-operated equipment or human-maintained technology that **(A)** produces zero emissions of any air pollutant that is listed pursuant to section 15 108(a) (or any precursor to such an air pollutant) and any greenhouse gas other than water vapor; or **(B)** captures 100 % of the emissions that are produced by an ocean-going vessel at berth **$750,000,000** • Specifically for ports located in non-attainment areas (Houston) 40% of top 150 ports are located in NAAQS non-attainment or maintenance areas — EPA Ports Initiative	Port Decarbonization Focus- Foundational Element #1: Cross Value Chain Collaboration Foundational Element #2: Fuel Pathway Foundational Element #3: Business/Economic and Logistical Case for a Green Corridor

Program	Description	Amount / Tax Credit	Green Corridor Foundational Element
Greenhouse Gas Reduction Fund	Greenhouse Gas Reduction Fund	**Total = $27,000,000,000** **$7,000,000,000** • Zero-emission technologies to enable low-income, disadvantaged communities to deploy or benefit from zero-emission technologies including distributed technologies on residential rooftops and to carry out other GHG reduction activities **$11,970,000,000** • Purpose of providing financial and technical assistance (General Assistance) to eligible recipients **$8,000,000,000** • Additional amount for low income and disadvantaged communities **Eligible Recipient** The term "eligible recipient" means a nonprofit organization that — **(A)** is designed to provide capital, including by leveraging private capital, and other forms of financial assistance for the rapid deployment of low- and zero-emission products, technologies, and services; **(B)** does not take deposits other than deposits from repayments and other revenue received from financial assistance provided using grant funds under this section. **(C)** is funded by public or charitable contributions; and **(D)** invests in or finances projects alone or in conjunction with other investors	All Aspects of the Green Corridor
Carbon Capture Tax Credit	Extension and Modification of Credit for carbon capture, storage, and sequestration. To qualify, the technology must have a capture design capacity of at least 75%	- $60/ MT for utilized CCCS - $85/ MT for sequestered CCS - $130/ MT for utilized DAC - $180/ MT for sequestered DAC Qualified Facility: Any industrial facility or Direct Air Capture (DAC), construction of which begins before January 1, 2033 i.e., construction begins before such date or original planning and design for such facility includes installation of carbon capture equipment. DAC captures > 1,000 metric tons during the taxable year and for electricity generating facility, capture no less than 18,750 metric tons of qualified carbon oxide during the taxable year with a minimum of 75% design capture capacity. For other facilities, captures no less than 12,500 metric tons of qualified carbon oxide during the taxable year	Foundational Element #2: Fuel Pathway

Program	Description	Amount / Tax Credit	Green Corridor Foundational Element
Biodiesel Tax Credits	Extension of incentives for biodiesel, renewable diesel and alternative fuels. Extension of second-generation biofuel incentives	$1/gallon (Extension until December 31, 2024) The term "qualified biodiesel mixture" means a mixture of biodiesel and diesel fuel (as defined in section 4083(a)(3)), determined without regard to any use of kerosene, which— (i) is sold by the taxpayer producing such mixture to any person for use as a fuel, or (ii) is used as a fuel by the taxpayer producing such mixture.	Foundational Element #2: Fuel Pathway
Industrial Emissions Reduction Investments	Advanced Industrial Facilities Deployment Program	$5,812,000,000 Office of Clean Energy Demonstrations to provide financial assistance to eligible entities to carry out projects for: • Purchase and installation or implementation of advanced industrial technology • Retrofits, upgrades or operational improvements to install or implement advanced industrial technology • Engineering Studies and other work needed	Foundational Element #2: Fuel Pathway
Clean Fuel Production Tax Credit	Clean fuel production credit	$1/gallon In order to receive the full credit, the fuel must have a life-cycle emission level of less than 50 kilograms of CO_2e per mmBTU	Foundational Element #2: Fuel Pathway
Biofuels Investments	Funding for Section 211(O) of the Clean Air Act	**Total: $15,000,000** • $5,000,000 for development and establishment of tests and protocols regarding environmental and public health effects of fuel or fuel additives	Foundational Element #2: Fuel Pathway

Table 6: Inflation Reduction Act's Impact on Green Corridors.

2.4.2 US INFRASTRUCTURE INVESTMENT AND JOBS ACT (IIJA)

On November 15, 2021, the IIJA was passed by U.S. Congress which is a $1.2 trillion bill that touches every sector of infrastructure, from transportation and water to energy. The bill aims to spend $550 billion in new spending above baseline levels. Out of the new spend, nearly 50 percent ($283.8 billion) will be spent on the transportation sector with approximately $17 billion worth of funding available to the domestic maritime sector over the next five years. The IIJA will be a major enabling tool in the green corridor space with numerous financial incentives that align themselves very well with maritime decarbonization. Some of those are listed below. Maritime decarbonization of IIJA when looked at through the angle of green corridors, makes it a very powerful tool. For example, $8 billion has been set aside for development of regional hydrogen hubs and they are perfectly in alignment with needs of the development of an alternative fuel pathway. Irrespective of the type of alternative fuel utilized, it must take the hydrogen or hydrogen-based fuel pathway. Some of the big-ticket provisions of the regulation and how they impact the shipping industry are listed in the following table.

Maritime Decarbonization and IIJA			
Department	**Section of the Act**	**Areas of Interest**	**Funding**
Department of Transportation	Section 11110. Nationally Significant Freight and Highway Projects	Includes project for marine highway corridors	Each grant ≥ \$25M Total of \$10.8B
	Section 11115. Congestion Mitigation and Air Quality Improvement	Includes projects on marine highway corridor, connector or crossing	Up to 10% of CMAQ funds on marine related projects
	Section 11116. Alaska Highway	Allows federal-aid highway funds to be used for the Alaska Marine Highway, including vessels, terminals, docks, floats, ramps, etc.	Allows 100% federal share for projects
	Port Infrastructure Development Program	Wide range of development projects to improve resiliency of ports to address sea-level rise, flooding, extreme weather events, earthquakes and tsunami inundation as well as project that reduce or eliminate port-related criteria pollutant or greenhouse gas emissions	Total of \$2.25B
	Section 71102. Electric or Low-Emitting Ferry Pilot Program	New program to provide grants for purchase of electric or low-emitting ferries and electrification or other emission reductions from existing ferries	Total of \$250M
	Section 11402. Reduction of Truck Emissions at Port Facilities	New program: (1) Study emission reductions in ports, including electrification of ports, (2) Study technologies for reducing truck idling in ports, and (3) Test, evaluate, and deploy projects for reducing emission from idling truck	Total of \$250M
	Federal Highway Administration Highway Infrastructure Program	Possible maritime scope under a Joint Office of Energy and Transportation to study, plan, coordinate, and implement issues of joint concern to the agencies. Amendments added funding to carry out construction of ferry boats and ferry terminal facilities	Large overall funding Total of \$342M for ferry boats and terminals
Department of Energy	Section 40209. Advanced Energy Manufacturing and Recycling Grant Program	Specifically includes funding for electric or fuel cell maritime vessels as well as technologies, components, materials and charging and refueling infrastructure of maritime vessels within the overall scope of the program	Total of \$750M
	Section 40314. Additional Clean Hydrogen Programs	Establishes new Regional Clean Hydrogen Hubs program to support development of at least 4 hydrogen hubs. Ports are well-positioned to serve as hydrogen hubs.	Total of \$8B
	Section 41201. Office of Clean Energy Demonstrations	Provides a new office to issue grants for large demonstration projects, including carbon capture, advanced nuclear reactors, energy storage, Regional Clean Hydrogen Hubs, electric grid reliability, and energy improvements in rural and remote areas	Total of \$21.5B

Table 7: IIJA and Green Corridors.

Future analysis should involve a deeper dive into each of the programs and understanding of how each of the stakeholders can take advantage of these funding opportunities. This will require a lot of effort on the part of the stakeholder group interfacing with the respective agency responsible for the funding. Governmental and regulatory support is one of the most critical aspects of the development of the green corridor and hence, should be front and center of the feasibility study.

2.4.3 CLEAN ENERGY MARINE HUBS AND GREEN CORRIDORS

On September 23rd, 2022, at the Clean Energy Ministerial (CEM), the concept of Clean Energy Marine Hubs (CEMH) was officially announced which is envisaged as a public-private platform between energy, maritime, shipping and finance communities to help further development of clean fuels while de risking the investment. The platform already seems to have growing interest with Panama, Norway, Canada, United Arab Emirates and Uruguay having come out in support. CEMH and Green corridors are complementary concepts and fit like a hand in a glove into the overall framework of shipping value chain decarbonization. CEMH has a specific emphasis on clean fuels with shipping playing the role of transporter and connector of supply to demand. The shipping value chain being diverse and disaggregated, all these initiatives are like different parts of the puzzle where the whole is greater than the sum of its parts. The US Department of Energy (DOE's) regional hydrogen hubs can be considered as a sub-set of Clean Energy Marine Hubs.

In the U.S., numerous hydrogen hub proposals have sprung up after the Department of Energy (DOE) released a notice of intent (NOI) to fund the bipartisan infrastructure law's $8 billion program to develop regional clean hydrogen hubs. These hubs have a natural synergistic relationship with the marine industry as an enabler of the hydrogen value chains. A clean hydrogen hub is defined as a network of clean hydrogen producers, potential clean hydrogen consumers and connective infrastructure located in proximity.

The contiguous maritime domain and operating areas for vessels utilizing hydrogen or hydrogen-derived fuels embody proximity and will form an essential foundational element of a green corridor (i.e., a fuel pathway). The maritime industry stakeholders also include unions representing mariners and port workers, marine industry groups for different sectors of the maritime industry, and regulatory agencies such as the Coast Guard, the Maritime Administration, the Environmental Protection Agency (EPA), the Bureau of Safety and Environmental Enforcement (BSEE) (for offshore connection), and local port authorities. Marine classification societies, ship registries, flag States for international carriers, and insurers are other groups of stakeholders that may need to be involved in specific projects.

Hydrogen hubs that can supply to multiple types of end users have a competitive advantage. For example, hydrogen storage in ports can provide convenient fueling for vessels and port infrastructure, but because of intermodal co-locations of transportation systems, storage at the port can also readily support fueling stations for rail, highway vehicles and even nearby airports. Developing a hub using a green shipping corridor framework can promote the maritime common storage space and transportation regulations as well as standardized infrastructure features (bunkering connections, shore power connections, etc.) for scaling to a national network.
In the maritime domain, key existing facilities and infrastructure can readily support hydrogen hubs, including:

- Current offshore fossil energy production that can incorporate carbon capture
- Current/near-term offshore wind for offshore renewable power to generate green hydrogen
- Subsea pipelines, power cables, operating equipment and geological storage features
- Aging offshore assets to be repurposed for carbon capture and/or renewable energy production offshore
- Port facilities for onshore hydrogen production/storage/use/distribution (including bunkering barges/vessels)
- Harbor/river/waterway infrastructure for supporting movement of hydrogen and hydrogen-derived fuels
- Shipyards and waterfront manufacturing facilities can support construction/deployment of clean energy technology in the maritime domain

The green shipping corridor framework is fundamental to the hydrogen hub maritime aspect due to its commodity-flow focus and vital contribution to the Justice 40 government initiative (environmental justice benefits) for local disadvantaged communities. Hydrogen hubs can use the green shipping corridor framework to establish baseline emission levels for all targeted activities and forecast net emission reductions associated with those activities from fully implementing the hydrogen hub's well-to-wake (WTW) life cycle. The below figure provides a conceptual map of how hydrogen hubs could be connected to green corridors.

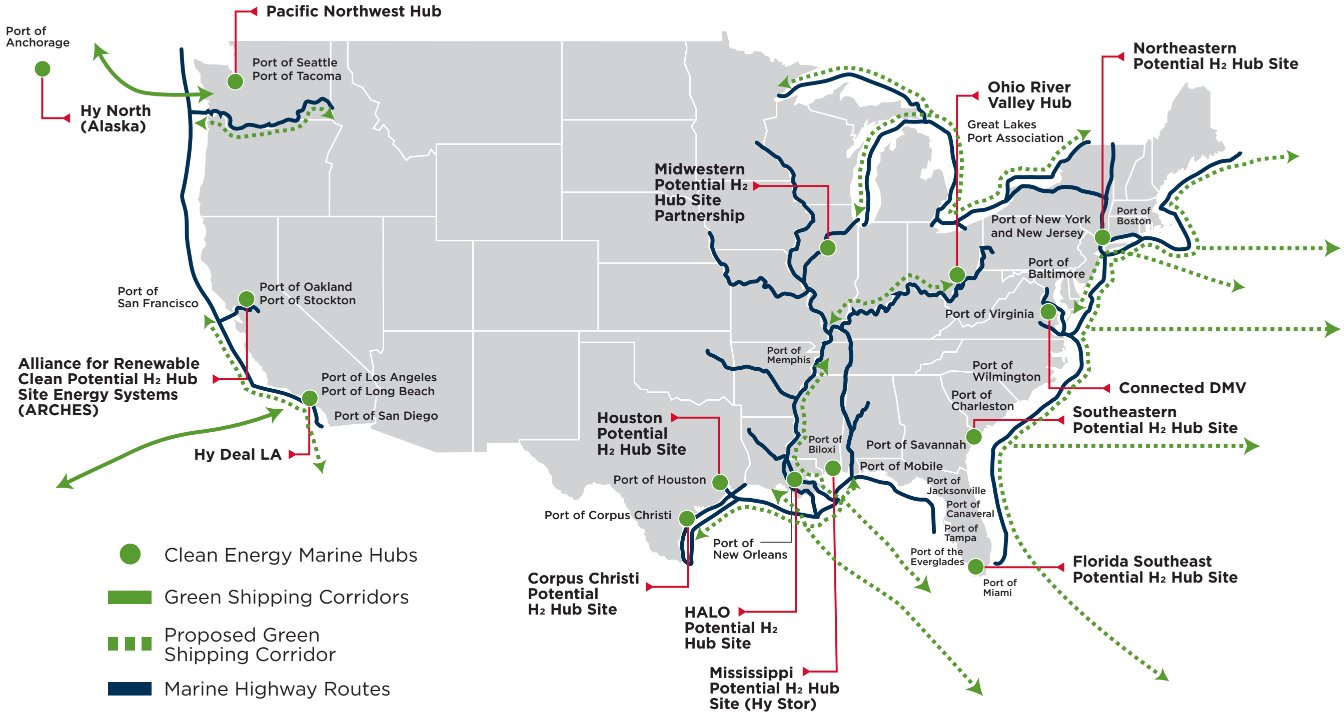


Figure 13: Connecting Hydrogen Hubs to Green Corridors.

2.4.4 EU-FIT FOR 55 MARITIME INDUSTRY PROVISIONS

The number 55 represents a 55 percent emissions reduction target which the EU wants to achieve by 2030 compared to 1990 which is an increase from 40 percent which was the initial target. Some of the provisions directly impact the maritime sector particularly the revisions to the EU ETS trading system which is expected to extend to shipping. Under this scheme, a certain cap is set for a company, so that if it is exceeded, the company would need to buy allowances which can be traded as needed. This would provide a push for shipping stakeholders to reduce their carbon footprint or risk getting fined up to 100 euro per tonne of unaccounted CO_2.

Additionally, the Fuel EU maritime program for a green European maritime space from 2025, will require commercial vessels of 5,000 gross tonnes and above and calling on European ports to source and operate on less carbon intensive fuels (alternative fuels) and from January 2030, it will also impose onshore power supply for all energy needs while at berth, for some ships. The Energy Taxation Directive (ETD) will remove all outdate exemptions and incentives for the use of fossil fuel, making fossil fuels more expensive. The alternative fuel infrastructure regulation will also require EU member states to step up the availability of LNG and ensure onshore electrical power supply by 2030 in core EU ports. It is apparent that each of these requirements align with the core foundational elements of a green corridor and will force many of the stakeholders to actively participate in it.

3.0 EMISSIONS SCOPE, BOUNDARIES AND METRICS

A very important aspect in the development and continuous successful operation of a green corridor is the need for a palette of metrics to be in place so that there is quantification of the decarbonization effect of the initiative. The emissions scope, boundary and metrics will vary based on the jurisdiction of each of these corridors and the level of ambition they aim to achieve.

3.1 LIFE-CYCLE EMISSIONS ESTIMATION

Fundamentally, a green corridor's success is a function of its greenhouse gas (GHG) emissions reduction potential and for that to be a controlling metric, the calculations need to be robust and should follow commonly accepted standards such as ISO 14064-1, GHG protocol requirements and other maritime industry specific methodologies. To further improve confidence in the estimation, they may need to be assured or certified by independent third parties.

To improve the robustness of maritime emissions estimations, life-cycle analysis (LCA), which is the estimation from well-to-tank (WTT) and tank-to-wake (TTW) of the fuel related emissions, is the commonly accepted norm for estimating the impact of each value chain stakeholder of the corridor. Each of the value chain stakeholders should clearly demarcate their boundary and consistently calculate their baseline emissions. The baseline emissions profile should be an indication of the current operations prior to conversion to a green corridor. For example, what is the emissions estimate currently without the aspects of the green corridor considered, including both a current day snapshot and a future forecast. At a high level, the maritime emissions inventory will include the following:

Ship Operator/Owner/Fuel Producer

Total Emissions = Ship Emissions (TTW), Fuel Production (WTT), Weather Conditions

1. Ship Emissions (TTW)
    - Vessel Fuel Consumption – Ship Emission Factors, Routes and Operational Conditions (AIS calls), Weather (Sea State, Resistance), Engine Power, Engine Load, Fuel Consumption
2. Fuel Production (WTT) – Upstream (Oil and Gas Plants), Downstream (Refineries, Liquefaction Plant)
    - Upstream and Downstream Oil and Gas – Emission Factors, Fuel Demand, Fuel Production, Venting and Flaring, Facility Emissions

3.2 SHIPYARD EMISSIONS

LCA methods have been applied to shipping since the 1990s and have demonstrated that they can be utilized effectively to estimate a ship's life-cycle emissions. Numerous LCA software have been developed to assess the impacts of the ships including those developed by the Norwegian University of Science and Technology and the National Maritime Research Institute of Japan. Additionally, a Swedish consortium of maritime organizations has developed an LCA tool for the energy efficiency of ships. The usual life span of an ocean-going ship is 20 to 25 years from cradle to grave and during that timespan, the emerging technology and market developments could modify the footprint of the ship.

Shipbuilding emissions may not apply to all green corridors but will be a very useful metric to consider when converting existing traditional routes to green ones, since many of these projects will require newbuilds and retrofitting of existing vessels. Ship building emissions can be divided into hull (material and protection) and machinery (main and auxiliary) impacts and play a major role in understanding the emissions over the entire life cycle of a green corridor. For example, there may be cases where retrofitting may be the best option possible from a GHG emissions perspective but since these emissions are front loaded, the impact could be divided over a large period. Taking shipyard emissions into consideration may also drive stakeholders to investigate sustainable forms of materials such as recycled and green steel which will further improve the sustainability performance of the corridor. Shipbuilding emissions can be divided into the following specific operations.

a) Hull emissions

  i) Hull material
    - Ship building – Steel production, cutting, blasting, material transport
    - Maintenance – Steel production, cutting blasting, material transport
    - Dismantling – Steel dismantling
    - Operations – No emissions during hull material construction

ii) Hull protection
- Ship building – Coatings, anodes, material transport
- Maintenance – Coatings, anodes, material transport
- Dismantling – No emissions
- Operations – No emissions

b) Machinery emissions

i) Main engine and auxiliary engine
- Shipbuilding – Construction, shop tests, trials
- Operations – Fuel consumption (This will be covered under the tank-to wake emissions of the ship when operating, but not emissions while completing test runs)
- Maintenance – Main spares
- Dismantling – Steel recycled and re-used

The framework above will provide the following pieces of data on a per ship basis:
- Emissions – This framework could be utilized for all emissions, but the focus of the exercise from a green corridor should be on the CO_2 equivalent emissions
- Air emissions results per life-cycle stage
- Air emissions per ship system element, per sub system, total
- Comparisons between different operational ship profiles
- Examination of different operational scenarios

The results from the framework will be a powerful piece of the decision-making process with comparative analysis of various ships and their operational and shipbuilding emissions. For example, when comparing the baseline emissions to the new "green corridor" emissions, the use of alternative fuels, the greening activities on the port side that have been completed will clearly quantify the impact of the corridor.

3.3 BASELINE EMISSIONS INVENTORY FOR PORT AND VESSEL OPERATIONS

Port emissions inventory will be a major component of the GHG footprint of any port-centric corridor since, fundamentally, the decarbonization will revolve around vessels and port decarbonization which will include electrification of shore-side infrastructure and development of cold ironing facilities to reduce vessel emissions while waiting at the port. Port emissions are typically from mobile sources and then can be divided into the following categories:

1) Ocean-going vessels when berthed in the port
   a) While located in the port, the auxiliary engine is still operating, and the option of cold ironing are not available in every port.
   b) As part of decarbonization initiatives, the port can consider developing cold ironing facilities which will be a part of the green corridor investments.
2) Harbor craft
   a) Harbor crafts typically operate very close to the port and are integral to its operations and hence, will be considered as part of the emissions inventory.
   b) Harbor craft applications are fit candidates for electrification and will help reduce the footprint of the port.
3) Cargo handling of the equipment
   a) Cargo handling equipment includes equipment such as yard tractors and cranes which are used for moving cargo and supplies around a port. These are non-road equipment and since they fall under the non-marine sector sources, it may require a closer study of the equipment manufacturing sector emissions factors. They are a prime candidate for electrification.

4) On-road Vehicles

   a) Typically, on-road vehicles are comprised of heavy-duty diesel trucks, cars, light-duty trucks and buses. Vehicles could be either electrified or converted to hydrogen fuel cell powered vehicles and could be amongst the low-hanging fruits that every port should consider.

5) Rail

   a) There are typically two types of locomotives that support port-related cargo operations, switcher locomotives, which are smaller capacity engines, that are used inside the boundary of the port and line-haul locomotives, that travel long distance, which will fall outside the boundary of the port. The yard engines or switcher locomotives could be electrified considering the lower hauling capacity required in comparison to the long-distance line-haul locomotives.

Ports are such a critical stakeholder in the development of a green corridor, they can take lead utilizing governmental incentives to decarbonize and signal intent which will help build momentum towards decarbonization of the shipping industry. Currently, U.S. EPA, Environment and Climate Change Canada and other private non-governmental research organizations provide detailed methodologies and guidance on conducting a port inventory. The challenge is that there is very little overlap on methodologies, scope and boundaries, requiring clarification before inventory development since all the ports need to have a commonly accepted baseline inventory with similar assumptions.

3.4 INDEPENDENT VERIFICATION

Since the green corridor's fundamental goal is to achieve carbon emissions reduction, it is important that the methodologies, emission factors, activity data and calculations are certified by an independent third party with a detailed audit trail. There are numerous organizations that certify carbon avoidance and emissions reductions to maintain the environmental integrity of the project.

This will also allow project stakeholders to obtain robust reduction and voluntary carbon credits which could play an important role as a revenue stream and push many of the economically unviable projects into the green. Some of the carbon certification programs such as Gold Standard and Verra can help generate verifiable and tradeable GHG credits. There could be jurisdictions where compliance may require independent verification to obtain governmental support and it is advisable to keep the carbon emissions calculations and sustainability as the fundamental focus which is the driving variable of these initiatives.

Additionally, considering the wide swath of impact a green corridor could have on the surrounding communities, other sustainable development goals (SDGs) could also be included in the certification process making the project more attractive for sustainable financing options. Any green corridor project at a minimum could help achieving the following SDGs, SDG-7 (Affordable and Clean Energy), SDG 13 (Climate Action), SDG-8 (Decent Work and Economic Growth) and SDG-9 (Industry, Innovation and Infrastructure).

The assessment will include calculations of baseline GHG emissions or baseline GHG removals by sinks followed by calculations of project GHG emissions and actual net GHG removal by sinks. The process also takes into consideration leakage to arrive at an actual GHG emissions reduction or net GHG removal value.

4.0 ANNOUNCED GREEN CORRIDORS

Numerous green corridors have been announced recently and some of them are listed below and are also indicated in the map below. None of the corridors are currently in operations but announcements have been made and, in some cases, feasibility assessments have begun which indicates movement in the right direction. Some of the announced corridors and their status is listed in the table below and the figure below shows the locations.

Route	Comments
Montreal to Antwerp	November 2021 — A memorandum of understanding (MOU) was signed with Green Field Biofuels being one of the known participants with the Port of Montreal and Port of Antwerp. Liquid bulk is the main focus.
Los Angeles to Shanghai	January 2022 — Signed Partnership with Maersk, CMA, CGM, COSCO, Shanghai International Ports Group (SIPG), coZEV (cargo owners zero emission vehicles initiative), Maritime Tech Coop. (Asia).
Chile	April 2022 — Chile Ministry of Energy and Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping plan to establish a government funded Chilean Green Corridor Network.
St. Lawrence waterway	April 2022 — Focused on bulk (ore, grain, cement etc.) with members of the Canadian chamber of Marine Commerce (CMC) evaluating the potential for a green shipping corridor with collaboration from government and research and development. CMC represents 100 clients including shippers, ports etc. and including transport Desgagné's, CLS Algoma central, Transport Canada.
Port Hedland (Australia to Japan)	April 2022 — Focused on iron ore and includes BHP, Rio Tinto, Oldendorff Carriers and Star Bulk Carriers. The consortium Global Maritime Forum (incl. Rio Tinto et al.) inked a letter of intent (LOI) between miners (charterers) and owners to evaluate fuels and routes.
Ports Gdynia, Hamburg, Roenne, Tallinn and Rotterdam	March 2022 — Five European ports joined to form the European Green Corridor Network for Northern Europe and the Baltic region with the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping acting as a partner.
Port Halifax and Port of Hamburg	September 2022 — An MOU was signed between the Halifax Port Authority and the Hamburg Port authority to setup a green corridor with a focus on bunkering infrastructure and development of a green hydrogen pathway between the two ports and countries (Canada and Germany).
Pacific Northwest - Alaska Green Corridor	May 2022 — Ports of Seattle, Vancouver and Juneau with three major cruise corporations and cruise industry trade associations supported by three maritime forums have announced their effort to explore the feasibility of the world's first cruise-led green corridor.
BlueSky Maritime Coalition Gulf of Mexico (GOM)	The Gulf of Mexico and Lower Mississippi River Corridor is yet to be announced formally, but it is one of the initiatives that is being considered by the Blue-Sky Maritime Coalition (BSMC), which is a not-for-profit organization of members of which ABS is a founding member.

Table 8: List of Announced Green Corridors.

Figure 14: Map of Currently Announced Green Corridors.

5.0 CONCLUSION

This publication aimed to provide a high-level overview of the concept of the green corridors starting with the different frameworks, foundational elements which included cross value chain collaboration, fuel availability, port readiness, regulatory and policy support followed by a few specifics on the quantification aspect of emissions. Below are the key conclusions on the status of the concept and future trajectory.

- Numerous green corridors have been announced particularly between Clydebank signatories which indicates seriousness and follow-up action post COP26.
- Some green corridors have made progress towards a feasibility assessment but none of them have come forward with detailed plans or metrics on how these green corridors will come to fruition which indicates either slow movement or signals the magnitude of the task at hand.
- Green corridors being an all-encompassing idea which covers most aspects of the shipping value chain will require a detailed framework along with a tremendous amount of coordination amongst the stakeholders to get this off the ground.
- The U.S. Department of State (DOS) has provided high-level guidance on green shipping corridors and the current administration has promulgated several climate related laws that have created a supportive regulatory and policy framework which the shipping industry could take advantage of over the next decade. This is the decade of action, and the time is now to make rapid strides towards establishing decarbonization initiatives in the shipping industry.
- Formation of a green corridor is a techno-regulatory-commercial undertaking and will require comprehensive expertise. Forming a consortium based on a pre-feasibility assessment followed by a top-down approach analyzing each part of the value chain and their individual criteria will help to make decisions based on solid quantitative backing.
- From a fuels perspective, LNG, ammonia, hydrogen and methanol seem to be the front runners, from a decarbonization perspective and from a technology standpoint, battery powered, and fuel cell vessels could play a role at least for short-range applications. Onboard carbon capture will be a useful technology to help bridge the gap between traditional fuels and alternative fuels. Nuclear vessels are a possibility but the public relations issues may prevent usage despite being technologically sound and proven.
- According to ABS' future fuel mix forecast, alternative fuels will take off post-2030 which means construction of those vessels should start in the next two to three years and even in 2050, there will be enough vessels which will still operate with traditional fuels. When vessels with alternative fuels begin operating, they will find a natural home in the announced green corridors assisting with viable operations despite the higher expected fuel costs.
- Green shipping corridors are a nascent conceptual idea which will need to be tested in the physical world. If there is an industry that can make this work, it is the shipping industry with its rich history of cooperating with numerous stakeholders in a supply chain. Cooperation and collaboration are at the bedrock of any green shipping corridor.

6.0 ABS SUPPORT

Leveraging decades of maritime experience, ABS can provide technical and advisory support to government agencies and industry stakeholders on policy, regulatory analysis, grant evaluations, project oversight and industry outreach/technology transfer. ABS can also provide sustainability services for all green corridor stakeholders which is important in the pre-feasibility, feasibility and execution phase of the project. Areas of support include:

ENERGY TRANSITION AND DECARBONIZATION

- Clean Energy in the Maritime Domain
- Offshore Wind (DOE Loan Program Office, NOWRDC, etc.)
- Marine Energy (DOE Teamer Facility)
- Advanced Nuclear Technology (DOE R&D Grant with INL)

DECARBONIZATION OF THE MARITIME DOMAIN

- Energy Efficiency, Electrification, and Alternative Fuels Guides and Advisory Services for Maritime Operations (Commercial/Government Vessels & Associated Port/Shore Facilities)
- Carbon Capture, Utilization, and Storage Applications in the Maritime Domain (Shipboard and Offshore)
- New Technology Qualification (NTQ) and approval in principles (AIP) for Novel Applications
- Sustainability and ESG Management

REGIONAL CLEAN ENERGY COALITION & INNOVATIVE RESEARCH

- Hydrogen and Carbon Capture Hubs
- Green Shipping Corridors
- Applied Research Projects with Research Partners (Academic, Small Business, NGOs, etc.)

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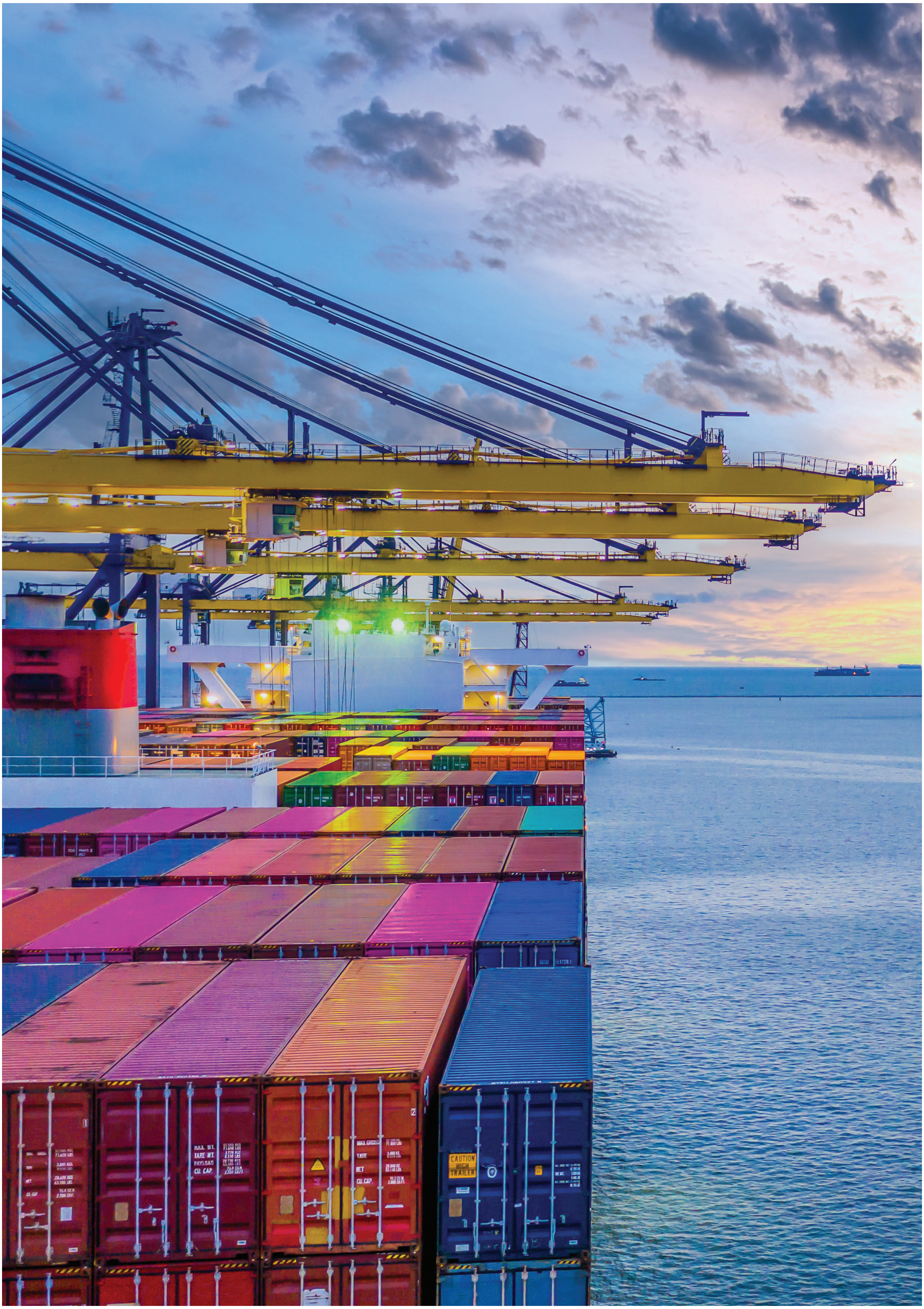
LIST OF ACRONYMS AND ABBREVIATIONS

ABS	American Bureau of Shipping
ANSI	American National Standards Institute
CAPEX	Capital Expenditures
CCS	Carbon Capture and Storage
CCS-SSGF	Carbon Capture and Sequestration in Sub Sea Geological Formations
CCUS	Carbon Capture, Utilization and Storage
CDR	Carbon Dioxide Removal
CFR	Code of Federal Regulations
CH_3OH	Methanol
CII	Carbon Intensity Index
CO_2	Carbon Dioxide
DAC	Direct Air Capture
DOE	Department of Energy
ECBM	Enhanced Coal Bed Methane
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency
ETS	Emission Trading Scheme
EU	European Union
GHG	Greenhouse Gas
H_2	Hydrogen
H_2O	Dihydrogen monoxide (water)
H_2S	Hydrogen Sulfide
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act
IMO	International Maritime Organization
IOGP	International Association of Oil & Gas Producers
IPCC	Intergovernmental Panel on Climate Change
IQR	Inter Quartile Range
IRA	Inflation Reduction Act
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
LNG	Liquefied Natural Gas
LP/LC	London Protocol and London Convention
LPG	Liquefied Petroleum Gas
MARAD	United States Maritime Administration
Mt	Megatonnes
MTBE	Methyl Tert Butyl Ether
NH_3	Ammonia
OPEX	Operational Expenditures
PC	Port Calls
SCC	Standards Council of Canada
SOx	Sulfur Oxides
TAME	tert-amyl ether
TTW	Tank to Wake
UN	United Nation
UNFCCC	United Nations Framework Convention on Climate Change
WTT	Well to Tank
WTW	Well to Wake



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