Port of Vancouver E-Methanol Study

Discussion Paper
Prepared by Oceans North and Arup

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1. Introduction

Oceans North is a non-profit organization supporting climate action and marine conservation. From small craft harbours to big-city ports, Oceans North is working to decarbonize the marine industry by helping create zero-emission vessels, develop green shipping corridors, and advance port electrification and shore power implementation. As part of this work, Oceans North is supporting efforts to create a made-in-Canada zero-emission marine fuel supply chain.

As a signatory to the Clydebank Declaration, Canada has committed to developing green shipping corridors: low or zero-emission trade routes linking ports with access to clean fuels and shoreside infrastructure. Moving quickly on these projects is vital to enhancing the country's climate competitiveness as other jurisdictions advance policy frameworks and technologies that will change the marine transportation sector. The market for low-carbon shipping fuel, for example, is expected to grow to more than 500 million tonnes by 2040, with an estimated market value of 4.3 trillion USD[1]. Canada is well positioned to help lead this transition, but it will require significant forethought and investment.

At the Port of Vancouver, the country's largest port, there are already two green shipping corridors in development: the Pacific Northwest to Alaska Green Corridor, which is focused on the cruise industry, and the North Pacific Green Corridor Consortium, which is addressing bulk commodity shipping. However, the specifics of which fuels and technologies will enable decarbonization of these corridors have yet to be decided.

Oceans North partnered with Arup, a global engineering consultancy with expertise in infrastructure, energy, and sustainability, to advance a conceptual development plan for a large-scale e-methanol production plant to fuel bulk carriers and cruise ships calling at the Port of Vancouver. Several major ship lines and maritime analysts have identified e-methanol as a critical energy source for decarbonizing ocean-based trade and transportation, citing its potential to deliver deep well-to-wake emissions reductions compared to Heavy Fuel Oil (HFO).

The goal of the study was to bring the idea of e-methanol from a general possibility to a more specific technical understanding. What demand could a plant sustain at the Port of Vancouver? What inputs would be required to produce the e-methanol? And what would be the potential costs, opportunities, and associated risks?

The study began by identifying initial e-fuel demand for the cruise and bulk carrier vessels calling at the Port of Vancouver, and then explored the opportunities, risks and constraints of a large-scale e-methanol production plant, with goal of enabling further discussion regarding a Canadian e-methanol supply chain.

The e-methanol production facility conceptualized in the study would help move green shipping corridors from the realm of discussion to reality by using electrolysis-produced green hydrogen (H_2) and Direct Air Capture (DAC), with a total output of 200,000 tonnes per annum (tpa) by 2040.

1. Global Maritime Forum, Decarbonisation of shipping could create up to four million green jobs, 9 May 2024 https://globalmaritimeforum.org/press/decarbonisation-of-shipping-could-create-up-to-four-million-green-jobs

While the project has the potential to displace approximately 11.5 million tonnes of carbon emissions across its lifetime and would represent a major step forward green shipping corridor development on the West Coast, there are some significant risks that must be carefully considered and managed with regard to allocations of electricity, fresh water, and land. In addition, the business case for the plant also needs to be addressed based on the relatively high cost of the fuel.

E-Methanol Production Facility at a Glance

- Annual production of 200,000 tonnes by 2040
- Displaces 11.5 million tonnes of carbon emissions across facility lifetime
- Reduces well-to-wake emissions by 90% to 100% compared to Heavy Fuel Oils
- Requires significant allocations and permitting for electricity, fresh water, and land.

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2. Context

Canadian ports play a significant role in the country's economic prosperity. As Canada seeks to diversify trade and grow the economy, these same ports will need to decouple growth in trade and tourism from growth in carbon emissions and air pollutants to be climate competitive. Globally, the shipping sector is transitioning to zero- and near-zero-emission fuels, driven by regional and international regulatory frameworks to achieve net-zero shipping emissions by or around 2050.

In addition to the economic benefits, the transition to net-zero is important for the health of the climate, oceans, and communities. Shipping represents about 3 percent of global emissions—more than the aviation sector, and equivalent to those of a large, industrialized country. Reducing these emissions will help mitigate the worst impacts of climate change and improve local air quality in coastal communities.

Key to this transition are green shipping corridors: specific maritime routes where ports, shipping companies, and other value chain partners collaborate to accelerate the development, testing, and adoption of scalable zero- and near-zero-GHG fuel technologies. Canadian ports are active participants in the development of at least five green shipping corridors across the country.

In 2022, the Ports of Vancouver and Victoria, along with the ports of Seattle, Juneau, Sitka, Skagway as well as leading cruise lines operating in the Pacific Northwest, launched the Pacific Northwest to Alaska Green Corridor. This was the world's first green corridor initiative focused on cruise ships, aiming to advance net-zero cruises between Washington State, British Columbia, and Alaska.

In 2024, the Port of Vancouver and the Port of Prince Rupert joined global industry leaders from North America, Asia, and Europe to announce the formation of the North Pacific Green Corridor Consortium (NPGCC). Its members and partners are working to decarbonize the value chain for commodities traded between North America and Asia, including agricultural products, metal concentrates, and steelmaking coal.

The central challenge in both green corridor projects is the same: how to build the supply and demand for scalable zero- and near-zero-GHG fuel technologies from the ground up. This report is intended to inform and complement the work of these corridors. The case studies we present use best available technology and scenerios for planning demand and supply.

E-methanol has been identified as a viable alternative fuel source for decarbonizing large ocean-going vessels at scale. Compared to conventional HFO, e-methanol has the potential to reduce emissions by 90-100%, offering significant environmental benefits needed to decarbonize shipping by 2050. The fuel has the potential to produce net-negative emissions reductions due to the use of capture carbon dioxide (CO_2) as a feedstock. E-methanol produced from renewable H_2 (via electrolysis) and (CO_2) from DAC are also compatible with international fuel standards such as the EU's Renewable Energy Directive (RED) Renewable Fuels of Non-Biological Origin (RFNBO) rules as well as the International Maritime Organization's (IMO) 2050 Net-Zero emissions goal.

Uptake of methanol in the sector is already gaining momentum. A recent report from the Global Maritime Forum[2] indicates that there are around 60 methanol-capable ships are on the water, more than 300 further ships on order, and 20 ports offering green methanol bunkering.

2. Getting to Zero Coalition, From pilots to practice: Methanol and ammonia as shipping fuels, August 2025 https://downloads.ctfassets.net/gk3lrimlph5v/42oVCMYa8EuGXsvd46hlH6/e7a183fa7adb94749676607ad72a2a8c/Getting_to_Zero_Coalition-From_pilots_to_practice__Methanol_and_ammonia_as_shipping_fuels.pdf

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3. Demand

For this conceptualization, Oceans North and Arup worked to determine a baseline fuel demand for the most frequently calling vessels to the port, with a focus on the vessel segments involved in the proposed green corridors. Looking at bulk and cruise-ship fuel consumption and demand, we developed two utilization scenarios: the first focuses on providing e-methanol for bulkers, with cruise vessels providing secondary demand; the second focuses on cruise ship demand, with bulkers providing secondary demand.

Demand scenarios include both cruise and bulker to illustrate how a blended demand model could address the seasonality of cruise demand and storage requirements, which will be discussed later in the report. The scenarios also envisage a phased approach to meeting this demand (discussed further in the Supply section) in order to maximize flexibility and the potential for adaptation as the project scales up.

Both scenarios highlight the sheer magnitude of e-methanol consumption required as vessels transition to zero-emission fuels, as well as the flexibility of offtake options for e-methanol.

3.1 Fuel Consumption and Demand Analysis

Each year, the Port of Vancouver welcomes more than 750 bulk carriers serving the potash, coal and grain trade. Another 300-plus cruise vessels call over the annual summer cruise season.

For this report, vessel energy demand was determined based on the estimated fuel consumption of representative bulk and cruise vessels that would typically be utilized along the proposed Vancouver-to-Alaska green cruise corridor and the bulk commodity green shipping corridor linking Vancouver to Asia.

For bulk carriers, panamax-size vessels were chosen to represent potential e-methanol demand from the North Pacific Green Corridor. Annual fuel consumption was calculated on the assumption that vessels spend 25% of the year at berth and 75% at sea. A typical voyage consumption is based on a round-trip to China (total sailing distance of 10,000 nm at 12 knots) with five days at berth at each end.

For cruise ships, a cruise vessel of approximately 80,000 gross tonnes was selected to represent potential e-methanol demand for the Alaska cruise route. Fuel consumption was calculated for a six-month Alaskan cruise season, assuming that vessels spend 50% of the voyage at berth or anchor and 50% at sea. A typical voyage consumption is based on a seven-day itinerary with the same split of berth/anchor and sea time.

The quantity of methanol consumed by each vessel was estimated based on the relative energy densities of HFO and methanol. These are taken to be:

- HFO Lower Calorific Value: 40,200 kJ/kg
- Methanol Lower Calorific Value: 19,900 kJ/kg

Therefore, one tonne of HFOe is approximately equivalent to 2.02 tonnes of methanol. No differences in engine efficiency have been considered.

A Panamax ship transporting cargo from the Port of Vancouver to China could make up to eight voyages a year. Over the year, it would burn approximately 6,000 tonnes of HFOe.

An 80,000GT cruise ship serving the Alaska cruise market may make 20 calls at the Port of Vancouver over a 6-month summer season. Over this period, it would burn approximately 17,500 tonnes of HFOe.

The equivalent demand metrics in terms of methanol are:

- Typical consumption of one Panamax bulk carrier over a full year: ~12,000 tonnes of methanol.
- Typical consumption of one cruise ship over a six-month cruise season: ~36,000 tonnes of methanol.

Fuel consumption estimates based on IMO 4th GHG study			
Ship Type		Bulk carrier - Panamax	Cruise
		60000-99999 DWT	60000-99999 GT
Assumed op profile (from PoV)	**% at berth**	25%	50%
	% at sea	75%	50%
Annual fuel consumption	**t-HFOe**	6000	
	t-Meth.	12000	
6 month fuel consumption	**t-HFOe**		18000
	t-Meth.		36000
Single voyage fuel consumption	**t-HFOe**	800	1400
	t-Meth.	1500	2700

Estimated fuel consumptions for representative vessels

3.2 Demand Utilization

It is assumed that the most frequently calling vessels at the port make good candidates for long-term off-take agreements and are most likely to both fuel at the port and consider the transition to alternative marine fuels. Analysis of port call data at the Port of Vancouver identifies eight bulk carriers that make more than 4 calls each and two cruise ships making more than 22 calls in 2023 and 2019 respectively.

A demonstration of representative vessel fuel consumption illustrates the potential demand for e-methanol at the port each year. Building fuel supply for both bulk and cruise corridors simultaneously would create economies of scale and offset the seasonality of the cruise sector, which typically runs from spring to fall in the Pacific Northwest, thereby limiting the need to stockpile fuel during winter months.

Scenario One – Prioritizing Bulk Carriers

The first scenario focuses on fuel demand for Panamax bulk carriers, with cruise ship fuel consumption considered as a secondary demand. The total annual demand at the completion of the plant would be approximately 217,000 tpa. This would provide sufficient e-methanol for 10 Panamax vessels and seasonal demand for two cruise ships.

Phase	Methanol production (tpa)	Approximate equivalent demand
1	50,000	Annual demand of 4 panamax
2	100,000	Annual demand of 6 panamax and seasonal demand of 1 cruise ship
3	150,000	Annual demand of 8 panamax and seasonal demand of 1 cruise ship
4	200,000	Annual demand of 10 panamax and seasonal demand of 2 cruise ship

Example presentation of demand metric scenario #1

Scenario Two – Prioritizing Cruise Ships

The second scenario focuses on fuel demand for cruise ships, with bulker fuel consumption considered as a secondary demand. The total annual demand at the completion of the plant would be approximately 192,000 tpa. This would provide sufficient e-methanol for two regularly calling cruise vessels and six Panamax vessels.

Phase	Methanol production (tpa)	Approximate equivalent demand
1	50,000	Seasonal demand of 1 cruise ship and annual demand of 1 panamax
2	100,000	Seasonal demand 2 cruise ships and annual demand of 2 panamax
3	150,000	Seasonal demand of 2 cruise ships and annual demand of 4 panamax
4	200,000	Seasonal demand of 2 cruise ships and annual demand of 6 panamax

Example presentation of demand metric scenario #2

3.3 Key Considerations

As the low-carbon fuel market develops, there are early-stage risks and uncertainties to consider. Demand risks include phasing with supply development, regulatory uncertainty, the timeline to replace or convert vessels, competition with other low-carbon fuels, and the overall cost of e-methanol, which is estimated to be up to eight times more expensive than HFOs at the early stages of commercial deployment.

The commercialization of methanol-compatible engines for most large vessel types including cruise and bulk carriers can provide some flexibility in fuel uptake timing, allowing ship owners to order new ships in advance of supply development.

Compared to other scalable fuels with very low GHG emissions, such as e-ammonia, e-methanol is safer and easier to handle, with higher compatibility with existing vessel and shoreside infrastructure.

Long-term offtake agreements between fuel producers and shippers, as well as national programs that help reduce the cost differential between HFOs and e-fuels, are critical to unlocking private-sector investment in e-methanol production.

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4. Supply

This report conceptualizes the development of an e-methanol production facility capable of producing 200,000 tpa. The facility would be constructed in four phases, with each phase producing 50,000 tonnes.

The e-methanol production facility would utilize low-carbon grid electricity, electrolysis-produced H_2, and CO_2 produced by DAC. The e-methanol production pathway considered in this report has potential to produce fuel with a carbon intensity of less than 10g CO_2-eq. / MJ, representing an almost 90% reduction compared to HFO. The ultra-low-carbon fuel is compatible with existing clean-fuel standards for shipping and would be eligible for incentives under regulations such as FuelEU and the IMO Net-Zero Framework currently under development.

While DAC (described in more detail below) is a less mature, higher-cost technology, DAC-produced e-methanol was favoured because of its low carbon intensity, increased flexibility and reliability it enables for the plant with regard to carbon supply, as well as the opportunity it presents to advance leading DAC technology being developed in British Columbia.

4.1 Plant Sizing

The facility's 200,000 tpa production capability considers a base-level e-methanol demand for the cruise and bulk corridors and aligns with what is technologically feasible and scalable, based on an assessment of e-methanol plants in operation and/or under development worldwide.

The plant would be built in four phases of 50,000 tpa, producing enough e-fuel to meet initial demand and allow production to scale with demand growth. The phased approach provides flexibility to be accelerated based on offtake demand. If sufficient demand exists at the start of development, the full-sized facility can be constructed immediately.

The 50,000 tpa phases align with the global development of e-methanol facilities and will allow for knowledge sharing from other operations and technological maturity. The sizing of this facility also takes into account existing operational and nearly operational e-methanol facilities worldwide.

According to the Methanol Institute, as of 2025, six e-methanol plants are operational globally, with production varying significantly. The largest facility currently produces 42,000 tpa. Three more plants are under construction, with dozens of additional plants in the feasibility stages, primarily located in Asia and Europe.

None of these plants, whether operational or under construction, are located in Canada. Several facilities are being explored in the United States, all of which are currently in the feasibility stage. A phased approach on Canada's West Coast enables the development team to learn during each phase, improving subsequent stages and positioning Canada as a major supplier of low-carbon shipping fuel. Being a first-of-a-kind (FOAK) plant in Canada adds risk to technology development and creates higher up-front capital costs.

Phase 1 is expected to begin operation after six years of development, which is longer than subsequent phases, and will include upfront engineering design. The following phases are anticipated to be implemented at three-year intervals. The entire facility would be fully operational 15 years from the start of development and nine years after commercial operations commence. This timeline enables technological learning and aligns production with vessel conversions across both the cruise and bulk industries.

Green Methanol Production Pathways

Methanol production requires a source of H_2 and carbon, typically in the form of carbon monoxide (CO) or CO_2. Traditionally, these feedstocks are sourced from fossil fuels such as natural gas and coal, and their production is emissions intensive.

Low-carbon or "green" methanol production pathways include bio-methanol, bio-e-methanol, and e-methanol. Each of these pathways has low carbon intensity when produced using renewable electricity, but differ in how the H_2 and carbon feedstocks are produced. DAC-e-methanol has the lowest carbon intensity, followed by bio-e-methanol and then bio-methanol.

- Bio-methanol uses H_2 and carbon feedstocks produced from biomass processing
- Bio-e-methanol uses the same biomass processing and adds green H_2 produced via water electrolysis to increase process efficiency
- E-methanol uses green H_2 produced via water electrolysis and CO_2 captured directly from the air or from industrial processes

While bio-based methanol production pathways are more commercially efficient due to the greater maturity of the carbon feedstock gasification technologies involved, bio-based methanol production is limited by biomass availability and proximity to the production site, which can result in additional complexity and emissions associated with harvesting and transporting this feedstock.

4.2 Direct Air Capture E-Methanol Production

The three core components of the conceptual e-methanol production facility are green H_2 production through water electrolysis, CO_2 capture via DAC, and methanol synthesis.

Green H_2 Production

Green H_2 is created through water electrolysis powered by renewable energy sources. Electrolysis uses electricity to split water into O_2 and H_2, releasing the O_2 into the atmosphere and using the H_2 as feedstock for methanol synthesis.

The production facility conceptualized in this study assumes the use of alkaline electrolyzers with freshwater as the water source. Alkaline electrolysis has slightly lower efficiency than other electrolyzer types, but it is the most mature and inexpensive technology.

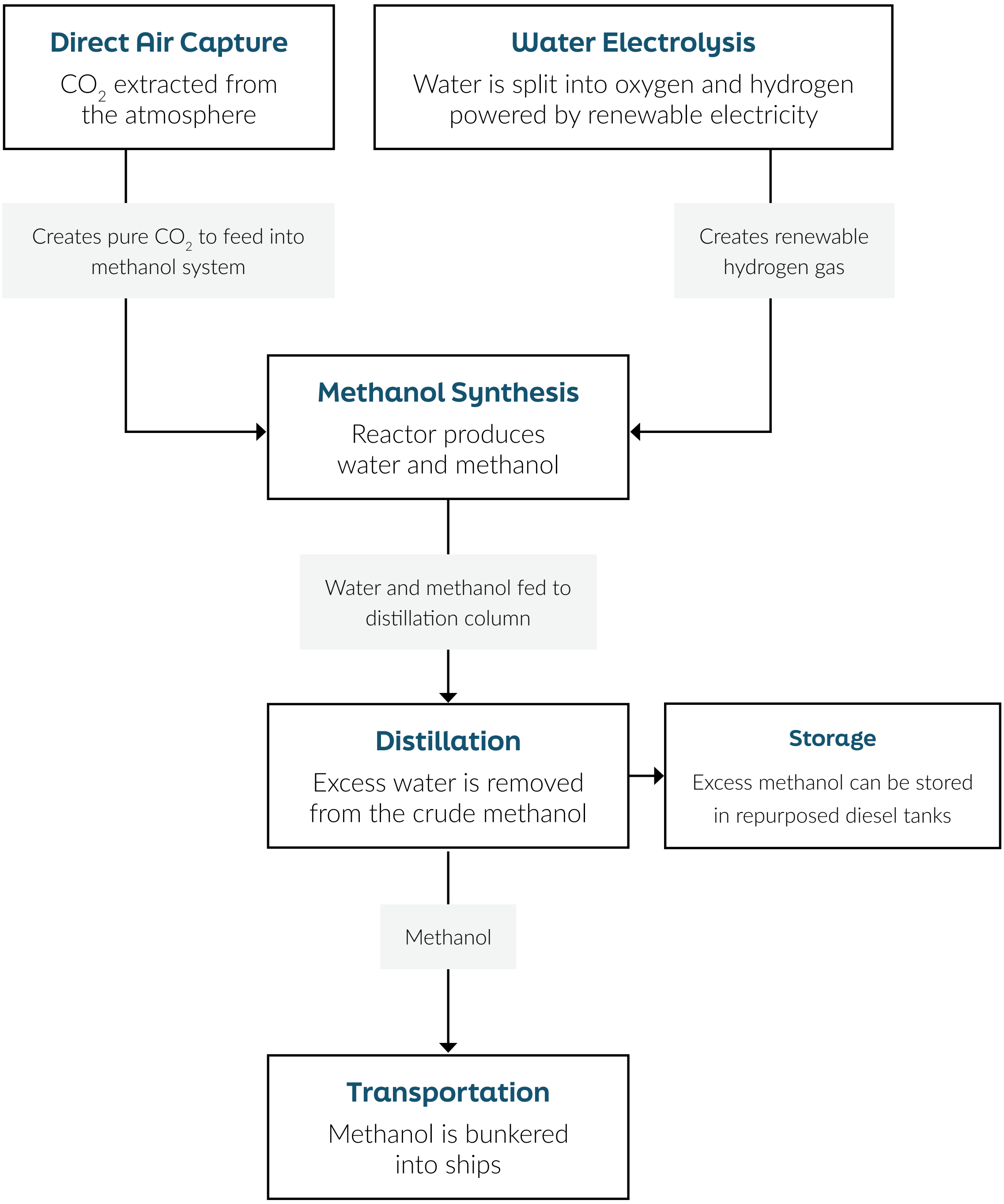
CO_2 Capture

DAC is a process to capture CO_2 directly from the atmosphere. The process uses large fans to blow ambient air into absorption towers filled with capture solvents. The capture solvents selectively remove CO_2 from the air stream. The solvent is then sent to a desorption tower to free the CO_2 back into a gaseous form for use in the methanol synthesis reaction. DAC technology offerings include solid sorbent and liquid solvent options.

This study assumes the use of a liquid solvent system due to its lower energy requirements. DAC is favourable for this facility because it guarantees a steady and consistent supply of CO_2 feedstock on site. In British Columbia, a company called Carbon Engineering is currently commercializing large-scale DAC technology, meaning that a made-in-Canada solution could be feasible.

E-methanol Synthesis

This facility assumes a synthesis reactor is used, which combines H_2 and CO_2 over a catalyst. The synthesis reaction produces both methanol and water, which is known as crude methanol. Crude methanol is sent to a distillation column to separate out the water and ensure the methanol meets the quality needed to run the ship engine.



E-methanol production and utilization pathway

4.4 Methanol Synthesis Feedstock Requirements

The proposed methanol synthesis process has three feedstock requirements: H_2, CO_2 and water (H_2O).

The conceptualization estimates feedstock requirements for each phase of development based on the assumptions that alkaline electrolyzers are used for hydrogen production, the liquid solvent DAC process is used for carbon capture, and a CO_2-to-methanol synthesis unit is employed.

Production of 1 tonne of e-methanol requires approximately 0.2 tonnes of H_2 and 1.4 tonnes of CO_2. Water is a by-product of this reaction, so for each tonne of methanol, there is also approximately 0.6 tonnes of water produced that can be recycled back into the electrolyzer.

For the full-sized plant producing 200,000 tpa of e-methanol, this corresponds to feedstock requirements of 40,000 tpa of H_2 feed and 80,000 tpa CO_2 feed, creating a 120,000 tpa of water byproduct.

Phase	1 50,000 tpa Methanol Output	2 100,000 tpa Methanol Output	3 150,000 tpa Methanol Output	4 200,000 tpa Methanol Output
Hydrogen Feed (tpa)	10,000	20,000	30,000	40,000
CO_2 Feed (tpa)	70,000	140,000	210,000	280,000
E-methanol Output (tpa)	50,000	100,000	150,000	200,000
Water Byproduct (tpa)	30,000	60,000	90,000	120,000

Estimated methanol synthesis feedstock requirements in each phase of the production plant

4.5 Key Considerations

DAC-E-methanol offers potential to significantly reduce emissions from shipping while providing flexibility and reliability regarding the supply of carbon as a feedstock.

DAC is a rapidly growing area of research, development and commercial application, with made-in-Canada solutions in the market worth incorporating into the project.

The facility's phased approach allows learning from other jurisdictions and aligns supply and demand.

Being a first-of-a-kind plant in Canada adds risk, however, the benefits of overcoming these risks will position Canada as a global leader in the production of ultralow-carbon shipping fuel.

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5. Utilities and Land Requirements

Access to renewable electricity, water, and industrial land located near or adjacent to the port is required for the development of the proposed e-methanol plant. Each of these requirements would have to be carefully planned including analysis of supply availability, and may not be suitable for the community.

The full-sized (200,000 tpa) e-methanol plant will need 432.4 megawatts of electricity. The annual water requirement would be 646.2 million litres per year, primarily for the water electrolysis process. Additionally, the facility will require 28-34 hectares of space, with 90% of the footprint being taken up by DAC. Proximity to the Port, power source, and water supply must all be considered.

5.1 Electricity

The production of e-methanol depends on access to substantial renewable power generation. In British Columbia, the main utility provider is BC Hydro, which operates predominantly on hydroelectric power. It is assumed that the BC Hydro grid would supply the power requirements for the proposed e-methanol plant. The province ranks among the lowest provinces in Canada in terms of electricity grid carbon intensity, with 15 grams of CO_2equivalent per kilowatt-hour (g CO_2CO_2e/kWh) for 2025.

Each development phase will require 108 MW to produce 50,000 tpa fuel, for a total power demand of 432 MW for the complete build out.

Phase	1 50,000 tpa Methanol Output	2 100,000 tpa Methanol Output	3 150,000 tpa Methanol Output	4 200,000 tpa Methanol Output
Power Demand (MW)	108.1(Total) 65.4 (H_2Prod) 14.4 (DAC)	216.2 (Total) 130.8 (H_2 Prod) 28.8 (DAC)	324.3 (Total) 196.2 (H_2 Prod) 43.2 (DAC)	432.4 (Total) 261.6 (H_2 Prod) 57.6 (DAC)
Annual cost of electricity (USD per year)	36,850,000	73,700,000	110,500,000	147,400,000

According to BC Hydro's Integrated Resource Plan, there is surplus capacity until 2036, meaning there is sufficient power available for Phases 1 and 2. From 2036 onward, however, the forecast is uncertain, with insufficient power generation to meet the forecasted load. During engagement for this study, BC Hydro indicated that Phases 3 and 4 would be subject to a capacity review. This uncertainty poses a risk to the project in securing sufficient grid capacity and determining power rates due to high demand.

In addition to potential supply challenges for electricity, the facility's operating costs will be highly sensitive to any changes in BC Hydro's electricity rates (more on this in Section 9.2).

5.2 Water

E-methanol production requires a large volume of treated H_2O , mainly due to water electrolysis to produce green H_2. Water electrolysis requires both processing and cooling H_2O. In addition to H_2 production, the e-methanol production process also requires cooling H_2O for DAC, methanol synthesis, and supporting equipment. Water treatment infrastructure will be required to ensure that processing H_2O meets the equipment specifications.

Typically, Metro Vancouver allocates its water service to industrial users through fully metered connections. Emerging challenges with industrial water supply in the Metro Vancouver region, due to a combination of climate impacts, growth, and aging infrastructure may require that new industrial users adopt water efficiency, recycling, or non-potable systems to secure reliable supply.

Phase one will require 161.3 million litres per year; phase two, 322.5 million litres per year; phase three, 484.5 million litres per year; and the full build will require 646.2 million litres per year.

Phase	1 50,000 tpa Methanol Output	2 100,000 tpa Methanol Output	3 150,000 tpa Methanol Output	4 200,000 tpa Methanol Output
Start date	2032	2035	2038	2041
Water requirement (million litres per year)	161.3	322.5	484.5	646.2

Annual water requirement for each phase of production

5.3 Land

The facility will require 28-34 hectares of industrial land for full construction. Approximately 90% of the total footprint will be taken up by the DAC modules.

Decisions on site selection will need to consider proximity to power and water supply, permitting requirements, and access to bunkering infrastructure. Industrial land represents about 4% of the region's land base, and there are existing constraints at the Port of Vancouver that could make finding suitable land for the facility challenging.

Phase	1 50,000 tpa Methanol Output	2 100,000 tpa Methanol Output	3 150,000 tpa Methanol Output	4 200,000 tpa Methanol Output
Start date	2032	2035	2038	2041
Footprint (hectares)	8-12	14-20	22-28	28-34

Annual footprint of production plant

5.4 Key Considerations

The project requires significant allocations of electricity, fresh water, and land, which could pose strategic risks. The project must ensure a balance between the allocation of local resources and the climate benefits of green shipping corridor development. Careful planning, load forecasting, early engagement, and clearly defined benefits at the local and regional levels will be essential for these types of projects to succeed.

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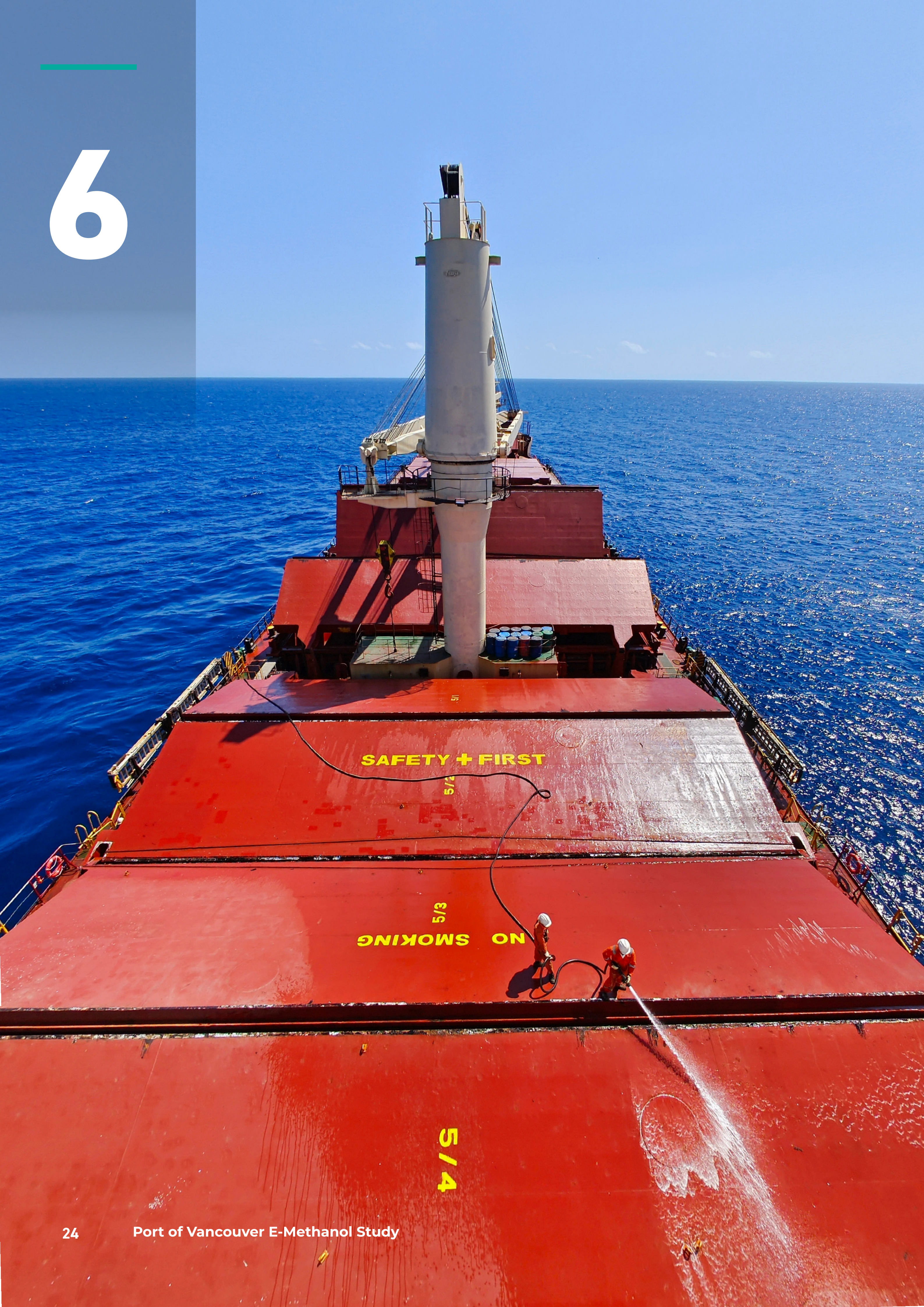

6. Storage and Bunkering

Additional considerations for utilizing e-methanol at the Port of Vancouver for green shipping corridor development include e-methanol storage and vessel bunkering.

6.1 Storage

Several factors, including methanol volume and demand variability between the bulk and cruise green corridors, will influence the amount of methanol storage required at the port.

Methanol has a lower energy density per unit volume than conventional HFOs, requiring 2.4 times more space to store the same amount of energy. It is estimated that 65,000 m3 of storage (3 large 20,000 m3 tanks and one medium sized 6,000 m3 tank) will be required for the full 200,000 tpa plant.

In a scenario where e-methanol is produced solely for the Alaska cruise route, surplus production during off-season months would need to be stored until high-demand periods.

From a safety and maintenance perspective, methanol is highly corrosive, necessitating cathodic protection and regular inspections. Methanol is stored at ports and terminals in above-ground fixed or floating-roof tanks or in smaller dedicated methanol storage tanks. Despite its corrosive nature, methanol storage development for the project is considered low risk, as it is a widely distributed chemical stored at over 120 ports worldwide.

6.2 Bunkering

The preferred approach for supplying e-methanol to bulk and cruise vessels is to use a bunker vessel in a ship-to-ship arrangement. Ship-to-ship bunkering involves using specialized bunker barges that are filled at a fuel storage terminal before travelling to the receiving ship to deliver the fuel. This method is well established and the most likely bunkering option at the Port of Vancouver, given the size of vessels under consideration and therefore the amount of fuel delivered in each bunkering event. The port already supports various fuel barges for supplying conventional fuel to larger vessels.

6.3 Key Considerations

Because methanol requires more than twice the storage space as HFO, storage infrastructure will need to be planned and considered in parallel with facility development.

Operational costs of bunkering methanol are generally expected to be consistent with those for conventional marine fuels. However, a specialized barge will be required for ship-to-ship bunkering which may represent significant capital investment that is potentially challenging for fuel suppliers to justify while demand remains low.

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7. Permitting

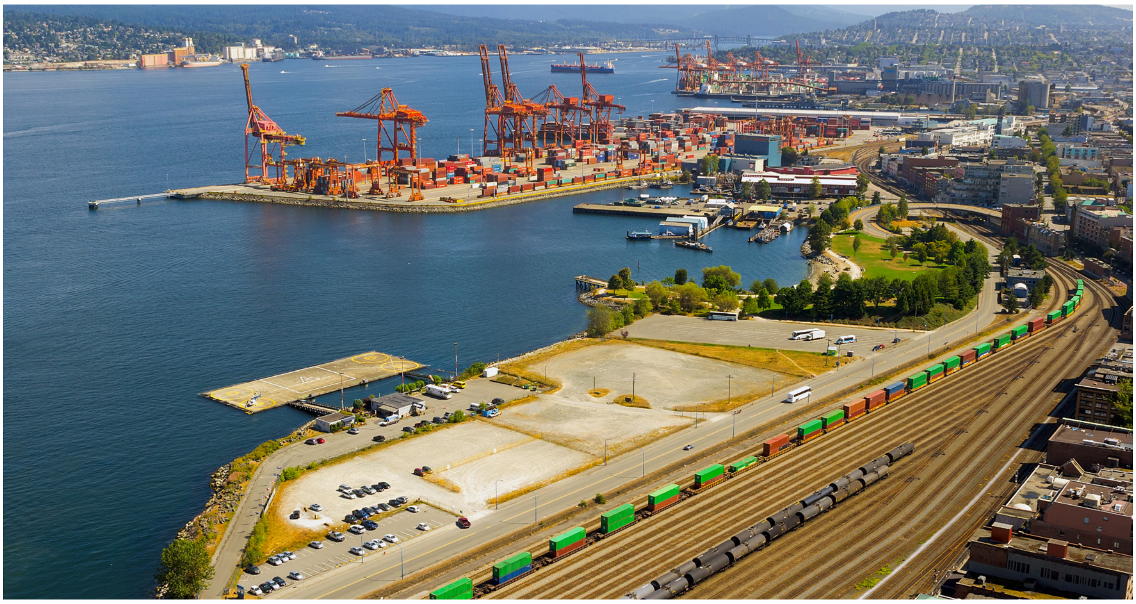
Indigenous consultation, environmental assessment, and permitting will be critical components of the proposed e-methanol production facility. The properties of methanol, the quantities of water and power required for production, and the novel nature of the combined processes that make up the plant may add complexity and delays due to protracted reviews and proactive community consultation. However, there is a precedent for methanol production in British Columbia that may ease the process and mitigate the risk of schedule delays. The existing DAC project in Squamish, B.C., may also help address potential permitting risks as the company is well-established.

Based on the standard permitting time frame in British Columbia, a 24-month process would align well with the typical project development cycle. The time frame required for the front-end engineering design, which is typically required before the start of detailed design and construction, requires at least 24 months and could take up to 36 months.

Several permits will be required, including a BC Energy Regulator (BCER) Permit, which ensures Energy Resources Activity Act compliance, an Environmental Assessment Certificate, which requires public consultation, an Air Quality Permit, a Building Permit and a Water Use Permit, which requires an environmental impact assessment.

7.1 Key Considerations

As a first-of-its-kind project in Canada, permitting and regulatory compliance may require additional public engagement and awareness building. Indigenous community engagement and benefit sharing, including project ownership, should be planned from early phases through to operations.



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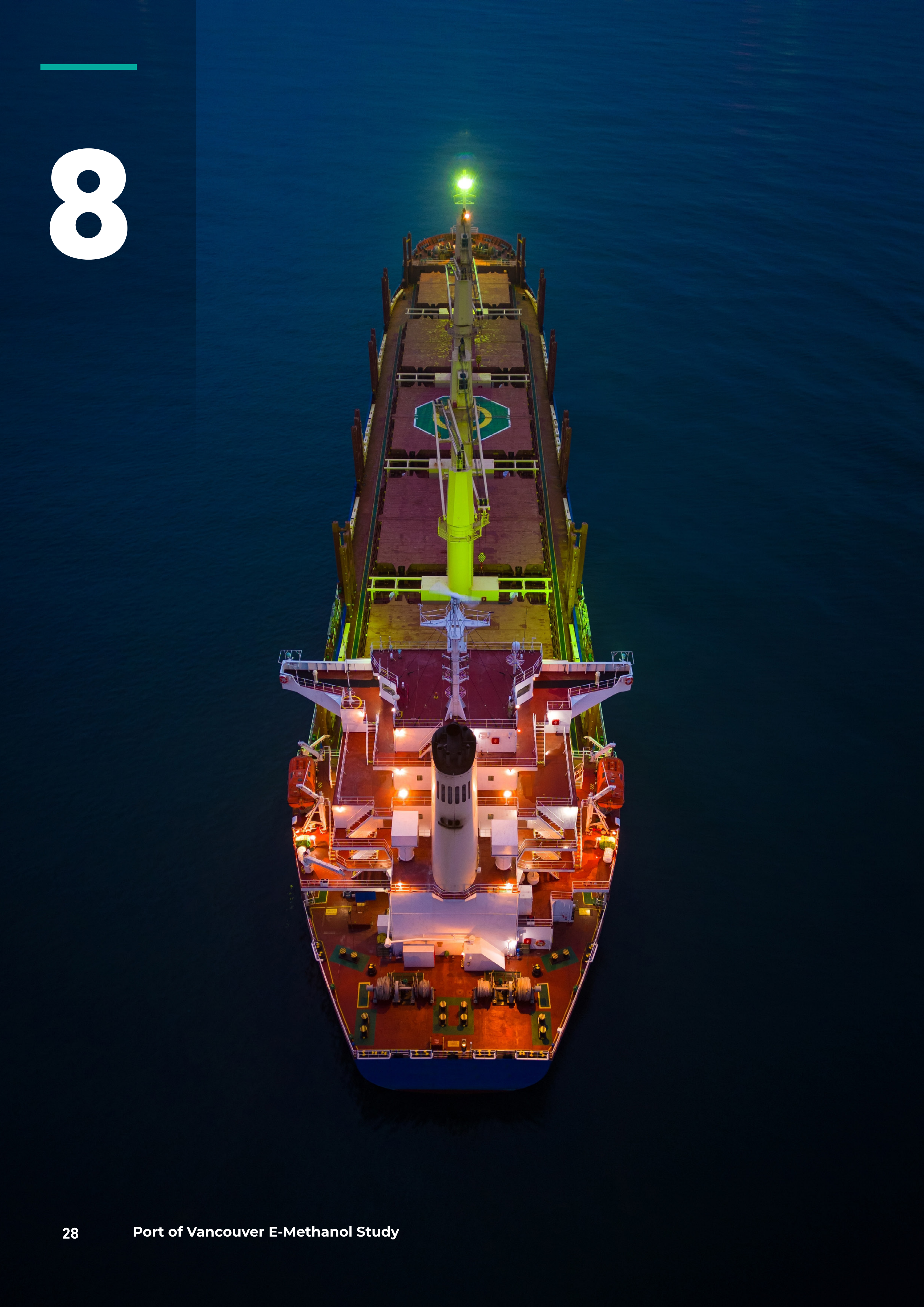
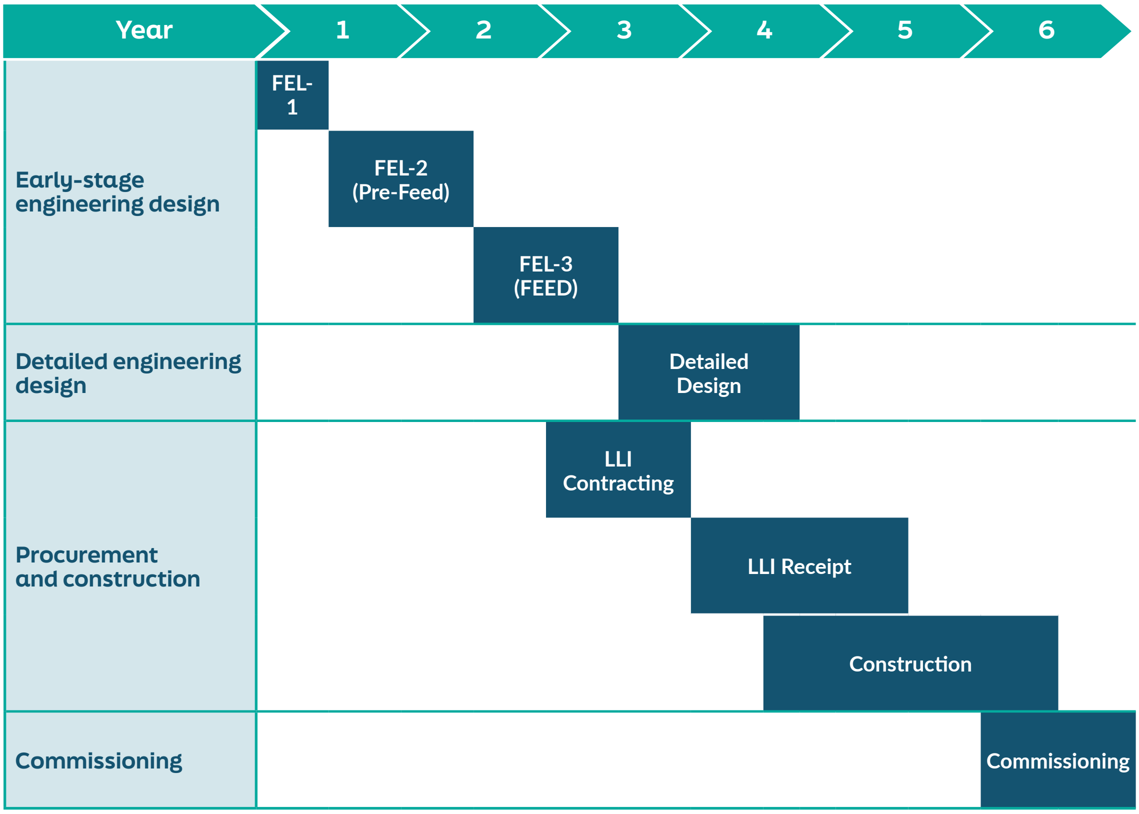


8. Implementation Schedule

The timeline from early-stage engineering to commissioning of the first phase of production is approximately six years.

Early-stage engineering design is estimated to take two years, followed by detailed engineering and procurement. Construction could begin 1 year into the engineering and procurement phase and will last for two years. Commissioning requires approximately six months prior to the start of commercial operation. The timeline for subsequent phases will tighten, and phases are estimated to roll out in three-year intervals.

The entire facility would be fully operational 15 years from the start of development.



FEL – Front-End Loading
FEED – Front-End Engineering Design
LLI – Long Lead Items

8.1 Key Considerations

Several potential constraints pose timeline risk. These include securing product offtake agreements, securing electricity grid interconnection to support facility requirements, obtaining permitting and regulatory approvals, procuring lead times for power system equipment, and securing financing.

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9. Costs

The cost analysis focuses on the three main sections of the plant: DAC CO_2 production, H_2 production with alkaline electrolyzers, and methanol synthesis. Arup used a combination of vendor information and internal and external benchmarks to quote capital costs for equipment through commissioning and to estimate the price of the planned phases. The three core plant sections were supplemented with balance-of-plant (BOP) to account for infrastructure and auxiliary systems required for the plant to operate.

The cost of the production facility at full development is estimated at $731 million USD. Annual operating costs are estimated at $300 million USD. The levelized cost of production based on the above CAPEX and OPEX is $1,860 USD per tonne of methanol produced.

9.1 CAPEX

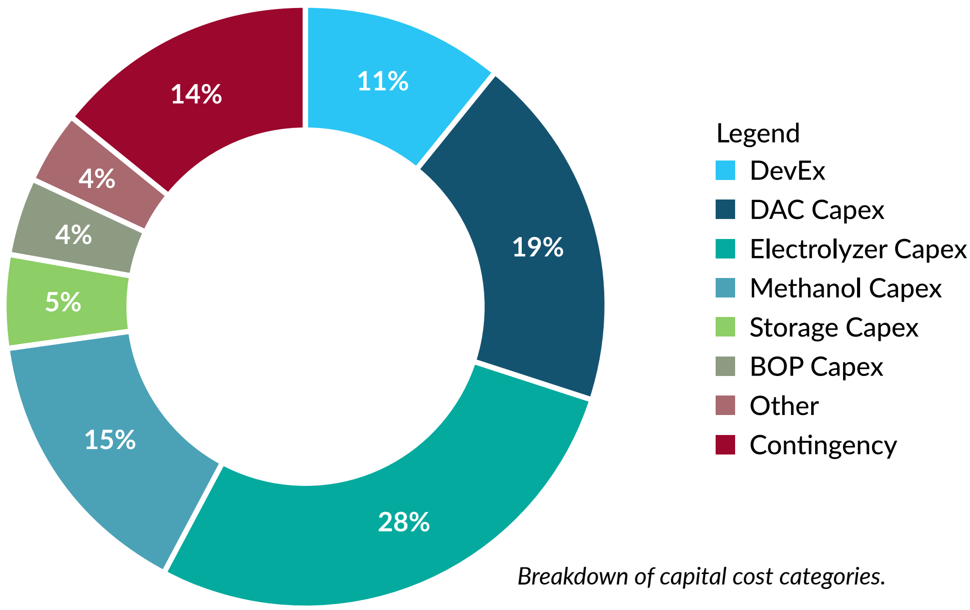
The plant CAPEX per 50,000 tpa capacity is approximately $182 million USD in 2025 dollars, and the total investment for all four phases will be roughly $731 million USD.

This results in an investment cost of $3,653 USD per tpa installed capacity (including contingency). This cost compares to the IRENA and Methanol Institute benchmark of $3,330 USD per tpa for DAC-based e-methanol.

The main CAPEX costs include:

- Direct Air Capture system: $138 million
- Electrolysis capacity: $206 million
- Methanol Synthesis Loop: $111 million
- Balance of Plant: $26 million
- Methanol Storage Cost: $38 million

Contingency, insurance, and other development cost represent 20% of the CAPEX cost.



Breakdown of capital cost categories.

CAPEX Category	Bench-mark	Unit	Benchmark Source	Cost for 200,000 tpa MeOH plant (USD)
Direct Air Capture (DAC), incl. install-commissioning; excl. CO_2 compression	500	USD per tonne installed CO_2 capture capacity	IEAGHG (2021)	$138 MM
Electrolysis, incl. BoP and H_2 compression	750	USD per kW of installed electrolysis capacity	Arup Internal, IRENA 2022	$206 MM
Methanol Synthesis Loop	876	USD per tonne of installed capacity	Arup Internal	$111 MM
BoP, incl. CO_2 compression and boundary connections	5%	% of Total CAPEX of DAC, Methanol Loop, and Electrolysis	Arup Internal	$26 MM
Methanol Storage	750	USD Per tonne of storage	Arup Internal	$38 MM
Total Direct Costs	Calculated			$519 MM
Other (insurance, certification)	5%	% of Total Direct Costs	Arup Internal	$26 MM
Contingency	20%	% of Total Direct Costs	AACE International Class 5 Estimate Guidelines (20-40%)	$103 MM
Total Development Expenses	10-15%	% of Total CAPEX prior to contingency and other costs	Arup Internal	$83 MM
Total Capital Investment (inc. DEVEX)	Calculated			$731 MM

Capital cost breakdown and estimated CAPEX for 200,000 tpa plant

9.2 OPEX

The OPEX cost at full build is approximately $300 million USD per year. This includes operational costs for CO_2 production via DAC ($110 million), H_2 production via alkaline electrolyzers ($150 million), and methanol synthesis ($40 million).

The relatively high cost of purchasing electricity from the BC Hydro grid will be a challenge. Based on BC Hydro's Rate Schedule 1894, with a 10% discount applied to represent the discount offered for low-carbon fuel production, the 200,000 tpa e-methanol plant would incur approximately $150 million USD per year in electricity costs. Because electricity costs will comprise the majority of the plant's operating costs, even small changes in either BC's rates or electricity usage will have significant repercussions on fuel prices.

9.3 Cost and Comparison to HFOs

The Levelized Cost of Production (LCOP) is a metric used to compare the cost of producing a certain product against alternatives. The LCOP takes into account the CAPEX, OPEX and the weighted average cost of capital (WACC). This results in a real comparative number taking into account cost of debt and required returns by investors.

The LCOP for this plant will be approximately $1,860 USD per tonne. This compares to equivalent costs of roughly $383 USD for marine gas oil, $357 USD for very low sulfur and $234 USD for bunker oil, meaning that on an energy equivalent basis the e-methanol is expected to be eight times more expensive than HFOs.

Fuel	USD/MeOH equivalent tonne
Marine Gas Oil	$383
Very low sulfur fuel oil	$357
Heavy Fuel Oil	$234
E-methanol	$1,860

Comparative equivalent energy cost of e-methanol and other fuels

9.4 Key Considerations

The high cost of e-fuel compared to HFOs is a significant barrier for adoption.

While the higher cost of electrolyzer and DAC technology is expected to decrease over time, the relatively high cost of purchasing electricity from the BC Hydro grid is a challenge for low-carbon fuel projects that will have to be addressed.

The IMO's green fuel fund contemplated in the Net-Zero Framework is intended to de-risk early adopters of green shipping fuels. However, national level incentives are will also be needed to address the high cost of e-fuel for early adopters.

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10. Emission Reduction Potential

E-methanol produced from the concept facility can deliver a significantly lower carbon intensity than HFO, assuming the electricity used is derived from renewable sources and the CO_2 used as a feedstock is extracted from the atmosphere using DAC.

Well-to-Wake Emissions

The full lifecycle GHG emissions of a marine fuel, in terms of grams of CO_2-equivalent, is often dubbed "Well-to-Wake" to describe the emissions incurred at every step in fuel production up to and including use of the fuel and is typically calculated as the sum of:

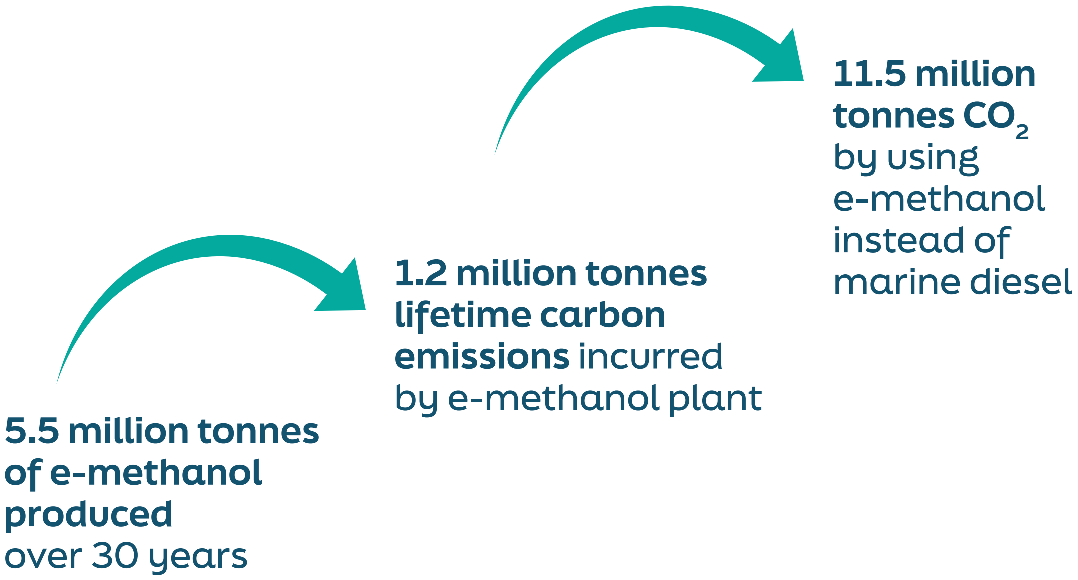
- "Well-to-Tank" emissions, which include the direct, indirect, and embodied emissions associated with the extraction, processing, transport, bunkering, and storage of a marine fuel;
- "Tank-to-Wake" emissions, which include the emissions associated with the use, or combustion, of the fuel to generate energy to power the marine vessel.

According to the Methanol Institute[3], the lifecycle emission reduction of renewable electricity-based methanol will be between 90% and 100% when compared to conventional fossil fuels. This corresponds to well-to-wake GHG emissions of between 0g and 10g CO_2 per MJ for e-methanol compared to a baseline GHG intensity of 95.5g CO_2 per MJ for HFO.

Total methanol production over the facility's lifetime is estimated to be 5.5 million tonnes based on a 30-year design life for the plant and three years of operation at each of phases 1-3. Phase 4 would commence at year nine and operate for 21 years. Assuming a 90% GHG intensity reduction is achieved, this 30-year production period would incur approximately 1.2 million tonnes of CO_2 while displacing 11.5 million tonnes of CO_2 assuming vessels are switching from using conventional HFO.

At the point of combustion, methanol can also deliver significant reductions in compound emissions compared to conventional fuels. This includes the release of nitrogen oxides, sulphur oxides, and particulate matter. These reductions can contribute to improved local air quality and reduced environmental impacts.

3. Methanol Institute, Carbon Footprint of Methanol
http://www.energycentral.com/energy-biz/post/carbon-footprint-methanol-lQyJRfywJphj7lJ



E-methanol carbon reduction potential of e-methanol plant

10.1 Key Considerations

E-methanol has considerably lower carbon intensity than HFO. A comparison of well-to-wake GHG emissions using the high-end range for each shows at least a 90% reduction when switching from HFO to e-methanol. The proposed e-methanol plant's 30-year production period would displace 11.5 million tonnes of carbon dioxide.

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11. Conclusion

Decarbonizing marine transportation is an environmental and economic imperative. However, how this transition will take place—and what fuels and technologies will power it— is still being decided. This study represents an important step by examining the practical considerations that would be involved in developing one of these potential fuels, and how it could supply emerging green shipping corridors.

The development of a large-scale e-methanol production facility at or near the Port of Vancouver could provide an adequate fuel supply for both the Pacific Northwest to Alaska Green Corridor and the North Pacific Green Corridor Consortium. While the 200,000 tpa e-methanol production facility conceptualized in the study would be one of the largest e-methanol production facilities in the world, and a Canadian first, the research demonstrates that there are no technological impediments to plant development, including pursuing a direct air capture e-methanol plant.

The plant was designed to be scaled in 4 phases to accommodate evolving fuel demand. At the end of its development, there would be enough e-methanol to supply two large cruise ships serving the Vancouver-to-Alaska cruise corridor and at least 10 Panamax bulk carriers trading with Asia. Working together, the cruise and bulk corridor development consortia can create economies of scale and overcome challenges concerning the seasonality of the cruise corridor and storage. While these vessels represent only a fraction of the total market, the project would position Canada as a serious competitor in the emerging low-carbon shipping fuel market. This market is expected to grow to more than 500 million tonnes by 2040, with an estimated market value of 4.3 trillion USD.

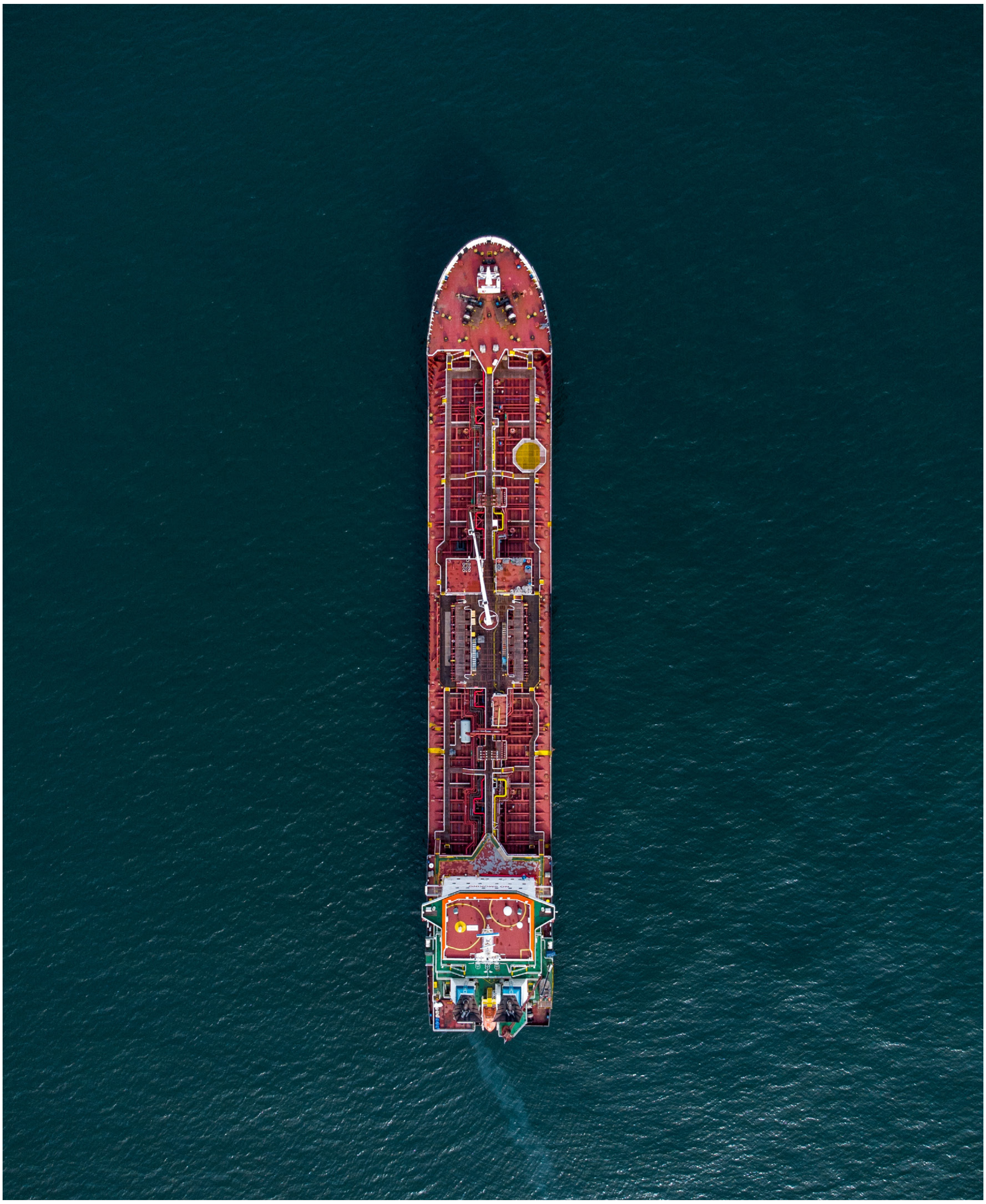
The greenhouse gas emissions benefits of developing an e-methanol supply for green shipping corridor development are also clear. Switching from HFO to an e-methanol facility such as this reduces well-to-wake emissions by at least 90%. The plant's 30-year production period would displace 11.5 million tonnes of carbon dioxide, as well as reducing other pollutants that affect human health.

Despite the benefits, there are risks that will need to be carefully considered going forward. Some can be managed through planning and coordination: the commercialization of methanol-ready ship engines would allow investments in new ships and retrofits to occur out of sync with fuel supply development, while a phased development approach would allow technologies to mature across the 15-year project development. Others, such as the risks associated with the allocation of electricity, water, and land, may prove to be more challenging and would require additional research, community engagement and planning.

Finally, the business case underpinning the project will need to be addressed in order to advance green shipping corridor development on Canada's West Coast. The e-methanol produced at the proposed facility would be eight times more expensive than conventional marine fuels . Long-term off-take agreements between shippers and fuel producers will be needed to unlock investments in e-fuel production. In addition, a suite of national and international interventions, including tax credits, grants, cost-for-difference contracts, and market-based mechanisms will be needed for e-fuel to be competitive with conventional marine fuel oils.

Given the long operational life of ships and associated infrastructure, the future of marine transportation will depend on the decisions we make today. While further discussion around the practical barriers and opportunities presented by the transition to zero-emission fuels is necessary, developing these fuels is technologically and could present a significant market opportunity for early actors.

We look forward to the discussion ahead on with the two existing green shipping corridors, ship owners, community partners and environmental advocates, and the fuel supply chain that operate through the Port of Vancouver.



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12. Appendix of Sources

Section	Source
Demand	Arup memo examining publicly available data from Port of Vancouver and specs of Panamax and cruise vessels. Vancouver Fraser Port Authority (2024). "2024-04-17 Briefing Note Bulker Methanol Demand" Vancouver Fraser Port Authority (2024). "2024-04-19 Briefing Note Cruise Methanol Demand"
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