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Zero-Carbon for Shipping

Sailing carbon-free along North America’s west coast

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Who is Ocean Conservancy?

Ocean Conservancy is working to protect the ocean from today's greatest global challenges. Together with our partners, we create science-based solutions for a healthy ocean and the wildlife and communities that depend on it.

Ocean Conservancy's shipping emissions campaign focuses on targeted policy changes and science-based solutions with the goal of reducing carbon emissions and bolstering protections for the marine environment, its living marine resources and the communities that are part of and dependent on ocean ecosystems.

Ricardo Energy & Environment

At Ricardo Energy & Environment, our vision is to create a world where everyone can live sustainably: breathing clean air, using clean energy, travelling sustainably, accessing clean water and conserving resources. Adopting renewable electrofuels for shipping would bring the world closer to these aims.

Since the 1950s, we have worked to deliver improvements in air quality, pioneered the use of renewable energy technology and worked on the development and implementation of The Paris Agreement on Climate Change, helping countries and organizations to mitigate climate change by reducing greenhouse gas emissions. ee.ricardo.com

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Executive summary

The shipping sector presents a significant opportunity in the transition from fossil fuels in North America. Often operating out of sight and out of mind for the general public, the shipping sector remains the backbone of the global supply chain. It's decarbonization presents some unique challenges including long ship lifetimes, high energy demands and the consideration of fuel infrastructure requirements in various regions. Yet the solutions and scalable technological advancements that will allow the sector to decarbonize have already been devised and many are on the road to implementation.

Zero-carbon fuels have an important role to play in transitioning the shipping industry to a zero-carbon and emission free future, alongside the adoption of improvements in vessel energy consumption and operational efficiency.

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The west coast of North America is an important and valuable route for the shipping industry. A significant proportion of the trade between the United States, Canada, and Asia (especially China and Japan) happens through or interacts with ports in this route. Decarbonization of vessel traffic through this route would therefore deliver tangible decarbonization benefits and could also be a catalyst of wider decarbonization for the industry as a whole.

This report explores the potential opportunity for five major ports on the west coast of North America, of adopting zero-carbon electrofuels: green hydrogen and ammonia produced with renewable power with no associated emissions from their production. Each Port has a considerable opportunity for adoption of zero-carbon electrofuels:

Los Angeles (California): Building on sustainability aspirations to decarbonize the busiest port in the United States. Being able to offer zero-carbon fueling options to the huge numbers of vessels in the area could support take-up of these fuels significantly.

Port of Oakland (California): Outstanding potential for renewable electricity generation can support a green hydrogen economy beyond the shipping industry. Mixing renewable energy resources both near the port and further afield can help decarbonize adjacent industries and rail operations in the future.

Port of Tacoma (Washington): Enabling electrofuel adoption while decarbonizing local passenger transport. Zero-carbon power can be used to decarbonize local ships moving passengers and vehicles and produce electrofuels to allow larger ships to switch fuels.

Port of Vancouver (British Columbia): Getting Canada's largest port ready for a zero-carbon future. Producing and supplying electrofuels can help fill the revenue gaps that fading coal imports will eventually leave behind.

Unalaska, Aleutian Islands (Alaska): Disruptive opportunities in a small and remote island. The unique combination of untapped renewable energy resources and local needs can give birth to complete electrofuel supply chains and even circular economies.

Together, these ports have the potential to form a zero-carbon shipping corridor up and down the west coast of North America. This corridor would provide vessels with multiple refueling stops that would allow them to adopt electrofuels without compromising their range. To take this step, vessels will need to be able to access these same facilities and resources in their other regions of destination and are likely to require more frequent refueling than fossil fuel-powered ships.

By developing and promoting zero-carbon fueling infrastructure along this route, there is a further opportunity to drive the change across the shipping industry, leveraging the influence that these ports and the associated stakeholders have. The characteristics and opportunities shown by these case studies could act as a blueprint for other ports – both in North America and beyond.

Adoption of zero-carbon shipping fuels such as hydrogen and ammonia can have benefits far beyond the shipping sector. These spill-over benefits can benefit the community and region around the port, and the country beyond:

Creating new and future proof sources of income for local economies by seizing the opportunity to attract and service a low-carbon shipping fleet.

A commercial, competitive benefit in domestic and international markets which will increasingly demand zero-carbon shipping for products and materials.

Lowering barriers for establishing renewables at scale to provide general power supply through economies of scale, establishing supply chains and developing capability and skills.

Increasing opportunities to deploy renewables at scale through economies of scale, establishing supply chains and developing local capability.

Supporting the business case for renewables through operating production infrastructure flexibly to use renewable generation at peak times when it otherwise might be curtailed.

Reducing reliance on fossil fuels which not only brings carbon benefits, but also a reduced vulnerability to price shocks in the future.

Green hydrogen and ammonia can support decarbonization of other sectors, for example being used in transport, agriculture or industry.

Real potential in job creation in the new renewable energy and zero-carbon fuels sectors, which is an important aspect in a just transition.

Potential to build investable projects that attract funding from the private sector and increase international climate funding.

Enabling a zero-carbon shipping lane on the North American west coast can drive the shift towards a sustainable shipping industry

Global trade has seen sustained growth for decades and is expected to progressively increase as the world moves past the effects of COVID-19 and lockdowns [1]. The shipping industry accounts for upwards of 90% of global trade and continues to reap the benefits economically. Even during COVID-19 there were backlogs of ships anchored outside of Ports along the west coast of North America, trying to keep up with consumer demand. The environmental cost of this booming trade market is that the shipping industry is responsible for close to a billion tons of CO_2e per year [2], nearly the same emissions of Texas and California combined [3].

The International Maritime Organization (IMO) has set a target to reduce emissions by at least 50% by 2050 (relative to 2008). The United States' Climate Envoy John Kerry has also called for adopting a target of full decarbonization for shipping in the same time frame, in line with the temperature goals of the Paris Agreement. These commitments are good, but tangible action must follow to remain below a 1.5 degree global temperature rise. Given that shipping's GHG emissions have increased about 10% from 2012-2018 [4], reaching this reduced emissions goal is becoming an increasing challenge for the industry. Electrofuels – fuels produced using renewables and that have zero emissions through their lifecycle – can be part of the solution.

Local action can play a key role in overcoming these challenges, especially considering that domestic shipping emissions, as the 4th Greenhouse Gases (GHG) study of the IMO revealed, are much higher than initially thought; making up to 40% of yearly emissions for some vessels [4]. The recently announced commitments of the United States, which is seeking to deploy 30 GW of offshore wind by the end of this decade in addition to their zero emission target for shipping by 2050 [5], can serve as a catalyst. This creates a unique opportunity for ports, local actors, and industry players to take initiative and lead through action and example.

This report looks at the potential opportunity of adopting zero-carbon electrofuels in ports along the west coast of North America. Together, these ports have the potential to form a zero-carbon shipping corridor on the west coast of North America, enabling local zero-carbon shipping routes and bunkering for zero-carbon vessels headed further afield. This would not only reduce shipping emissions significantly but would pave the way and serve as a blueprint for future initiatives, helping to drive the global industry towards a zero emissions future.

This report is the second in the Ocean Conservancy's report series Zero-Carbon for Shipping, a sequel to Zero-Carbon for Shipping: Propelling investment in South and Central America with hydrogen-based shipping fuels [1]. This series was created as a natural progression from the previous works by Ocean Conservancy, Environmental Defense Fund (EDF) and GtZ, including Sailing on Solar – Could green ammonia decarbonize international shipping? [2] Electrofuels for shipping: How synthetic fuels from renewable electricity could unlock sustainable investment in countries like Chile [3] and South Africa: fueling the future of shipping, South Africa's role in the transformation of global shipping through green hydrogen-derived fuels [4]. Other related work in this area includes the ICCT study "Liquid hydrogen refueling infrastructure to support a zero-emission U.S.–China container shipping corridor [5]"

Zero-carbon fuels can be made using renewable electricity to decarbonize the shipping sector

Carbon-containing electrofuels

Carbon-containing electrofuels (such as e-diesel and e-methanol) require carbon dioxide as an input. This needs to be extracted from an external source (air, seawater or biomass) for the fuel to be carbon-neutral over its lifecycle because the carbon dioxide ultimately returns to the atmosphere when the fuel is burned. Direct air capture is a technology that requires significant amounts of electricity and is not currently commercially available at the scale required to produce shipping fuels.

Blue hydrogen-based fuels derived from fossil sources

Currently, the most common method of producing hydrogen is through a process known as steam methane reforming (SMR), with fossil fuels used as the main input. Hydrogen produced in this way, coupled with carbon capture and storage (CCS), is known as 'blue hydrogen' and can be combined with other molecules to produce a range of blue fuels. CCS is required to capture carbon dioxide created in the process of producing the hydrogen. Blue hydrogen is considered low carbon, but not zero emissions, as CCS is not able to capture and store 100% of the carbon emissions. There are also greenhouse gas emissions associated with the process of extracting, transporting and storing the required fossil fuel.

Fuels derived from biomass

Fuels derived from biomass sources are often considered carbon-neutral because the carbon they release when burned was absorbed from the air as they grow. However, converting fertile land to grow biomass crops can be problematic and unsustainable especially if it replaces food production or natural habitats. Diverting existing crops to fuel production, moreover, can trigger new GHG emissions from tropical deforestation (indirect land-use change) by raising the price of agricultural commodities [6]. Biofuels can also be produced from waste products, however location of these resources and distribution adds an element of complexity to its production.

Why green hydrogen and green ammonia were chosen for this report

Green hydrogen and ammonia do not contain carbon and do not emit carbon dioxide or black carbon at any point in their lifecycle (as they are produced using renewable electricity). If the Nitrogen used for producing ammonia is extracted from the environment, the total net Nitrogen emissions released from using the fuel would be zero. This report focuses on green hydrogen and green ammonia because the USA is in a good position to capitalize on its abundant renewable electricity potential to produce them at industrial scale.

As this report shows, development of infrastructure to produce green hydrogen and green ammonia will increase demand for renewable electricity plants, strengthen supply chains, create clean jobs and reduce costs of renewable technologies in the region. Electrofuel production, however, should not compete with the power grid for renewable resources. Renewable power requirements for electrofuel production should be installed over and above what is required to decarbonize the electricity mix, including industrial and agricultural applications.

Green electrofuels can be produced, handled, stored and used safely

Like all fuels, there are safety risks and handling requirements associated with the use of green hydrogen and ammonia. This will need to be addressed by the industry moving forward. However, this should not be seen as a major barrier for adoption of these fuels; fuels used today are subject to codes, best practices and standards that have been developed over years of expertise, which have allowed them to be used widely and safely in a variety of applications, environments, and conditions [7]. The same can be done for electrofuels.

The main risks associated with both electrofuels and the most commonly used fuels in the shipping industry are summarized below [8]:

Marine gas oil	LNG	Green hydrogen	Green ammonia
Extremely flammable	Explosive and extremely flammable	Extremely flammable (invisible flame) and explosive	Flammable and explosive (when compressed)
Toxic to aquatic life	Risk of cryogenic burns	Risk of cryogenic burns (if liquid)	Toxic to humans and aquatic environments

Hydrogen has been used for decades in chemical refining, oil rigs, ammonia production and even spaceship propulsion. Ammonia is already an important chemical used readily as a key ingredient in the nitrogen fertilizer for agriculture, and for this reason the USA is one of the world's leading producers and consumers of ammonia. In 2020, the US was estimated to have produced 14 million metric tons of ammonia [9].

To support this activity, the American National Standards Institute already have regulations for the handling, transfer and transport of ammonia. Further guidelines are provided for the design, construction, repair, alteration, location, installation and operation of ammonia systems in the USA [10]. Similarly, Fertilizer Canada have the Ammonia Code of Practice for ammonia distribution, storage and handling of ammonia to ensure safety and security [11].

Addressing safety will be a necessary step in adopting electrofuels, yet it should not stifle efforts to both continue to advance their adoption or to simultaneously continue implementing a variety of other decarbonization options, such as energy efficiency, optimization of operational practices and electrification. Successfully meeting the decarbonization challenge for the industry will call for timely and sustained action from the industry on multiple fronts.

North America could kick-start the production and adoption of electrofuels for shipping across the world

The United States and Canada are key trading partners for major economies around the world. Its west coast serves as the cornerstone for its vast trade with Asia (mainly China and Japan). Its high traffic density and trading volumes, coupled with its vast resources and expertise, can make the region an important piece in the decarbonization of the shipping industry.

Political momentum also adds to the potential key role that the region can play, putting North America in a good position to become a pioneer in shipping decarbonization. The United States government has also sent strong signals in this regard, as they announced recently that they will be working with the IMO, and taking domestic actions, to reach zero emissions for international shipping by 2050 – a major step up from the current 50% reduction target. This could be an important turning point and could provide significant momentum to the growing efforts of adopting electrofuels in the shipping industry.

Supplying these electrofuels and deploying the renewable capacity needed to produce them, would also allow the local economy to leverage on its competitive advantages and expertise to seize additional benefits:

Creating new and future-proof sources of income for local economies: Current reliance on fossil fuels is forecast to decline, which is a risk to the communities and economies that rely on these industries. Zero-carbon fuels can provide an alternative, future-proofed industry, and can be leveraged to attract and service a low-carbon shipping fleet, securing a market for the future.

A commercial, competitive benefit in domestic and international markets: Businesses and their customers will increasingly demand zero-carbon shipping for products and materials. Being able to offer new zero-carbon fuels for commercial vessels will provide a competitive advantage for the goods traded through these ports.

Increasing opportunities to deploy renewables at scale: Significant volumes of renewable electricity generation infrastructure will be required to supply the production of zero-carbon electrofuels. This could reduce practical, financial and political barriers for the wider adoption of renewable technologies, through economies of scale, establishing supply chains and developing local capabilities and acceptance.

Supporting business cases for renewables: Zero-carbon electrofuels production can provide a reliable, flexible and valuable use for renewable generation, supporting the business case for its development. At peak generation times, renewable generation that might otherwise be curtailed, could be used to produce zero-carbon electrofuels.

Reducing reliance on fossil fuels: Adopting zero-carbon electro fuels not only brings carbon benefits, but also a reduced vulnerability to price shocks in the future from fossil fuels which are imported to the port.

Decarbonisation and synergies with other industries: Green hydrogen and ammonia can support decarbonization of other sectors. For example, hydrogen can be used as a part of low carbon steel production, green ammonia can be used in agriculture, and zero-carbon fuels can be used in heavy transport or machinery. This means that the development of a zero-carbon fuel sector around these ports could also provide opportunities for decarbonization in other sectors.

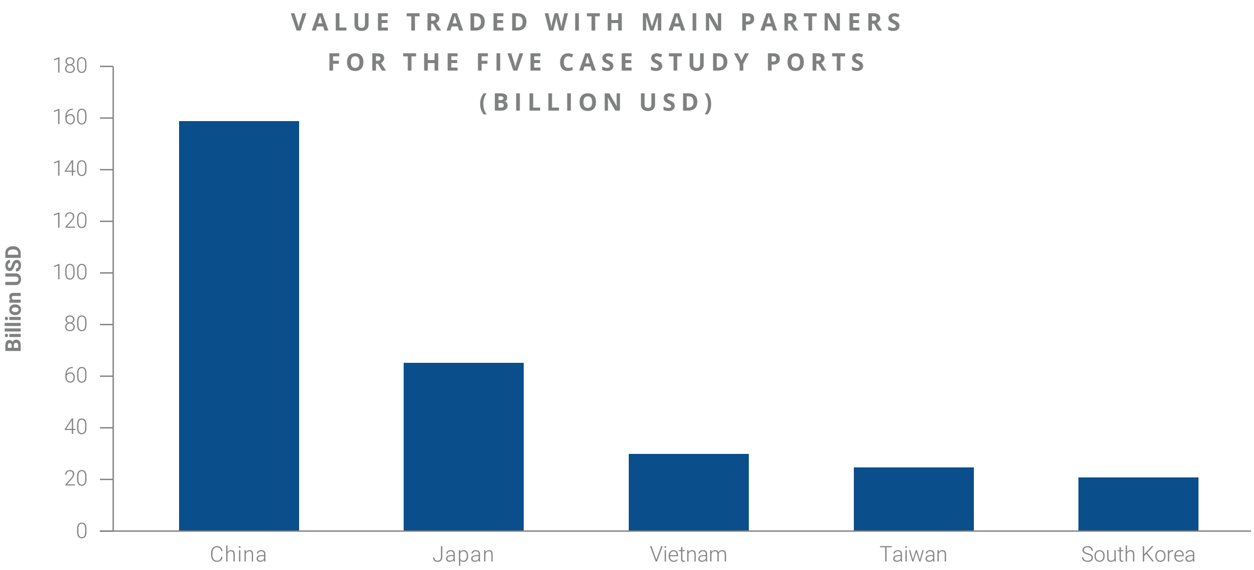
Real potential in job creation: There is the potential for the creation of a wide range of jobs created the new renewable energy and zero-carbon fuels sectors. This is an important aspect in a just transition that positively impacts not only the environment and delivers social and economic benefits for communities and local economies.

Potential to build investable projects: There is the opportunity to build project that are economically attractive and that can attract funding from the private sector and increase international climate funding.

Ports on the west coast of North America are well suited to adopt electrofuels and together could form a zero-carbon shipping corridor

Noting North America's advantageous position and the strategic opportunity to drive shipping decarbonization, this study focuses on five representative ports along the west coast of the region, and shows how they could become the building blocks of a zero-carbon shipping route that stretches from the south of the United States to the Bering Sea. Together, these ports accounted for over 300 billion US dollars of trade in 2018.

With the high traffic experienced in this route and the resources and opportunities identified, there is a clear and tangible opportunity to achieve significant decarbonization by producing and supplying electrofuels in these ports. These locations, or others like them, could position themselves at the forefront of the electrofuel economy, helping build a path for decarbonizing the rest of the industry, while capitalizing on the significant spill-over benefits that this could unlock for its local economies.



Source: [12] – Excludes Unalaska (no information available)

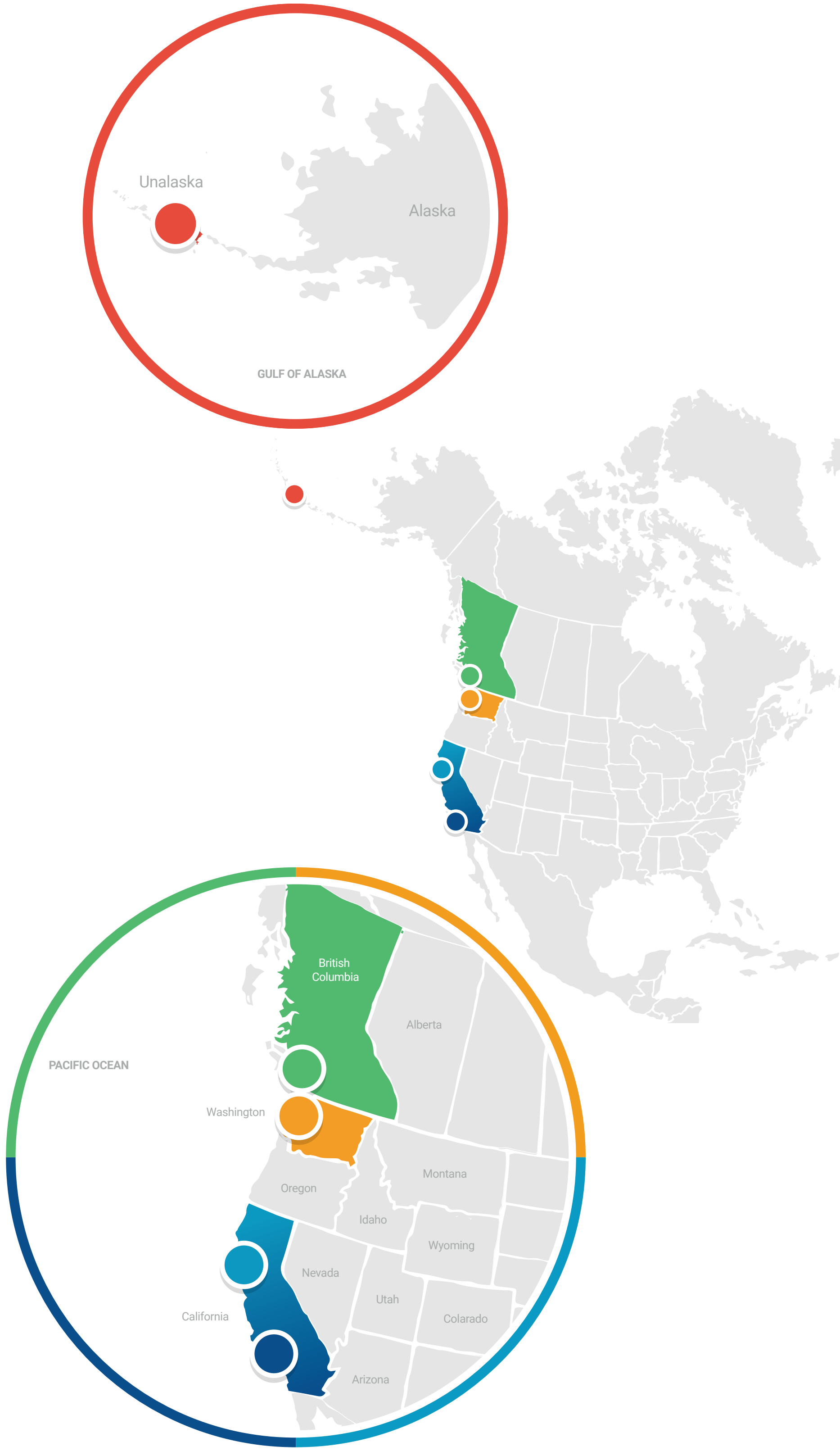
Unalaska:
Located in a remote island in Alaska, the Unalaska Port serves as an operation center for commercial fishing in the Bering Sea and is a major oil transshipping point [13].

Vancouver:
The largest port in Canada in terms of tons of cargo [15]. Already deploying infrastructure for alternative fuels that, coupled with local resource and environmental incentives, could also pave the way for supplying electrofuels.

Tacoma:
Emissions from the local grid are low [14] and opportunities for decarbonizing the fleet that the port serves are abundant.

Oakland:
Ambitious environmental plans and abundant local resources mean that the port is well placed for producing, supplying, and using electrofuels.

LA/Long Beach:
Busiest port of the United States [12] and a pioneer in decarbonization, with efficiency, electrification and even hydrogen initiatives already in place.

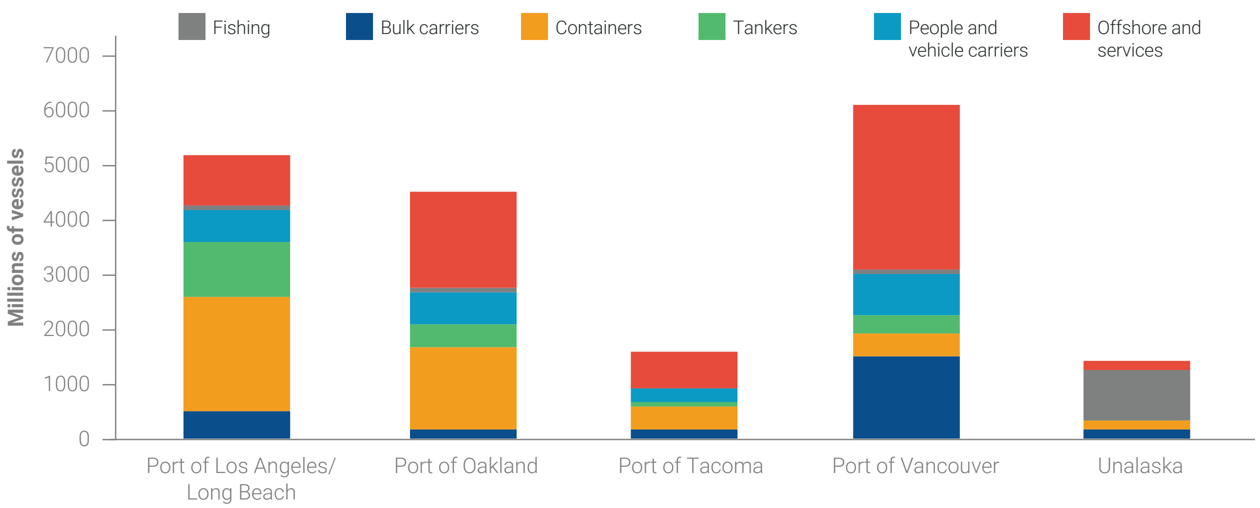


Deploying renewable energy and zero-carbon fuels infrastructure can enable electrofuel markets in these five locations

The five case study ports included in this report serve a high volume of a wide variety of ships. Decarbonizing at least a fraction of this traffic could significantly reduce emissions from shipping traffic, and could be the first step towards driving the widespread deployment of electrofuel production capacity and infrastructure for domestic and international ports.

Local economies around these ports could benefit from the development of a zero-carbon fuels sector, as they would be supplying a significant volume of electrofuels to these ships, and benefitting from the associated trade. The demand for zero-carbon fuels may start modest, but it is likely to progressively increase through to 2050 as more and more zero-carbon vessels are adopted.

DEPARTING SHIPS AT EACH PORT



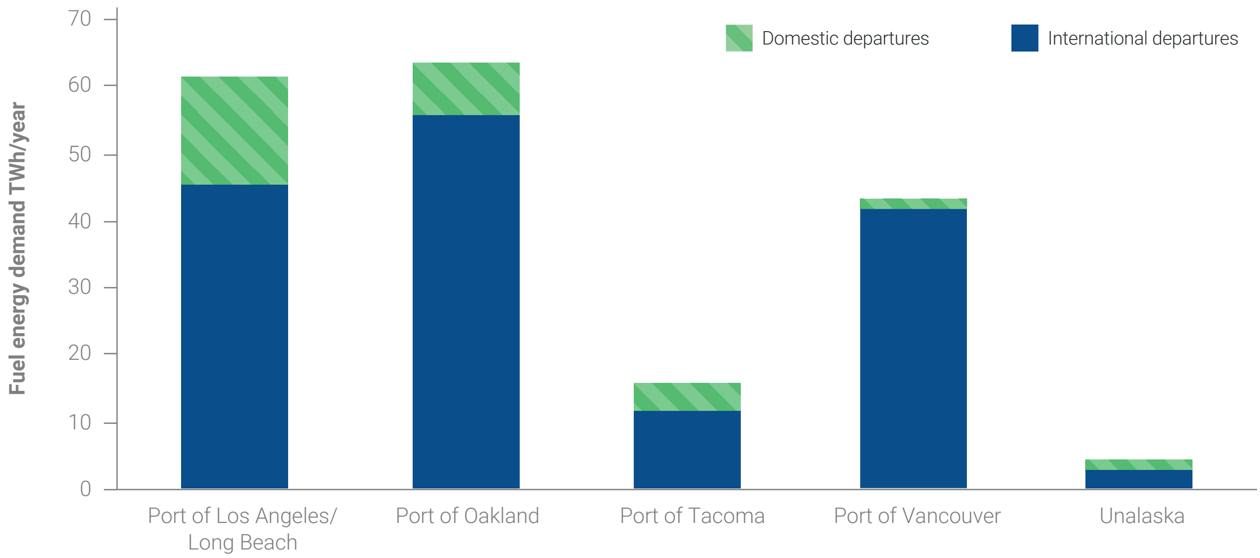
Vessel categories are defined in Appendix 1

The significant expertise and wide collaboration networks found in these ports, coupled with the high renewable resource potential in the region, could become key strategic advantages that allow them to seize the opportunity, create these markets and position themselves as its centerpieces.

The total fuel energy demand for vessels visiting all five case study ports is 188.5 TWh per year. However, the adoption of zero-carbon fuels by shipping vessels will be gradual over time. If fuel demand for 5% of international shipping and 15% of domestic shipping is met by zero-carbon fuels by 2030 (see call out box below), the aggregated fuel energy demand from these ports is estimated to be 37.6 TWh per year.

This demand would then grow over time as adoption increases, supported by technological advancements, additional political momentum or stronger regulations and incentives. This will add to the size of this potential opportunity for ports to establish future-proof and truly sustainable sources of income.

FUEL ENERGY DEMAND OF WEST COAST PORTS BY INTERNATIONAL AND DOMESTIC DEPARTURES



Adoption assumptions for international and domestic vessels

Zero-carbon fuel adoption of 5% by international shipping and 15% by domestic shipping by 2030 is used as a representative example of a 2030 adoption for the purposes of providing context for this report, and is not intended to be a forecast of actual adoption. The 5% adoption by international vessels aligns with work done by the Global Maritime forum [14]. For domestic vessels, it can be expected that adoption of zero-carbon fuels will be easier due to shorter journeys requiring less energy per journey, consistent policy and standards to support and incentivize adoption, and the potential availability of zero-carbon fuels across the different case study ports and beyond. A 15% adoption rate was selected for domestic vessels. The methodology used to estimate electrofuel and renewable energy requirements is presented in Appendix 2.

North America has an abundance of renewable energy potential that can be leveraged to support zero-carbon fuel production

The development of renewable energy infrastructure to provide zero-carbon fuels must be considered in addition to that needed to decarbonize the domestic demand.

The United States total electrical consumption is nearly 4,000 TWh per year (2019) [16]. It is estimated that supplying 100% of the vessels visiting the case study ports in the U.S. with hydrogen would require the 206 TWh per year of renewable electricity, and if ammonia was used, renewable electricity requirement would be 308 TWh per year (see Appendix 2 for calculation methodologies used for these values).

A report published by National Renewable Energy Laboratory (NREL) in 2020 [13] predicts that the United States holds more than 325,000 TWh per year of technical renewable energy potential. This figure includes achievable generation considering technology performance, topography limitations and environmental and land-use constraints, but not considering economic feasibility. While feasible potential will be considerably lower than this total, this value indicates the significant scale of the renewable energy potential covering solar, offshore and onshore wind, geothermal and hydropower.

In Canada it is a similar story; in total Canada consumes nearly 550 TWh per year of electricity (2019) [17]. In order to supply the vessels visiting the Port of Vancouver, Canada's largest port, with hydrogen fuel would require an estimated 61 TWh per year of renewable electricity, or 96 TWh per year to supply the vessels with ammonia.

It is estimated that Canada holds a total of over 3,000 TWh per year of feasible renewable energy potential [18]. Feasible potential considers physical constraints and economic limitations for renewable development.

This shows that production of zero-carbon fuels for shipping will not constrain renewables for other supply.

The United States of America has an estimated

325,000 TWh per year

of technical renewable energy potential [15].

Which compares to an electricity grid consumption of nearly

4,000 TWh per year

This suggests ample renewable energy potential to produce green hydrogen and ammonia for shipping.

Summary

Decarbonization of the shipping sector is essential in the face of the ongoing impacts of climate change. Establishing a zero-carbon shipping lane along the west coast of North America would simultaneously reduce emissions from the multitude of vessels transiting that route and potentially be influential in driving decarbonization of the shipping industry in other ports and regions.

Many of these ports are already in the process of considering or adopting sustainability and decarbonization strategies, which creates a fertile environment in which zero-carbon fuel adoption can flourish. Meeting the ambition outlined in this report would call for even stronger efforts and closer collaborations between stakeholders. The continued momentum can be supported by appropriate market signals and incentives which will help drive zero-carbon fuel adoption - resulting in the realization of all the environmental and economic benefits they have to offer.

Taking local initiative in these ports can establish a strong reference for future projects both locally and abroad. If zero-carbon fuels can be deployed in very busy ports such as the port of Los Angeles; as well as very remote ones like the port of Unalaska; then opportunities for wider deployment worldwide are abundant and could set the shipping industry well on track to meet its current and future decarbonization goals.

Establishing zero-carbon fuel markets in these ports and others like them can nurture and future-proof local economies. Ports included in this study, just as many others around the world, could see their activity impacted by market shifts due to climate change. Production and supply of green zero-carbon fuels could provide them with new and stable sources of income from exporting and selling fuels, promote knowledge transfer, create green jobs, and support decarbonization of the wider economy.

Case Study: Port of Los Angeles

Building on sustainability aspirations to decarbonize the busiest port in the United States

The Port of Los Angeles has ambitious goals and activities towards more sustainable practices

Located on the south western coast of the United States, the Port of Los Angeles is the busiest port in the country and moved over 9.2 million twenty-foot equivalent units (MTEUs) and over 250 billion US dollars in cargo value in 2020 [19]. The Port is surrounded by dense urban areas with extensive industrial, power and rail infrastructure. Despite limited available space, there are ten solar photovoltaic (PV) plants in the vicinity of the port.

The port is a leader in decarbonization measures of both its own operations and the fleet it serves. It currently has 79 shore power stations, the most of any port in the world [20]. These stations allow ships to run their equipment on electricity rather than diesel power while at berth, reducing noise and pollution [21]. Through various initiatives, the port has already reduced particulate matter emissions from port operations by over 85%, and nitrogen and sulfur oxides emissions by 50% and 95% respectively (relative to 2005-levels) [22].

Collaborative efforts like the World Port Climate Action Program and the Port of Long Beach's Green Port Policy, as well as international research and development collaborations [20] [23] have been instrumental in driving this change. These programs have helped implement energy efficiency and propulsion electrification, decarbonize cargo-handling operations, deploy renewables locally, and even support the adoption of sustainable low-carbon fuels by establishing green terminals. They have a platform to educate and engage with local communities as they launch improvements for the benefit of public health and the environment [24] [25]. Despite this, the Port of Los Angeles is still one of the largest sources of air pollutants in LA and further work is required to reduce emissions further.

Transitioning to zero-carbon fuels would be a complex undertaking for the port, but the high level of vessel traffic means that there is an equally rich opportunity to support new zero-carbon vessels as they are adopted. The Port of Los Angeles would be ideal to serve as a blueprint showing that it is feasible for a busy, urban port to transition into a zero-carbon future. Inaction, on the other hand, has a steep cost both to human health and could result in other ports becoming the refueling point for zero-carbon fuel powered ships, representing a major opportunity cost for ports that stay behind.

The Port of Los Angeles is the busiest in North America, serving a wide variety of ships

International trade (Percentage of Cargo Handled)

1. Northeast Asia: 72%
2. Southeast Asia: 21%
3. Indian sub-continent: 2%
4. Middle East: 1%

LOS ANGELES' TOP 5 IMPORT COMMODITIES

Furniture
Auto Parts
Apparel
Electronics
Plastics

LOS ANGELES' TOP 5 EXPORT COMMODITIES

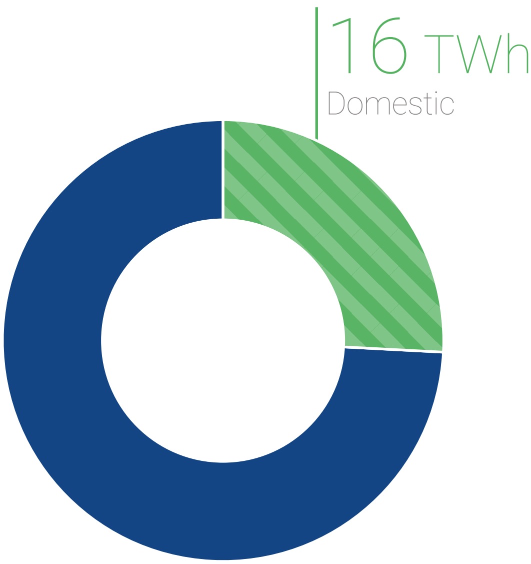
Pet/Animal Feed
Paper/Wastepaper
Soybeans
Scrap Metal
Fabrics/Raw Cotton

Source: [18]

The main goods arriving at the Port of Los Angeles (by volume) are furniture, automobile parts and clothes, while most of the exports are made up of paper, animal feed and fabric. Almost half (44%) of the traded value corresponds to trade with China and Hong Kong, followed by Japan with 13%.

These figures highlight how important Asian trade is for the port's activities. This means that for the successful adoption of zero-carbon fuels in this port by international trade vessels, ships would also depend on the availability of zero-carbon fuel supply and infrastructure in various ports in Asia. Some nations are already on their way to making this happen; Japan and China are already investing in hydrogen as a shipping fuel.

BREAKDOWN OF ENERGY USAGE BY VESSELS DEPARTING THE PORT OF LOS ANGELES [60]



Calculated energy from voyages departing Port of Los Angeles based on AIS data from 2018 [26]

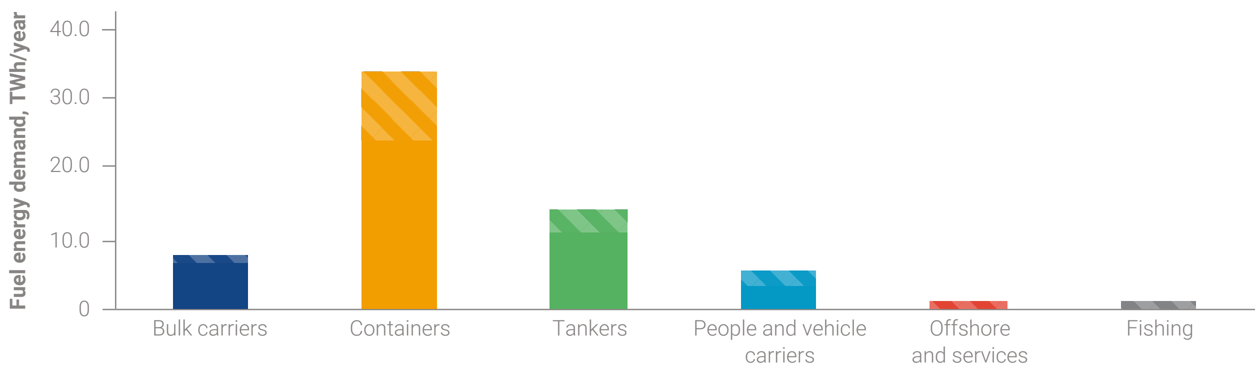
The most common vessel type visiting the Port of Los Angeles is container vessels. The charts below demonstrate the traffic and energy usage of vessels departing the Port of Los Angeles by vessel type.

Domestic container ships are the most common vessels departing the port; however, the highest energy usage is container ships on international voyages. This implies that vessels on domestic voyages are making a higher number of small journeys while international departures are making long voyages that use more fuel per journey, likely across the Pacific.

Domestic departures International departures

NUMBER OF VESSELS DEPARTING THE PORT OF LOS ANGELES IN 2018 BY VESSEL CATEGORY [26]

ENERGY USAGE OF VESSELS DEPARTING THE PORT OF LOS ANGELES IN 2018 BY VESSEL CATEGORY [26]

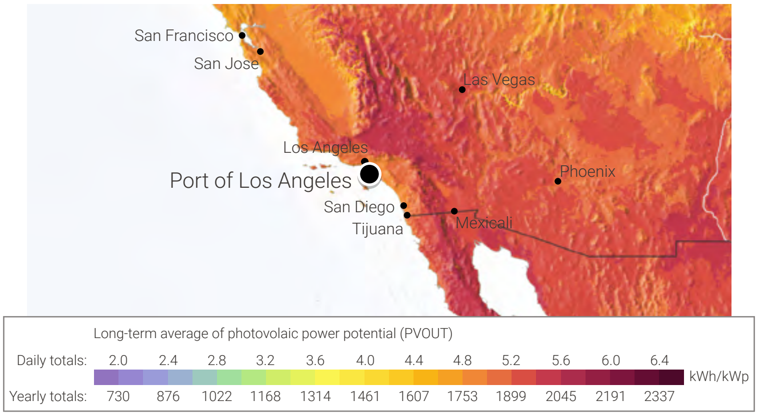


See appendix 1 for vessel category definitions. Energy calculations based on AIS data from 2018

The production of zero-carbon fuels can be supported by renewable energy resources offshore and further inland from the port

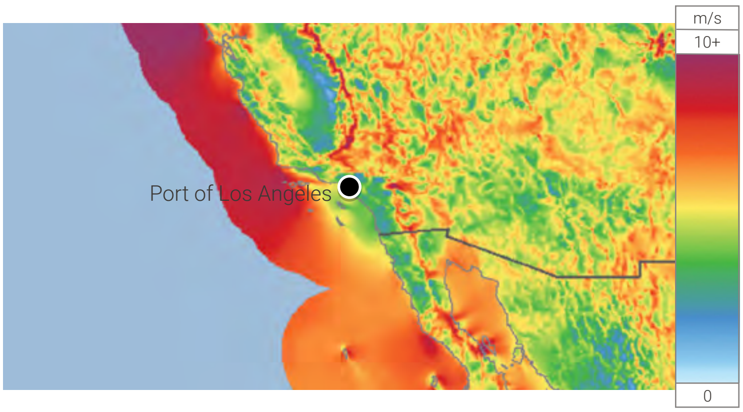
There is significant potential for renewable electricity generation in the state of California and nearby areas, including strong resource for wind, solar and potentially viable geothermal energy. The area immediately adjacent to the Port of Los Angeles is a built up open area with limited land available for wind or solar generation. Coupled with the high price of land it means onshore generation will have to be some distance from the port. However, there is promising offshore wind resource not far from the coastline, and recent government announcements provide optimism towards the feasibility of deploying offshore wind assets both in this port and other areas in the United States.

SOLAR ELECTRICITY GENERATION POTENTIAL AROUND LOS ANGELES



Solar PV electricity generation potential from SolarGIS.com used with permission

WIND ELECTRICITY GENERATION POTENTIAL AROUND LOS ANGELES



Mean wind speeds at 100 m hub height from GlobalWindAtlas.info used with permission [27]

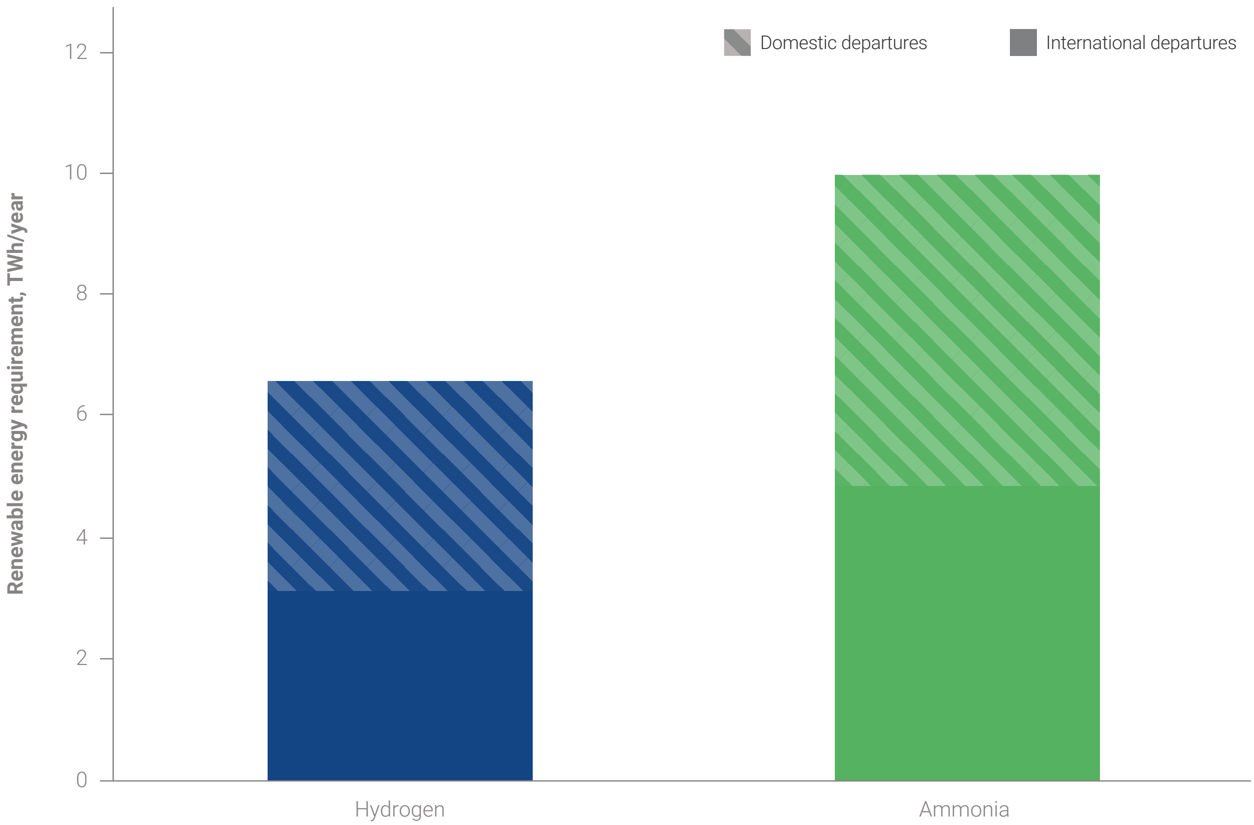
This potential could be leveraged to support the production of zero-carbon fuels. Where the renewable generation infrastructure is located a distance away from the production facilities, the wider grid could be used to deliver renewable electricity, potentially through private supply relationships between the generator, the production facility and the network operator. The benefit of situating renewable capacity away from the port will mean fewer constraints as to where generation can be sited, meaning that locations can be found that have high energy potential and avoid land use issues. Land used for renewable generation can also be used for other purposes, for example land used for wind farms can still be used for crops, and land used for solar farms can be shared with grazing livestock.

The infrastructure needed for the adoption of zero-carbon fuels up to 2030 can be scaled to the demand

The scale of the demand for zero-carbon fuels will depend on the speed of technology adoption. To provide a view of scale, a representative 2030 adoption case is used, which assumes that zero-carbon fuel is adopted by 5% of international vessels and 15% of domestic vessels. This assumption is used for the purposes of providing context for this report, and is not intended to be a forecast of actual adoption. The methodology used to estimate zero-carbon fuel and renewable energy requirements is presented in Appendix 2.

This case shows the renewable electricity generation requirements to produce sufficient green hydrogen or ammonia to meet the fuel demand of the port of Los Angeles. The calculations for these figures takes into account the efficiencies and losses of converting renewable electricity into zero-carbon fuel, and then using that fuel in the vessel.

RENEWABLE ENERGY REQUIRED TO MEET THE ZERO-CARBON FUEL DEMAND IN THE 2030 ADOPTION CASE



To meet the fueling demands of the representative 2030 adoption case through green hydrogen fuel, 6.7 TWh per year of renewable electricity would be required. To meet the demand with green ammonia, 10 TWh per year of renewable energy would be needed. It is possible that green hydrogen and green ammonia will be used in parallel, each being used for the vessel types and use cases to which they are best suited. This means that the actual renewable generation requirement will be somewhere between these figures.

The renewable electricity generation infrastructure that is required to meet these renewable electricity needs could be met through a variety of ways, for example, if all the capability was provided through solar, 3.7 GWp to 5.5 GWp of installed generation capacity would be required. If the needs are met through wind power, 2.2 GWp to 3.2 GWp of installed onshore wind generation capacity is needed, or 1.2 GWp to 2.1 GWp of offshore wind.

Hydrogen

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

3.7 GW
Solar

or

2.2 GW
Onshore wind

or

1.2 GW
Offshore wind

Ammonia

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

5.5 GW
Solar

or

3.2 GW
Onshore wind

or

2.1 GW
Offshore wind

THE SPACE NEEDED TO BUILD THIS INFRASTRUCTURE DEPENDS ON THE TECHNOLOGY:

1 GW of solar generation infrastructure would cover about 3,000 football fields

But this space could also be used to graze livestock

1 GW of onshore wind generation infrastructure would require about 64,000 football fields of land

But this land can also be used for growing crops and other agriculture

1 GW of offshore wind generation infrastructure would require about 26,000 football fields of ocean space

The Port of Los Angeles can build on the momentum of sustainable activity and available renewable resources to create a sustainable economy

The Port of Los Angeles is part of the World Ports Climate Action Program (WPCAP). The WPCAP includes 12 of the world's top leading ports and has implemented multiple initiatives thanks to international collaborations which include ports in Mexico, China and even the Panama Canal [28]. There is an opportunity here to leverage on the capacities and proactiveness that these actors and collaborative initiatives bring to not only drive the transition of this port, but also many others in the region and abroad.

This has driven the deployment of extensive sustainable infrastructure, including shore power stations, electric cargo handling equipment, both electric and fuel cell-powered trucks, and research towards the development of the world's first hydrogen-powered tugboat [29] [30]. Cargo handling equipment at the port is expected to reach net zero by 2030 and the drayage truck fleet is expected to reach it by 2035.

This ongoing momentum can be an asset for deploying zero-carbon fuels at the port and renewables either at the port or further inland, and to decarbonize the shipping fleet. There is an opportunity to build on the enormous sustainability ambitions of the actors involved in these initiatives and networks to decarbonize the busiest port in all the United States.

Driving the creation of green jobs for a just energy transition that not only safeguards the environment but also delivers social and economic benefits

With the energy transition underway and the current push for decarbonization commitments and regulation in the United States, the challenge of maintaining jobs and creating new future-proof capabilities is at the top of mind of industry leaders and policymakers.

Opportunities like these can become a platform for transferring skills and create opportunities for the existing workforce to be ready for the shift in demand towards green jobs and sustainability-related skills, all while decarbonizing the busiest port in the United States.

Case Study: Port of Oakland

Outstanding potential for renewable electricity generation can support a green hydrogen economy beyond the shipping industry

The port's proactive approach to sustainability and local resources can be a winning combination

The Port of Oakland is located in San Francisco in Northern California and is the 8th busiest port in the United States with over 2.5 million TEUs moved through it annually [31]. The port is in the Bay of San Francisco and is surrounded by a dense urban area, beyond which lies a mountainous area with a series of regional parks and preserves.

The Port of Oakland prides itself in its commitment to environmental stewardship. The measures that the port incorporates are wide ranging and focus on air quality, climate change impact, water pollution, habitat restoration and the local community [32]. Shore power is an example of an initiative with a significant impact. In 2019, 80% of the 1,419 vessel calls plugged into Shore power, thus cutting completely their emissions from auxiliary diesel engines [33]. Another example is the overall diesel emissions associated with port activities which have been reduced by 70% between 2005 and 2012 [32]. These reductions have helped to address environmental justice concerns in Oakland, adoption of zero-carbon fuels will aid this advancement further.

The ambitious net zero target in California, coupled with the excellent renewable energy resources and relatively clean grid energy, present an opportunity for the port. The path to decarbonizing shipping likely lies in hydrogen and hydrogen-derived fuels such as ammonia and the excellent renewable energy potential could help the port position itself at the heart of this transition.

Container ships and tankers are by far the largest fuel consumers at the Port of Oakland

International trade (Percentage of Cargo Handled)

1. Asia: 76%
2. Europe: 14%
3. Hawaii: 5%
4. Australia: 3%
5. Other: 2%

OAKLAND'S TOP 5 IMPORT COMMODITIES

Furniture

Packaging

Glass & glassware

Machinery

Electrical machinery

OAKLAND'S TOP 5 EXPORT COMMODITIES

Wood pulp

Fruits & nuts

Meat & fish

Beverages & spirits

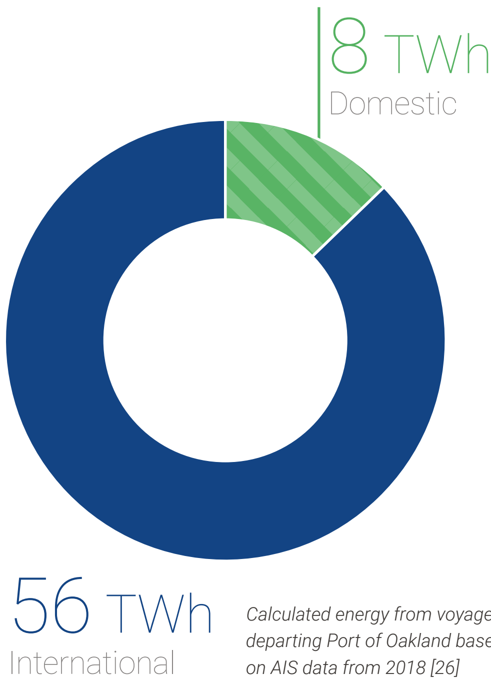
Grains & seeds

Source: [29]

Contrasting to an extent with the number of vessels, the total energy requirements of the different types of vessels shows that container ships are the largest energy consumers, accounting for over 80% of the energy consumption, mostly aimed at international shipping. Energy usage is calculated from the energy use by all departing international and domestic voyages to their destination.

This paints an optimistic picture for zero-carbon fuel adoption, as fewer vessels would need to be converted, and each conversion would shift a significant amount of demand away from fossil fuels and into the renewable energy space.

BREAKDOWN OF ENERGY USAGE BY VESSELS DEPARTING THE PORT OF OAKLAND [26]



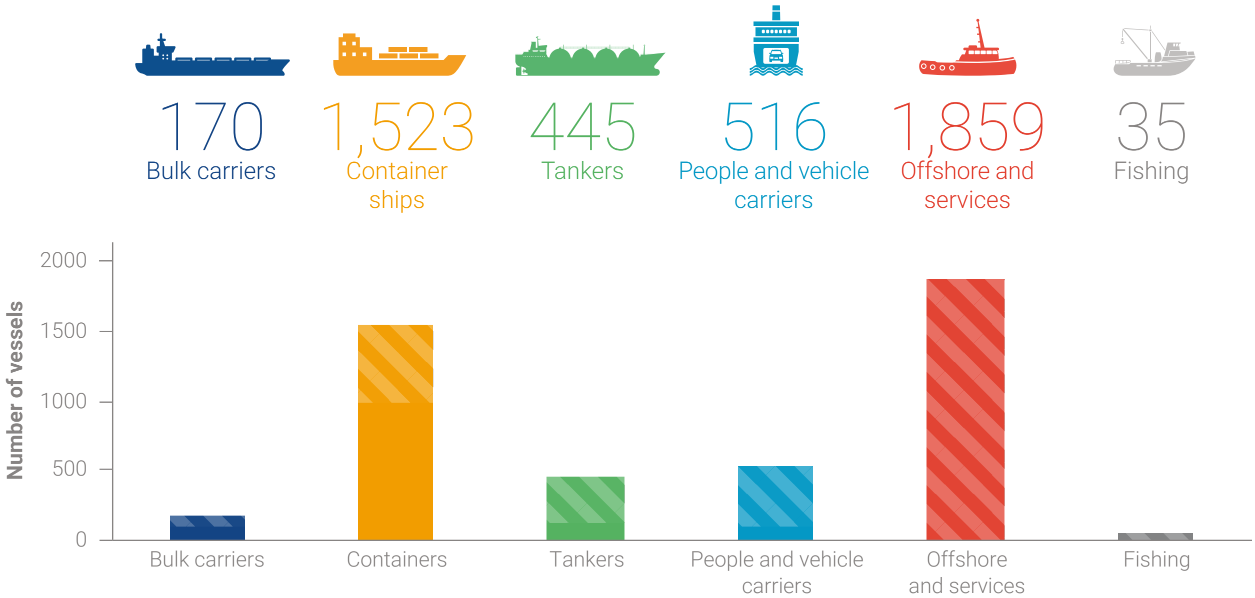
Calculated energy from voyages departing Port of Oakland based on AIS data from 2018 [26]

The charts below demonstrate the traffic and energy usage of vessels departing the Port of Oakland by vessel type.

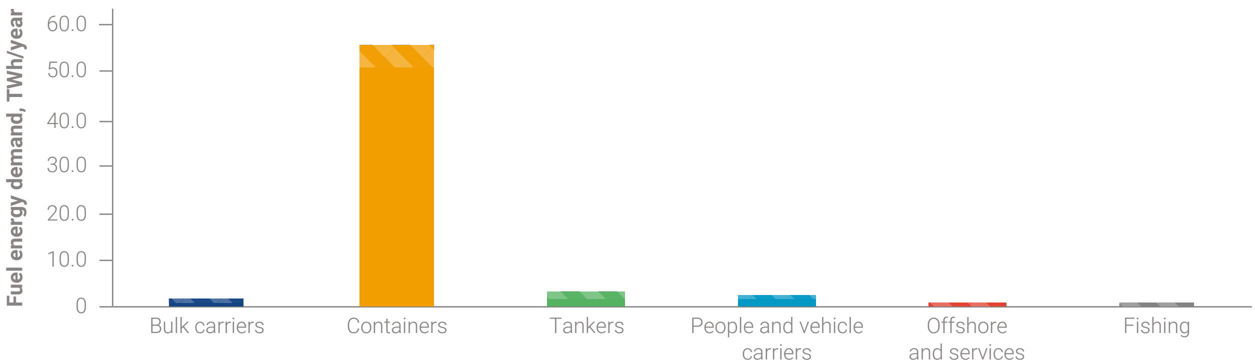
Domestic offshore and services vessels are the most common vessels departing the port; this may include servicing for offshore platforms, tugs and bunker vessels among others. However, by far the highest energy usage is by container ships on international voyages. This implies that domestic offshore and services vessels have short journeys and significantly lower energy requirement per journey than international container vessels.

Domestic departures   International departures

NUMBER OF VESSELS DEPARTING THE PORT OF OAKLAND IN 2018 BY VESSEL CATEGORY [26]



ENERGY USAGE OF VESSELS DEPARTING THE PORT OF OAKLAND IN 2018 BY VESSEL CATEGORY [26]

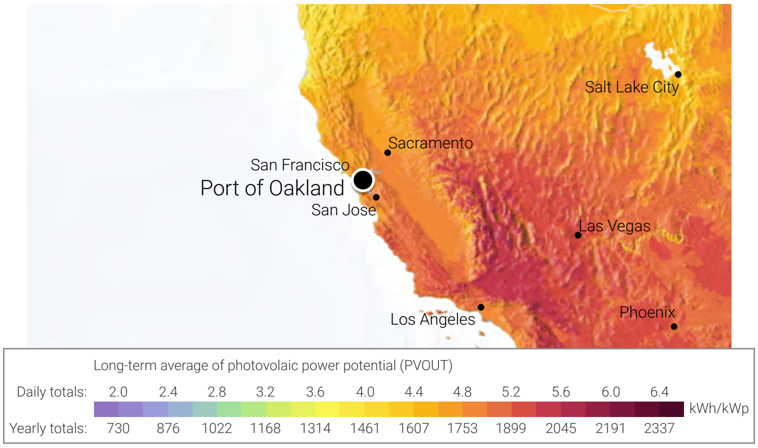


See appendix 1 for vessel category definitions. Energy calculations based on AIS data from 2018

Offshore wind and PV could be used to produce zero-carbon fuels

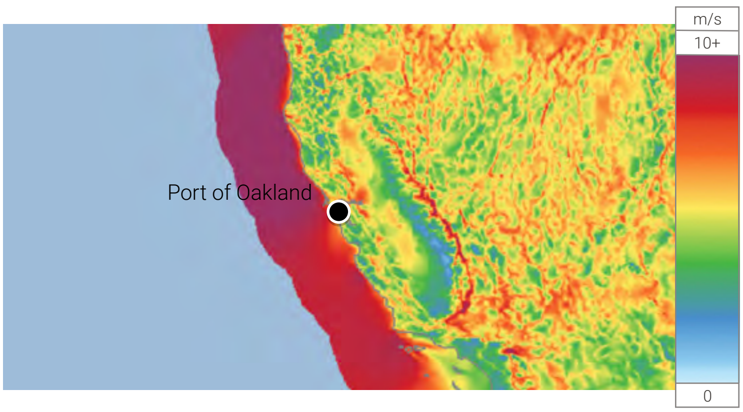
California is renowned for its excellent solar resource. While the solar irradiance in Northern California is not as high as in the south of the state, the area around Oakland boasts 4.35 kWh/m^2/day of average global horizontal irradiance, which improves to the east and reaches 5.12 kWh/m^2/day in Stockton [34]. There is also potential for offshore wind further out at sea, although onshore wind resource seems limited [35].

SOLAR ELECTRICITY GENERATION POTENTIAL AROUND OAKLAND



Solar PV electricity generation potential from SolarGIS.com used with permission

WIND ELECTRICITY GENERATION POTENTIAL AROUND OAKLAND



Mean wind speeds at 100 m hub height from GlobalWindAtlas.info used with permission [27]

Land availability for renewable energy developments in the San Francisco bay area is likely to be scarce, but there is significant potential further east, where already existing land use can be tied with renewable generation.

There is also significant rooftop potential for solar PV installations that could increase local renewable output, complementing inputs from the grid. Should the port adopt zero-carbon fuels, the existing fuel infrastructure could also be repurposed, opening way for additional zero-carbon fuels and renewable installations.

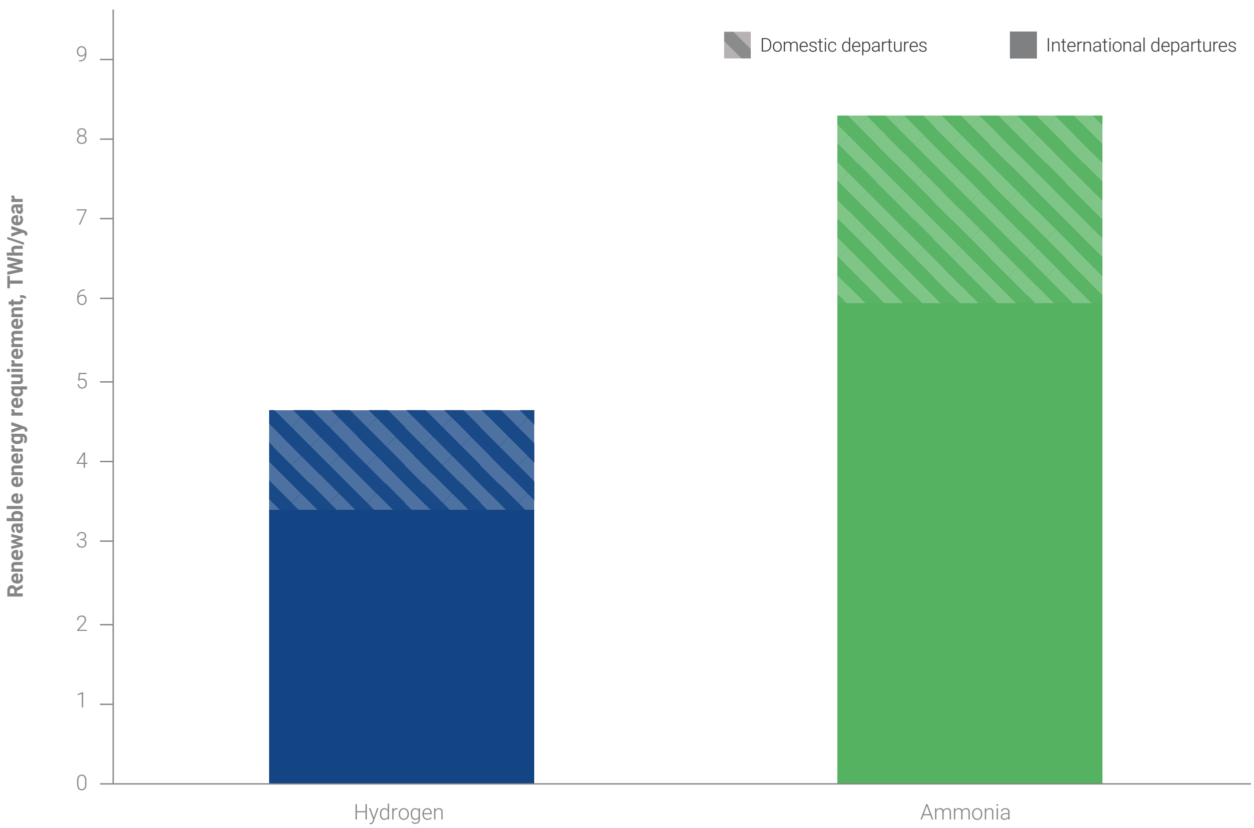
The infrastructure needed for the adoption of zero-carbon fuels up to 2030 can be scaled to the demand

The scale of the demand for zero-carbon fuels will depend on the speed of technology adoption. As with the other case studies, a representative 2030 adoption case is used. This demonstrates the amount of energy needed to meet the demand of green ammonia and green hydrogen on the assumption that 5% of international vessels and 15% of domestic vessels will have transitioned to zero-carbon fuels. The methodology used to estimate zero-carbon fuel and renewable energy requirements is presented in Appendix 2.

This case shows the renewable electricity generation requirements to produce sufficient green hydrogen or ammonia to meet the fuel demand of the Port of Oakland. The calculations for these figures takes into account the efficiencies and losses of converting renewable electricity into zero-carbon fuel, and then using that fuel in the vessel.

Due to The Port of Oakland's frequent international vessels the energy demand from its international vessels is high. By growing the adoption of domestic vessels to zero-carbon fuels in the port may act as a catalyst for international vessels demonstrating the feasibility of production and bunkering using zero-carbon fuels.

RENEWABLE ENERGY REQUIRED TO MEET THE ZERO-CARBON FUEL DEMAND IN THE 2030 ADOPTION CASE



To meet the fueling demands of the representative 2030 adoption case through green hydrogen fuel, 4.6 TWh per year of renewable electricity would be required. To meet the demand with green ammonia, 8.3 TWh/year of renewable energy would be needed. It is possible that green hydrogen and green ammonia will be used in parallel, each being used for the vessel types and use cases to which they are best suited. This means that the actual renewable generation requirement will be somewhere between these figures.

Hydrogen

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

3.1 GW
Solar

or

1.8 GW
Onshore wind

or

1.2 GW
Offshore wind

Ammonia

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

4.6 GW
Solar

or

2.7 GW
Onshore wind

or

1.7 GW
Offshore wind

THE SPACE NEEDED TO BUILD THIS INFRASTRUCTURE DEPENDS ON THE TECHNOLOGY:

1 GW of solar generation infrastructure would cover about 3,000 football fields

But this space could also be used to graze livestock

1 GW of onshore wind generation infrastructure would require about 64,000 football fields of land

But this land can also be used for growing crops and other agriculture

1 GW of offshore wind generation infrastructure would require about 26,000 football fields of ocean space

Initiatives at the Port of Oakland today can help decarbonize adjacent industries and rail operations in the future

Decarbonizing the shipping sector is a considerable challenge, and momentum is likely to build up slowly. There is an important opportunity to drive and influence the uptake of zero-carbon fuels. Industries nearby can become early adopters and zero-carbon fuels produced could even be used to power nearby rail operations.

Hydrogen-powered trains are already in operation in various countries and are being tested in many others [36]. Zero-carbon fuels produced at the port could be used in the future to power nearby railroad operations, and for scaling up the hydrogen pilots that the port has already started implementing.

Long term planning and coordination can enable larger initiatives

While surrounding industries and railways could have a role to play in the local hydrogen economy that could spawn as a result of adopting zero-carbon fuels at the Port of Oakland, they are likely to join the movement at different points in time. Long-term planning and strong stakeholder coordination would therefore be imperative for achieving success.

Their incorporation can be key for creating a solid economic environment and maximizing the use of resources and infrastructure, as well as enabling the bankability of its components, but to achieve this, cooperation and coordination must start sooner rather than later.

Case Study: Port of Tacoma

Enabling zero-carbon fuel adoption while decarbonizing local passenger transport

The Port of Tacoma is striving for sustainability, backed by both local and state-wide targets

Since 2014, the Port of Tacoma is part of the North West Seaport Alliance alongside the Port of Seattle. Both ports are located in the Puget Sound and are surrounded by dense urban areas and hills beyond it. The Port of Tacoma is the 10th largest in the US and in 2020 it received 1,684 vessels which translated in a total volume of nearly 3.3 million TEUs [37].

The North West Seaport Alliance actively pursues environmental programs to improve neighboring wildlife habitats and reduce its contributions to air and water pollution. Currently about 50% of container ships calling at the two ports are shore power equipped, but there are plans in place to equip the remaining large international container terminals by 2030 and cut diesel emissions from vessels further [38]. There are also efforts to reduce emissions from diesel trucks. Storm water run-off is treated to remove industrial pollutants. The Port of Tacoma also invests in offset purchases to support renewable energy projects.

The state of Washington has a net zero target for 2050 with two interim targets of 45% reduction from 2005 levels by 2030 and 70% reduction from 2005 levels by 2040 [39]. The Port of Tacoma has already embarked on a journey to cut its emissions. By leveraging the renewable energy potential in the state and taking up hydrogen derived fuels, the port has the opportunity to position itself at the forefront of the decarbonization of shipping.

The Port of Tacoma trades heavily with Asia, mostly for imports, yet most of its fuel demand is for departures

International trade (Percentage of Cargo Handled)

1. Asia: 90%
2. Europe and Middle East: 5.5%
3. Latin America & Caribbean: 4%

TACOMA'S TOP 5 IMPORT COMMODITIES

Furniture
Other Machinery
Motor Vehicle Parts
Toys & Games
Other Textiles

TACOMA'S TOP 5 EXPORT COMMODITIES

Hay & Forage
Frozen Potato Products
Paper & Paperboard
Scrap Paper
Other Foodstuffs

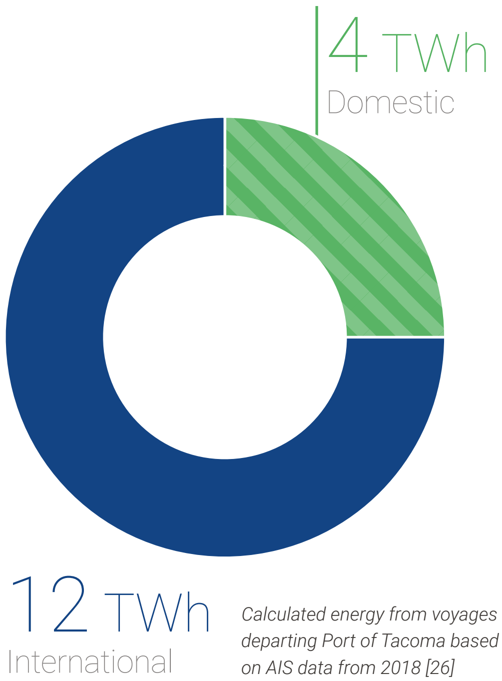
Source: [40]

The Port of Tacoma is oriented towards imports, which are responsible for 61% of the port's activity. The main imports are machinery, furniture, materials such as metals and plastics, and toys. The exports are predominantly foodstuffs and wood products. Its top five trading partners are all in Asia, with China in first place [41].

The total number of voyages through the port for 2018 is 3,256, with 996 unique vessel calls.

Container ships, which have the second largest number of vessel calls, are responsible for 64% of the energy consumption for all shipping. Apart from the People and Vehicle Carriers category, international shipping is responsible for most of the energy consumption.

BREAKDOWN OF ENERGY USAGE BY VESSELS DEPARTING THE PORT OF TACOMA [26]

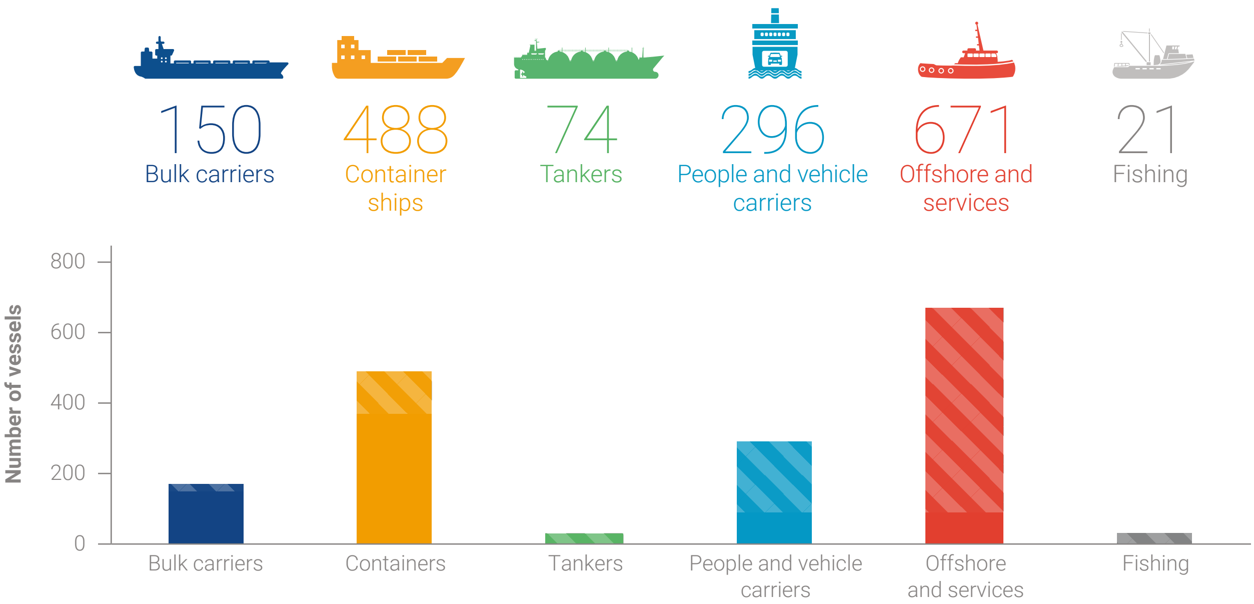


Calculated energy from voyages departing Port of Tacoma based on AIS data from 2018 [26]

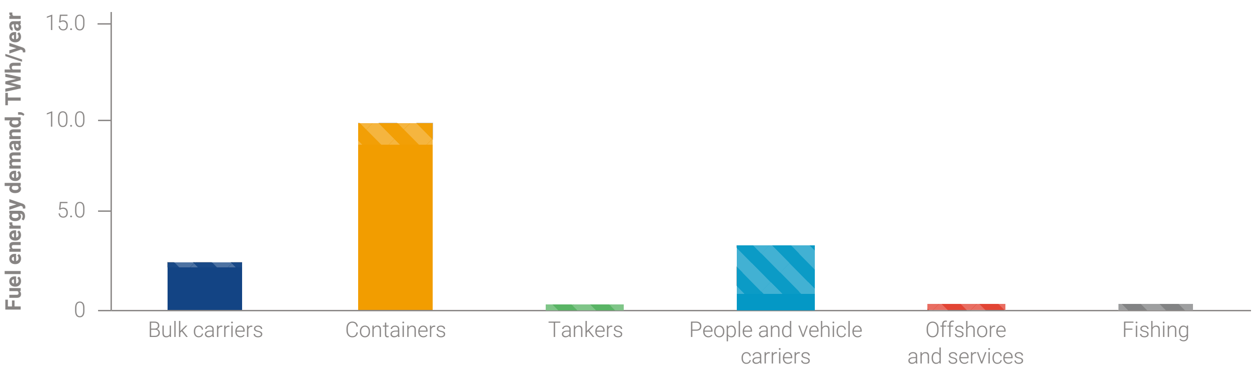
In total, international departures account for 12 TWh, while domestic departures account for 4 TWh. Energy usage is calculated from the energy use by all international and domestic voyages to their destination. The total amount of ammonia necessary for international shipping if direct use in ICEs is assumed is about 2 million tonnes for international departures, while for domestic departures the figure is 1 million tonnes.

Domestic departures   International departures

NUMBER OF VESSELS DEPARTING THE PORT OF TACOMA IN 2018 BY VESSEL CATEGORY [26]



ENERGY USAGE OF VESSELS DEPARTING THE PORT OF TACOMA IN 2018 BY VESSEL CATEGORY [26]

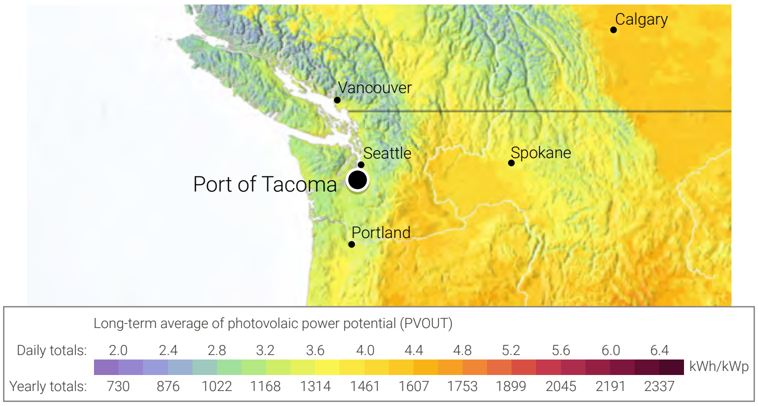


See appendix 1 for vessel category definitions. Energy calculations based on AIS data from 2018

Washington offers a highly decarbonized grid that can support local zero-carbon fuel production

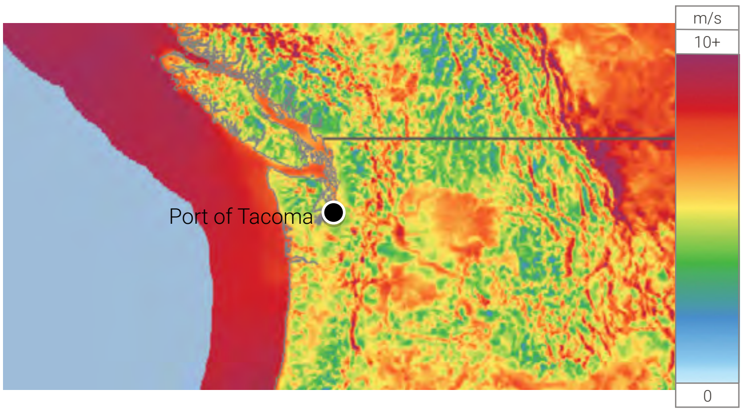
The state of Washington already produces nearly 80% of its electricity from low carbon sources, dominated by hydroelectricity, however there are environmental concerns associated with it. As a result, alternative sources need to be considered including a transition to wind and solar but also micro-hydro generation.

SOLAR ELECTRICITY GENERATION POTENTIAL AROUND TACOMA



Solar PV electricity generation potential from SolarGIS.com used with permission

WIND ELECTRICITY GENERATION POTENTIAL AROUND TACOMA



Mean wind speeds at 100 m hub height from GlobalWindAtlas.info used with permission [27]

Washington has a good solar energy potential with GHI of 3.47 kWh/m^2/day in Tacoma and 4.28 kWh/m^2/day in Kennewick in the south-east of the state. Wind potential is low on land and the location of the port does not allow large solar developments in the immediate vicinity, but additional sites can be explored throughout the State. Renewable generation sites can be co-located with agricultural activity.

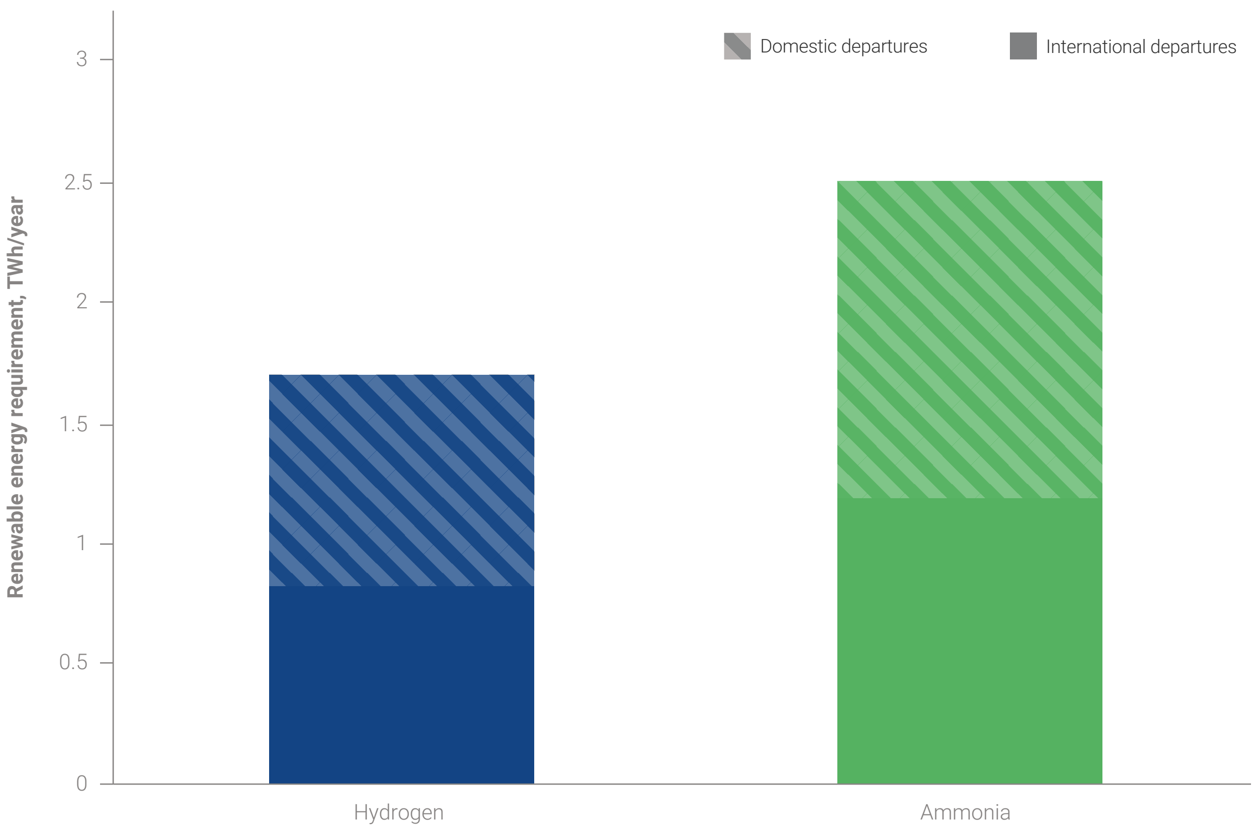
The infrastructure needed for the adoption of zero-carbon fuels up to 2030 can be scaled to the demand

The scale of the demand for zero-carbon fuels will depend on the speed of technology adoption. To provide a view of scale, a representative 2030 adoption case is used. This demonstrates the amount of energy generation required to produce the demand of green ammonia and green hydrogen on the assumption that 5% of international vessels and 15% of domestic vessels have transitioned to zero-carbon fuels. The methodology used to estimate zero-carbon fuel and renewable energy requirements is presented in Appendix 2.

This case shows the renewable electricity generation requirements to produce sufficient green hydrogen or ammonia to meet the fuel demand of the port of Tacoma. The calculations for these figures take into account the efficiencies and losses of converting renewable electricity into zero-carbon fuel, and then using that fuel in the vessel.

The amount of energy required to supply the domestic and international vessels, at the port of Tacoma are strikingly similar, likely due to the large amount of energy requirement from container ships on international voyages.

RENEWABLE ENERGY REQUIRED TO MEET THE ZERO-CARBON FUEL DEMAND IN THE 2030 ADOPTION CASE



To meet the fueling demands of the representative 2030 adoption case through green hydrogen fuel, 1.7 TWh per year of renewable electricity would be required. To meet the demand with green ammonia, 2.5 TWh per year of renewable energy would be needed. It is possible that green hydrogen and green ammonia will be used in parallel, each being used for the vessel types and use cases to which they are best suited. This means that the actual renewable generation requirement will be somewhere between these figures.

Hydrogen

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

1.3 GW
Solar

or

0.5 GW
Onshore wind

or

0.4 GW
Offshore wind

Ammonia

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

1.9 GW
Solar

or

0.8 GW
Onshore wind

or

0.6 GW
Offshore wind

THE SPACE NEEDED TO BUILD THIS INFRASTRUCTURE DEPENDS ON THE TECHNOLOGY:

1 GW of solar generation infrastructure would cover about 3,000 football fields

But this space could also be used to graze livestock

1 GW of onshore wind generation infrastructure would require about 64,000 football fields of land

But this land can also be used for growing crops and other agriculture

1 GW of offshore wind generation infrastructure would require about 26,000 football fields of ocean space

Locally deployed renewables can help decarbonize passenger transport and reduce local pollution

Reducing pollution from visiting ships can have a significant positive impact in the port's surroundings, which is densely populated. At the same time, initiatives that increase the amount of renewable generation available, as well as its related infrastructure, are likely to enable decarbonization of nearby loads and operations, bringing with it a wave of green jobs that leave behind a considerable amount of learning, knowledge, and transferrable skills that can catalyze and future-proof the local economy.

Cooperation and proactive initiatives at the port must seek to strike a balance between enabling the transition of the shipping industry – by providing the power and/or fuel sources decarbonized ships will need – while also making the best possible use of the available renewable resource.

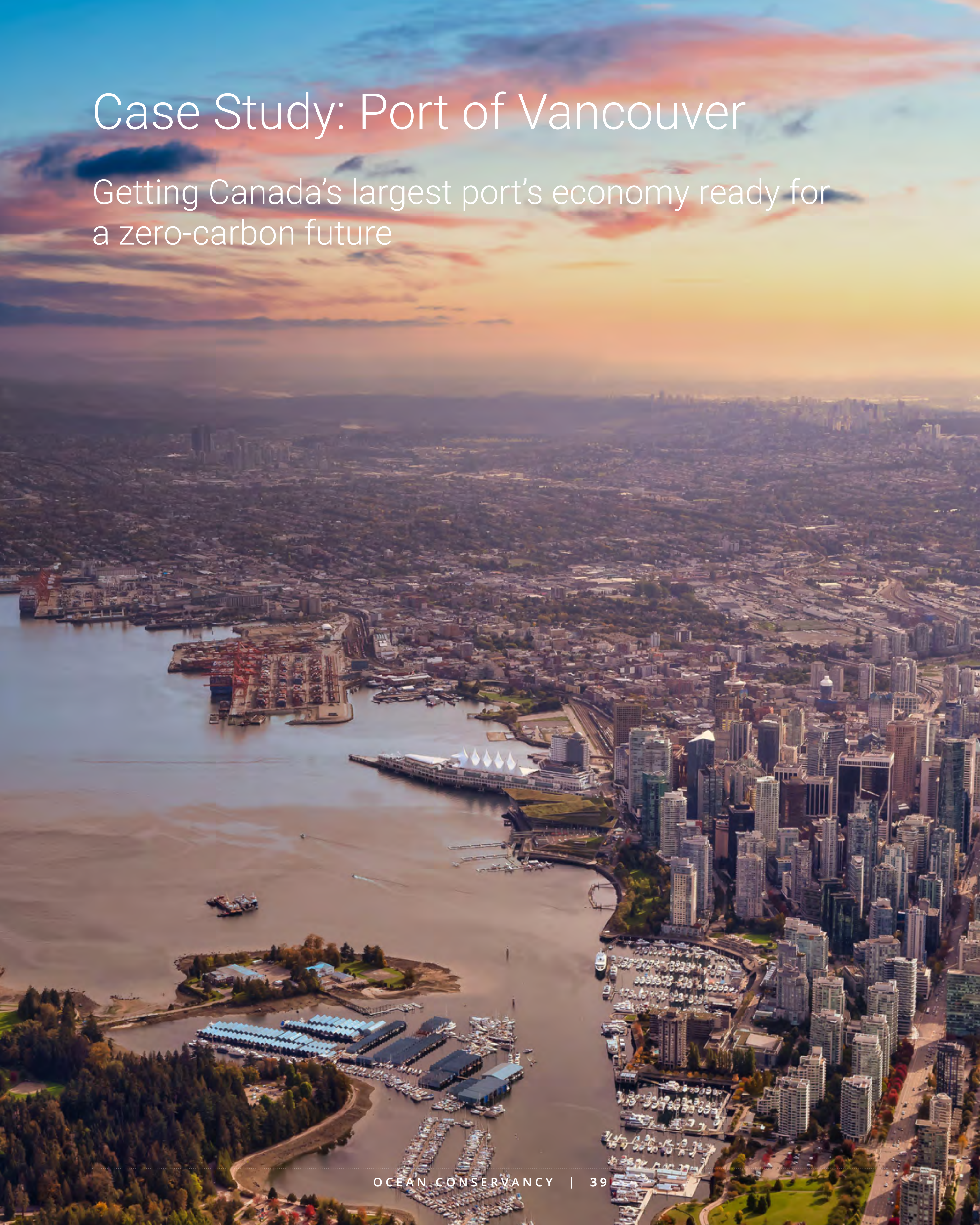
This is especially important around the Port of Tacoma, since it experiences significantly less traffic than the other major ports included in this study, but a much larger share of traffic of people and vehicle carriers, which make up 40% of the port's departures.

Finding the right balance

Local initiatives should strike a balance between decarbonizing local ships for passenger and vehicle traffic while enabling the transition of larger ships and making the best use of the available renewable resource.

Case Study: Port of Vancouver

Getting Canada's largest port's economy ready for a zero-carbon future



Vancouver is Canada's largest port and active in both impact mitigation and sustainability

The Port of Vancouver is located in an urban area, which, in turn, is surrounded by mountains. It is the largest port in Canada and is geared towards a diverse range of cargo, as well as cruise ships [42]. The port is responsible for a third of Canada's trade in goods outside of North America; the total volume of cargo in 2019 was 3,398,860 TEUs [43].

The port is a signatory to the World Ports Climate Action Program which focuses on efficiency improvements, emissions reductions and accelerating the development of sustainable low carbon fuels. Further to this, the port is part of the Northwest Ports Clean Air Strategy. Shore power is prominent in the ports effort to reduce its environmental impact - since 2009 the port has eliminated over 25,000 tons of GHG and nearly 700 tons of air pollutants [44]. Harbor dues discounts are available for ships that voluntarily adopt best practices and an incentive program is in place to reduce truck emissions too. The port is active in supporting the transition to natural gas as a marine fuel. The support of programs such as the Right to Quiet Society in Vancouver, which used vessel slowdown trials in the Straits surrounding the port, played a big role in driving discussions around ship efficiencies [45].

While very active in its efforts and collaborations related to emissions reduction, the Port of Vancouver could still expand its focus. While liquefied natural gas is undoubtedly a better alternative than heavy fuel oil, its role will likely be restricted to a transition fuel. By casting its sight beyond transition fuels and into hydrogen derived fuels, the Port of Vancouver can position itself for a green, zero carbon future.

The port of Vancouver trades heavily with Asia, especially coal, grains, and fertilizers

International trade (Percentage of Cargo Handled)

1. China: 50%
2. Korea: 10%
3. United States: 10%
4. Taiwan: 6%
5. Vietnam: 5%

VANCOUVER'S TOP 5 IMPORT COMMODITIES

Chemicals, Basic Metals & Minerals

Consumer & Related Goods

Machinery, Vehicles, Construction and materials

Forest Products

Petroleum Products

VANCOUVER'S TOP 5 EXPORT COMMODITIES

Grain, Specialty Crops & Feed

Coal

Forest Products

Fertilizers

Chemicals, Basic Metals and Minerals

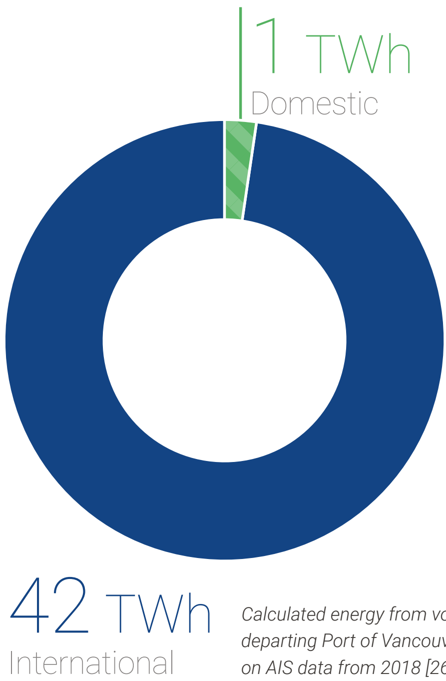
Source: [46]

The Port of Vancouver's activity is skewed towards imports, which account for 63% of the volume. Four out of the top five trading partners are in Asia, with China holding the first place and the US is the third largest partner. As a result, the vast majority of energy usage is from international vessels.

The port's largest imports are chemicals, basic metals and minerals, consumer goods, machinery, vehicles and construction materials, forest products and petroleum products. The largest exports are coal, grains and feed, forest products, fertilizers and chemicals, basic metals and minerals.

The total number of voyages is 12,362, carried out by 4,124 unique vessels, moving over 3 million tons of goods in 2008.

BREAKDOWN OF ENERGY USAGE BY VESSELS DEPARTING THE PORT OF VANCOUVER [26]



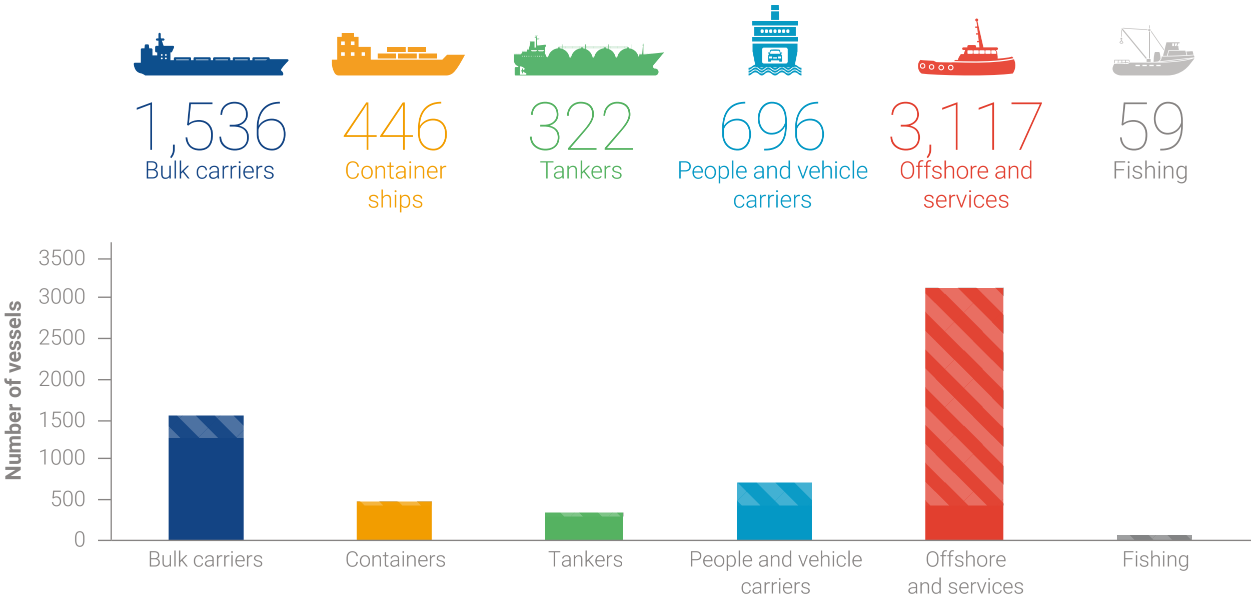
Calculated energy from voyages departing Port of Vancouver based on AIS data from 2018 [26]

The largest number of vessels are offshore and services, however these vessels only account for 1% of the total energy consumption. It can be expected that these vessels can adopt alternative methods of propulsion such as battery power as on shore charging facilities can be put in place in the Port of Vancouver to specifically charge these vessels. Bulk carriers are the second largest category in terms of number of vessels and the largest in terms of cargo but alone are responsible for 58% of the total energy consumption.

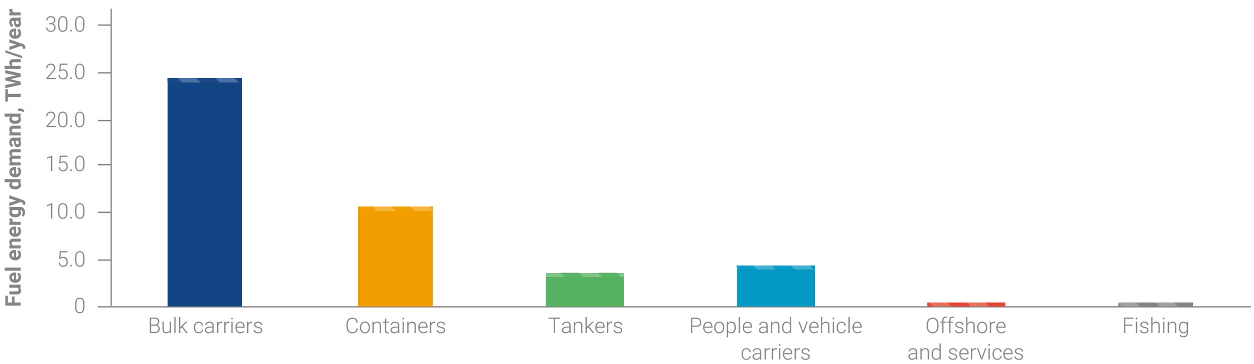
By a large extent, most of the energy used by vessels departing the Port of Vancouver goes towards international voyages; this is also the case for many of the ports in this study. Likely due to vessel traffic bound for the US and China.

Domestic departures   International departures

NUMBER OF VESSELS DEPARTING THE PORT OF VANCOUVER IN 2018 BY VESSEL CATEGORY [26]



ENERGY USAGE OF VESSELS DEPARTING THE PORT OF VANCOUVER IN 2018 BY VESSEL CATEGORY [26]

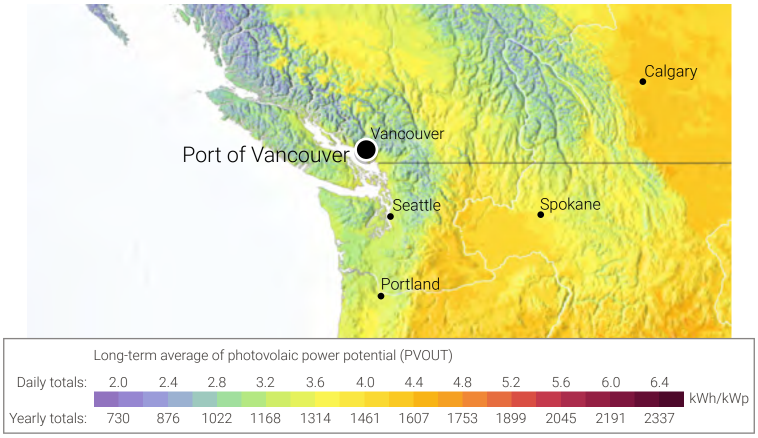


See appendix 1 for vessel category definitions. Energy calculations based on AIS data from 2018

Offshore wind and rooftop solar are both attractive options for the Port of Vancouver

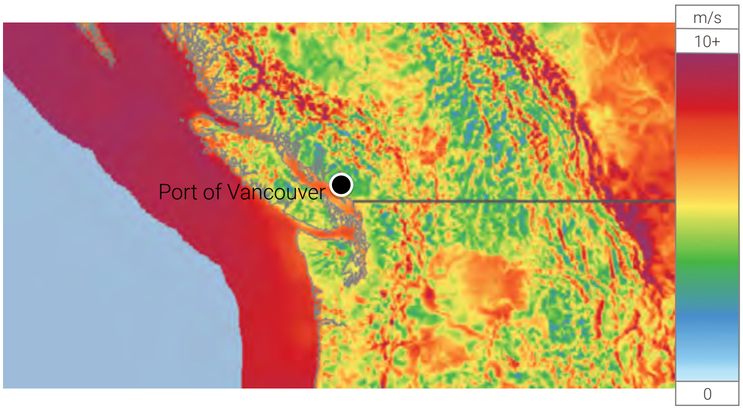
British Columbia is already supplied by low carbon electricity. However, most of it comes from large hydro. The environmental impact and the drive to decommission these power stations [47] means an alternative source of low carbon electricity will be needed to meet the growing needs of the shipping sector.

SOLAR ELECTRICITY GENERATION POTENTIAL AROUND VANCOUVER



Solar PV electricity generation potential from SolarGIS.com used with permission

WIND ELECTRICITY GENERATION POTENTIAL AROUND VANCOUVER



Mean wind speeds at 100 m hub height from GlobalWindAtlas.info used with permission [27]

The area around the Port of Vancouver has a good solar resource with average GHI of 3.55 kWh/m^2/day close to the port, and higher inland and away from the mountains [34]. There may be potential for offshore wind, however onshore wind would pose a challenge due to the geography of the region.

While this local resource could play a significant role in providing renewable energy sources for the production of zero-carbon fuels, renewable electricity generated elsewhere in Canada could also be leveraged, with the grid being used to supply the fuel production infrastructure.

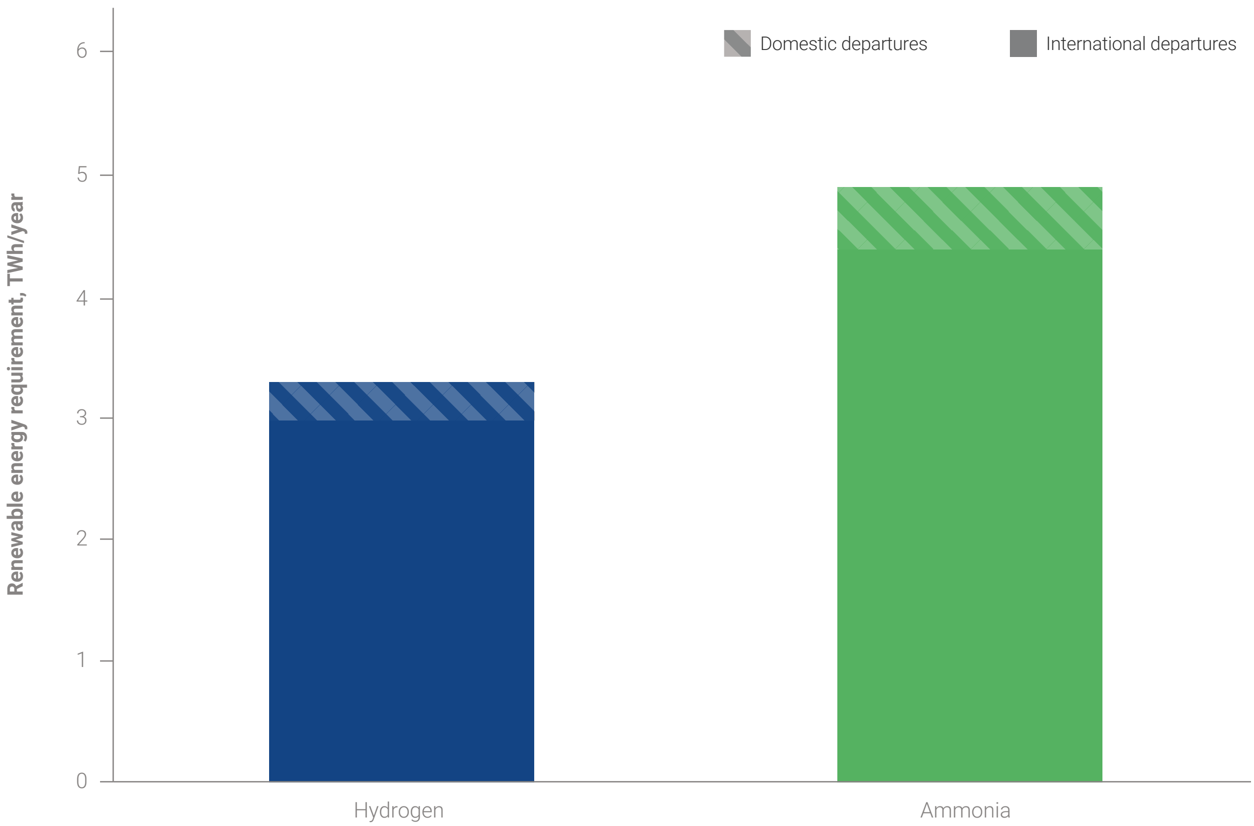
The infrastructure needed for the adoption of zero-carbon fuels up to 2030 can be scaled to the demand

The scale of the demand for zero-carbon fuels will depend on the speed of technology adoption. To provide a view of scale, as with the other case studies, a representative 2030 adoption case is used. This demonstrates the energy requirements to produce sufficient green ammonia and green hydrogen to meet the demand of 5% of international and 15% of domestic vessels adopting zero-carbon fuels for the Port of Vancouver. The methodology used to estimate zero-carbon fuel and renewable energy requirements is presented in Appendix 2.

This case shows the renewable electricity generation requirements to produce sufficient green hydrogen or ammonia to meet the fuel demand of the port of Vancouver. The calculations for these figures take into account the efficiencies and losses of converting renewable electricity into zero-carbon fuel, and then using that fuel in the vessel.

The vast majority of vessels departing the Port of Vancouver and bound for international ports which make the amount demand for international vessels significantly higher than the demand for domestic vessels.

RENEWABLE ENERGY REQUIRED TO MEET THE ZERO-CARBON FUEL DEMAND IN THE 2030 ADOPTION CASE



To meet the fueling demands of the representative 2030 adoption case through green hydrogen fuel, 3.3 TWh per year of renewable electricity would be required. To meet the demand with green ammonia, 4.9 TWh per year of renewable energy would be needed. It is possible that green hydrogen and green ammonia will be used in parallel, each being used for the vessel types and use cases to which they are best suited. This means that the actual renewable generation requirement will be somewhere between these figures.

Hydrogen

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

2.9 GW
Solar

or

1 GW
Onshore wind

or

0.7 GW
Offshore wind

Ammonia

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

4.4 GW
Solar

or

1.5 GW
Onshore wind

or

1.1 GW
Offshore wind

THE SPACE NEEDED TO BUILD THIS INFRASTRUCTURE DEPENDS ON THE TECHNOLOGY:

1 GW of solar generation infrastructure would cover about 3,000 football fields

But this space could also be used to graze livestock

1 GW of onshore wind generation infrastructure would require about 64,000 football fields of land

But this land can also be used for growing crops and other agriculture

1 GW of offshore wind generation infrastructure would require about 26,000 football fields of ocean space

Future-proofing the local economy by shifting from coal exports

Producing zero-carbon fuels and servicing a sustainable shipping fleet can bring new life to local economies in places where economic activities rely on goods and services that are expected to decline due to climate change or the market changes it is bringing.

Such could be the case of the Port of Vancouver, which greatly exports coal. Global demand for coal is falling rapidly as countries around the world close coal power plants to reduce emissions. Other exported goods include fertilizers, which are deemed harmful for climate and whose demand could decrease as the farming industry shifts towards more sustainable practices, and even controlled environment agriculture [48].

In the long term, these changes could impact the economics of the port, as well as of many other ports around the world, especially if they rely on the trading of fossil fuels or the servicing of the shipping fleet in its current state.

Producing zero-carbon fuels can allow the economy and community in and around Vancouver to transition away from the declining coal sector towards a sustainable and climate-friendly alternative. These new and future-proof sources of income can grow and sustain these economies for many decades to come.

Replacing legacy hydro capacity with wind and solar

While there is significant hydroelectric capacity and potential around the Port of Vancouver, there are concerns around their environmental impact. This could create spaces for other renewables like solar PV and wind to step in, helping decarbonize the local grid and potentially enabling local zero-carbon fuel production.

Case Study: Port of Unalaska

Disruptive opportunities in a small and remote island

Unalaska relies heavily on diesel fuel, yet has tremendous renewable energy potential

In the west corner of Alaska, there is a chain of 14 volcanic islands known as the Aleutian Islands. Within them, in the Unalaska island, the Port of Unalaska (also known as Port of Dutch Harbor) serves as the operation center for commercial fishing and an important petroleum handling point [49], making this small port a very important piece in the global shipping supply chain.

Local power and heating in the island are provided mostly using fossil fuels in an off-grid fashion, resulting in significant stand-by generation requirements and low power infrastructure capacity [50]. While the State of Alaska has seen previous attempts to implement emission reduction targets and energy efficiency measures [51], local policy appears to have stalled. There are currently no local targets or mandates beyond the country-wide commitments recently being set out by the United States government. Nonetheless, local actors have implemented sustainability-focused initiatives in the region, with house retrofitting and biofuels use for heating as the focus, exploration of exploitable geothermal, tidal and wave energy resources [52].

The island presents a unique combination of resources that could be harnessed to materialize disruptive opportunities seen only in a couple of other places around the world [53]. Its vast renewable potential can be used to produce green hydrogen that can be used to not only produce green ammonia for shipping, but also to supply heating for homes. Surplus electricity can also power homes and smaller vessels, while battery and/or hydrogen storage could provide security of supply. All of this while displacing the existing diesel-based generation.

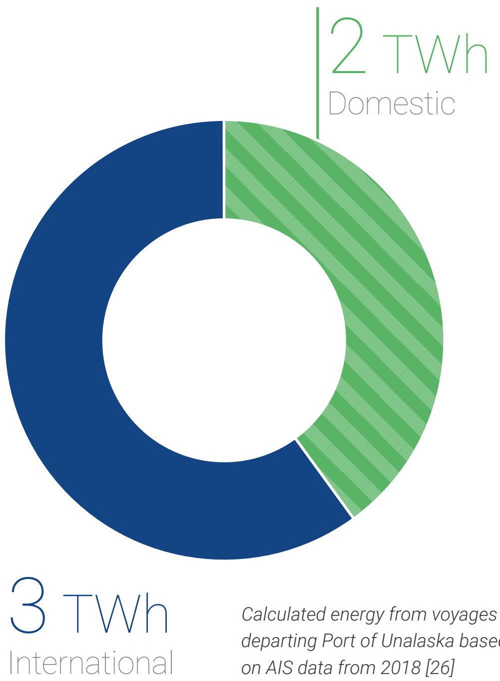
Fishing and petroleum are at the heart of the economy of Unalaska

Source: [54]

The port of Unalaska focuses on very few goods and commodities, which make up most of the traded volume at the port. In terms of imports, petroleum is the most traded good (90%) – although over 95% of this volume does not stay in the island – followed by food products and manufacturing equipment, which represent around 7% of imports.

Food products – specifically fish products – make up around 90% of the exports, placing the fishing industry at the heart of economic activity; manufactured equipment makes up an additional 6% of total exported volumes [54].

BREAKDOWN OF ENERGY USAGE BY VESSELS DEPARTING THE PORT OF UNALASKA [26]



Calculated energy from voyages departing Port of Unalaska based on AIS data from 2018 [26]

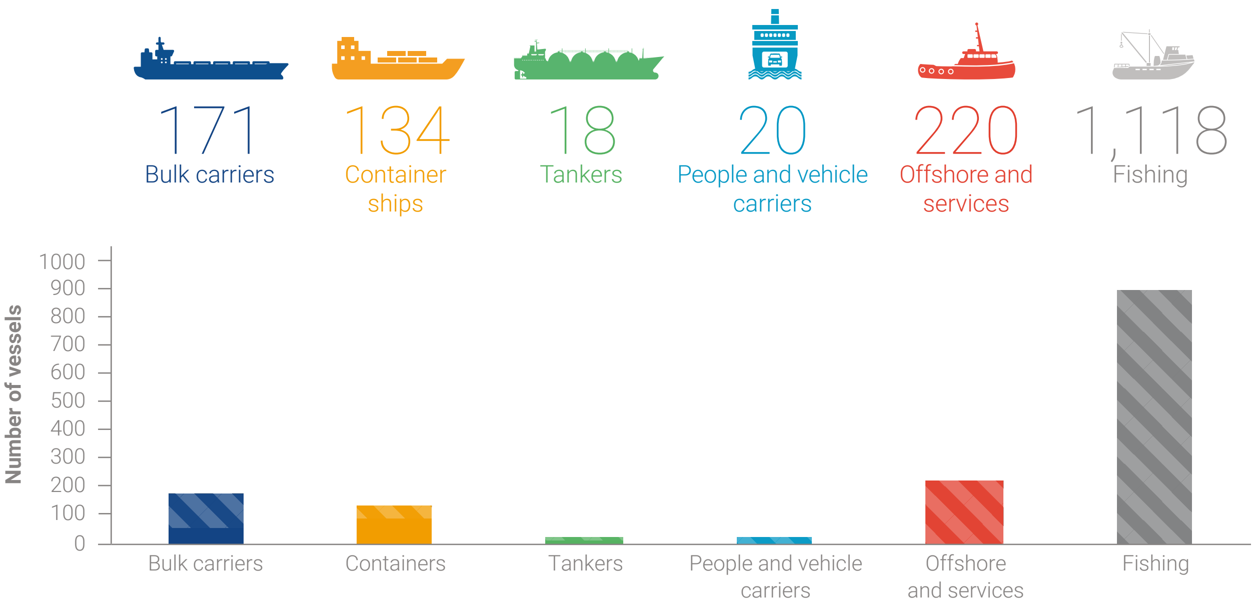
This port experiences relatively low trading volumes and visits when compared to other ports included in this study, yet its importance for both oil and fishing markets and supply chains place it in a critical role.

At the same time, volumes of energy demand from visiting ships are far from negligible, especially considering that this demand can become a way to make good use of the abundant renewable resource that is present in the area.

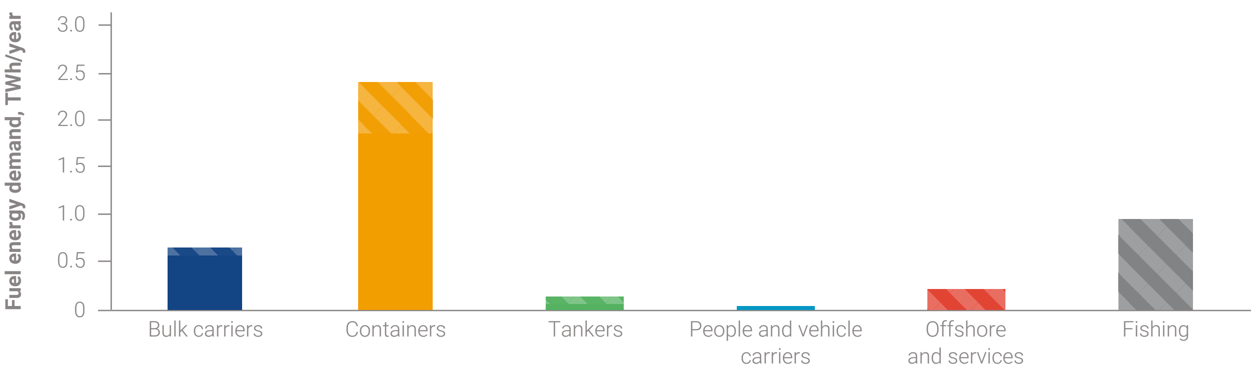
Total fuel energy demand for domestic departures is roughly 1.9 TWh per year, while the figure for international departures goes up to 2.6 TWh.

Domestic departures International departures

NUMBER OF VESSELS DEPARTING THE PORT OF UNALASKA IN 2018 BY VESSEL CATEGORY [26]



ENERGY USAGE OF VESSELS DEPARTING THE PORT OF UNALASKA IN 2018 BY VESSEL CATEGORY [26]



See appendix 1 for vessel category definitions. Energy calculations based on AIS data from 2018

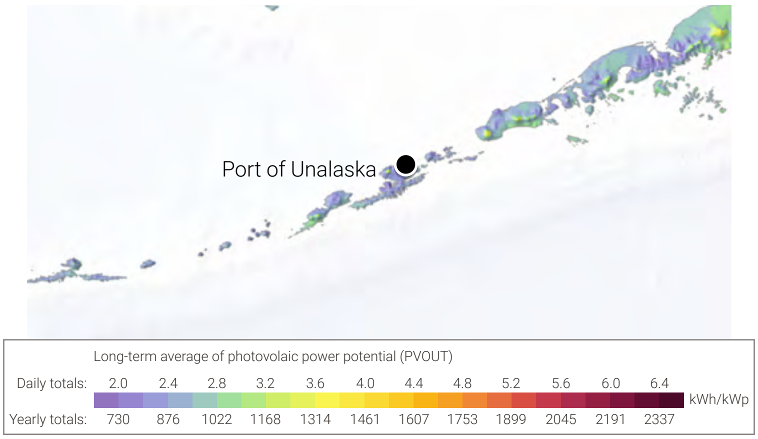
Local renewable resource can supply the needs of both the island and the fleet it services

The Aleutian Islands have great wind potential, both onshore and offshore (given the relatively small size of the islands). While this is a great advantage, it is difficult to exploit, given the high variability of the wind resource, and low local demand [55]. The Aleutian Islands have limited solar potential due to land available and weather conditions.

While there has been significant exploration aimed at finding exploitable geothermal resource, suitable sites have not been identified [56]. Tidal, wave and marine current energy could also be an option and early studies have shown potential [50] [52], although their cost and relative immaturity can pose a challenge.

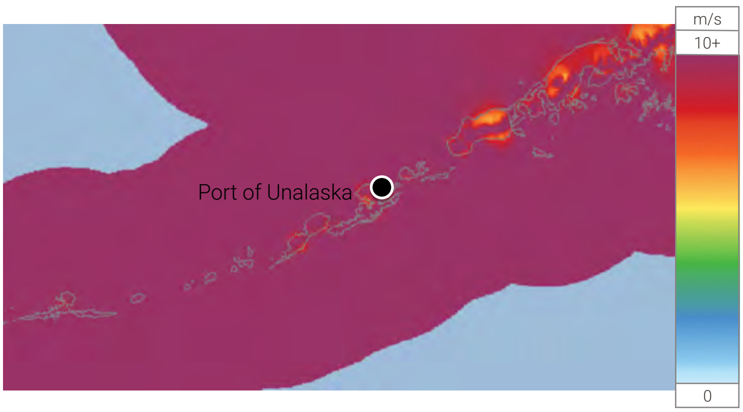
Wind power is a promising local renewable resource. Locally producing zero-carbon fuels like ammonia, however, could enable its use, since generation can be balanced between zero-carbon fuel production and local power demand. An element of hydrogen or power storage could also be added, so that energy produced at one point can be later used to produce power when it is needed, which could reduce or even eliminate the current reliance on diesel fuel for both power production and security of supply.

SOLAR ELECTRICITY GENERATION POTENTIAL AROUND UNALASKA



Solar PV electricity generation potential from SolarGIS.com used with permission

WIND ELECTRICITY GENERATION POTENTIAL AROUND UNALASKA



Mean wind speeds at 100 m hub height from GlobalWindAtlas.info used with permission [27]

The infrastructure needed for the adoption of zero-carbon fuels up to 2030 can be scaled to the demand

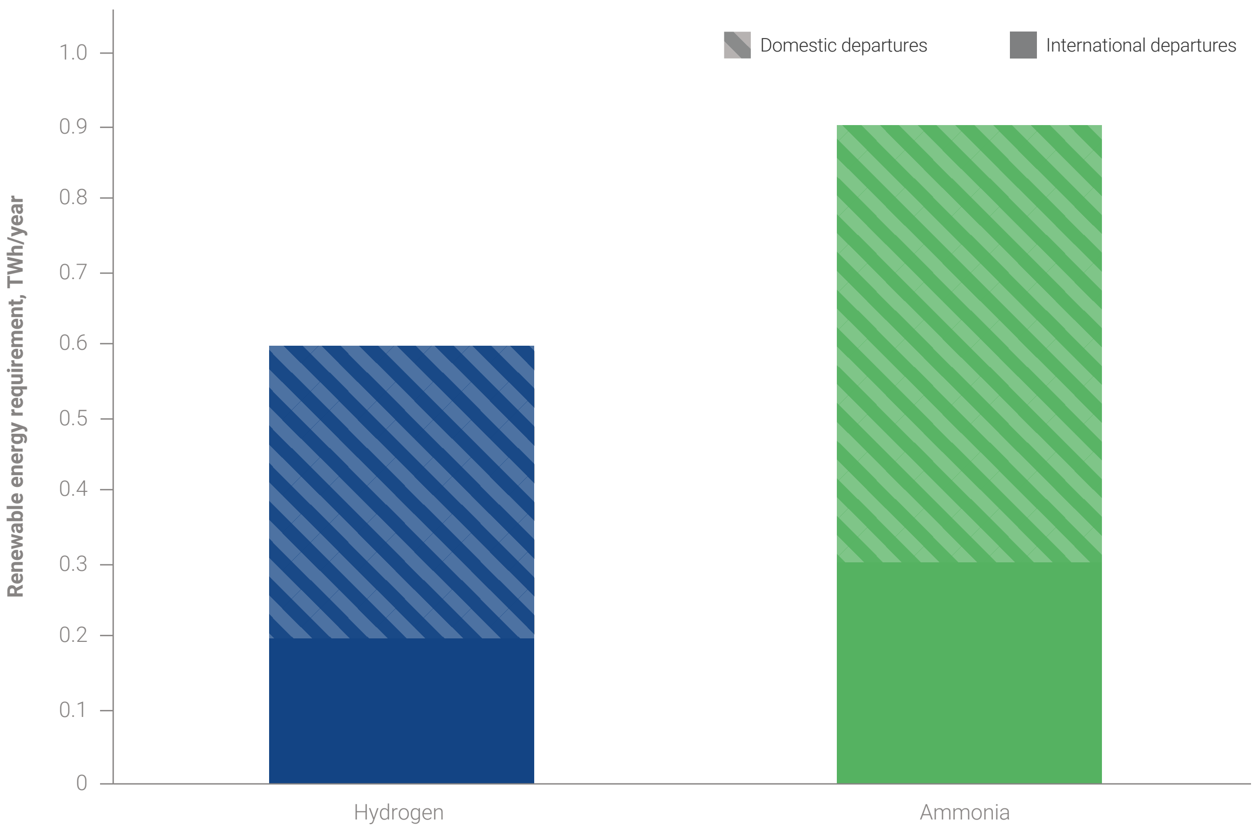
The scale of the demand for zero-carbon fuels will depend on the speed of technology adoption. To provide a view of scale, as with the other case studies, a representative 2030 adoption case is used. This demonstrates the amount of energy required to produce the fuel demand of Unalaska with green ammonia and green hydrogen based on the transition of 5% of international and 15% domestic vessels to zero-carbon fuels. The methodology used to estimate zero-carbon fuel and renewable energy requirements is presented in Appendix 2.

This case shows the renewable electricity generation requirements to produce sufficient green hydrogen or ammonia to meet the fuel demand of Unalaska. The calculations for these figures take into account the efficiencies and losses of converting renewable electricity into zero-carbon fuel, and then using that fuel in the vessel.

The port of Unalaska's vessel traffic is dominated by fishing vessels however there is a large energy demand from international container vessels.

The Port of Unalaska is an island and therefore has an islanded electrical grid. The adoption of renewable energy can reduce the reliance on fuel imports for its own electrical consumption and for its fishing fleet.

RENEWABLE ENERGY REQUIRED TO MEET THE ZERO-CARBON FUEL DEMAND IN THE 2030 ADOPTION CASE



To meet the fueling demands of the representative 2030 adoption case through green hydrogen fuel, 0.6 TWh per year of renewable electricity would be required. To meet the demand with green ammonia, 0.9 TWh per year of renewable energy would be needed. It is possible that green hydrogen and green ammonia will be used in parallel, each being used for the vessel types and use cases to which they are best suited. This means that the actual renewable generation requirement will be somewhere between these figures.

Hydrogen

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

0.1 GW
Onshore wind

or

0.1 GW
Offshore wind

Ammonia

PRODUCING ENOUGH FOR THE 2030 ADOPTION CASE

Installed generation capacity needed

0.2 GW
Onshore wind

or

0.2 GW
Offshore wind

THE SPACE NEEDED TO BUILD THIS INFRASTRUCTURE DEPENDS ON THE TECHNOLOGY:

1 GW of onshore wind generation infrastructure would require about 64,000 football fields of land

1 GW of offshore wind generation infrastructure would require about 26,000 football fields of ocean space

Zero-carbon fuels help harness Unalaska's vast renewable potential and enable circular economies

Moving forward, fishing operations in the region are expected to grow significantly, not only due to the natural growth of the industry and its demand, but also due to rising sea temperatures due to climate change which is expected to cause fish to move towards colder waters [57]. In this sense, the island does not face significant challenges in terms of maintaining its local economies and activities.

This certainly does not mean that the island should not be concerned about adapting to climate change and mitigating its impact or, perhaps more importantly, that opportunities are not present in this space for the island to capitalize on. This port presents a unique opportunity. Its vast renewable resource is currently untapped, with low local demand and the absence of interconnection as the main barriers for its exploitation. But producing zero-carbon fuels can become the link that allows the island to take advantage of it not only to meet their existing power needs, but also to provide renewable and affordable heat and supply zero-carbon fuels for the fleet of the future, as it is already being done in the Orkney Islands in Scotland [58].

Disruptive innovation and circular economies

There is an opportunity to enable a circular economy in Unalaska. The residue from the existing fish processing plant can be used to produce biofuels that, coupled with renewables, can power the production of hydrogen or other zero-carbon fuels, which can later be used to power the vessels that would capture more fish, closing the loop.

Initiatives like the OHLEH project in Scotland, where fish residue from a local salmon hatchery and local food residues are being used in this manner, have already successfully implemented this approach, which can be adapted for Unalaska [53]. This small and remote island should not be overlooked, as it can be the birthplace of disruptive initiatives that can serve as a replicable example for other ports and regions in the country and the world.

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Appendices

APPENDIX 1 VESSEL CATEGORY DEFINITIONS

Category	Size	Length (m)	Number of vessels globally	Capacity	IMO ship types
Bulk carriers	Large	195+	5308	>60,000DWT	Bulk carrier (such as grains, coal, ore, steel coils and cement), Refrigerated bulk and General cargo.
	Small	75-195	15410	<60,000DWT	
Tankers	Large	195+	3571	>60,000DWT	Liquefied gas tanker, Oil tanker, Other liquids tankers and Chemical tanker.
	Small	75-195	9312	<60,000DWT	
Containers	Large	260+	1554	>5,000TEU	Container ships: Small feeder and river vessels through to Panamax and Ultra Large Container Vessel.
	Small	125-260	3604	<5,000TEU	
People and Vehicle Carriers	Large	120-360	1306	Varies by type	Cruise, Ferry: Roll-on-Roll-off (passenger), Roll-on-Roll-off (cargo), Yacht, Vehicle and passenger-only ferry.
	Small	30-205	5725	Varies by type	
Offshore and Services	—	30-290	14264	Varies by type	Offshore (oil/gas and windfarm service & supply), Service, Tug, Bunker, Miscellaneous.
Fishing	—	5-145	8220	Varies by type	Fishing: Inshore to ocean.

Sources: Ricardo analysis and discussions with University College London [26]
DWT = Deadweight tonnage | TEU = Twenty-foot equivalent unit.

APPENDIX 2 METHODOLOGY FOR SIZING ELECTROFUEL AND RENEWABLE CAPACITY REQUIREMENTS

Hydrogen and ammonia

The hydrogen and ammonia requirements for each of the ports included in this report was estimated based on the following assumptions to calculate fuel energy requirements:

- The energy requirements for the vessels departing the port, using Automatic Identification System (AIS) data from 2018, provided by University College London [26]. These values are disaggregated by port, type of ship (bulk carriers, container ships, fishing vessels, offshore and services vessels, people and vehicles ships and tankers) and by journey (international and domestic).
- This energy demand was extrapolated to 2030 considering an annual demand reduction of 1.20% from the implementation of energy efficiency measures and operational standards.

To estimate the amount of renewable electricity generation required to produce adequate green hydrogen or ammonia to meet these energy requirements, the energy efficiency and losses associated with the production and use of the fuels needs to be taken into account. The effect of this is that the total renewable energy generation requirement is larger than the fuel energy requirement of the vessels alone.

It was assumed that:

The process of producing hydrogen using electricity and using it in a vessel has an overall efficiency of

70%

The process of producing ammonia using electricity and using it in a vessel has an overall efficiency of

47%

Renewable electricity generation installed capacity

To estimate the amount of renewable electricity generation capacity that would be required to produce the required volume of electrofuels, the capacity factors of different renewable technologies in each port were taken as a starting point. Except for the case of Unalaska, where more location-specific values were used, solar PV and both onshore and offshore wind capacity factors for each case study were taken as State-level averages [34] [59], as it is assumed that the generation infrastructure may be located away from the port in a suitable location.

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