# Washington Maritime Blue Maritime and Clean Economy Economic Analysis

**DISCUSSION DRAFT**

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*Prepared by:*

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*Community Attributes Inc. tells data-rich stories about communities that are important to decision makers.*

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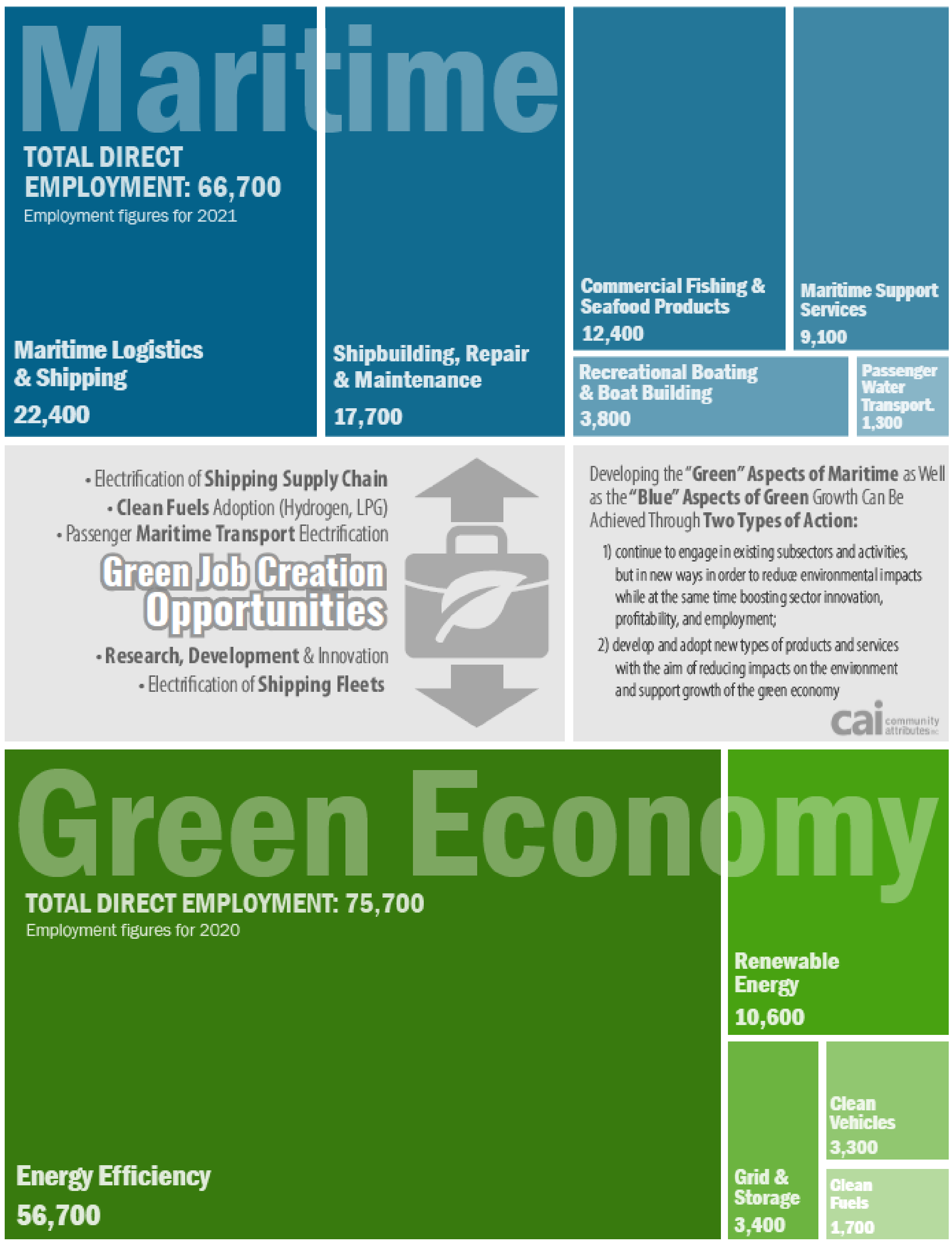
## Executive Summary

This report provides an update to the 2017 Washington State Maritime Sector Economic Impact Study, using the most recent data from federal and state sources. Additionally, this study discusses differing green economy definitions from existing literature, lays out the definition used for this report, and discusses the economic impact of green economy investment, and growth opportunities that the maritime and green industries present for each other.



## Maritime Sector Economic Impacts

Washington's maritime sector is diverse and covers a wide range of activities, including commercial and government shipbuilding, maintenance and repair, recreational boating, logistics and shipping, passenger water transportation, fishing and seafood processing, and maritime support services, such as naval architecture and training. In 2021, the statewide maritime sector directly employed **67,000 workers** and generated **$6 billion in labor income** and roughly **$27 billion in business revenues**. The maritime logistics and shipping subsector employed the most workers, with an estimated 22,400 workers in 2021, representing 34% of total sector jobs, followed by shipbuilding, repair, and maintenance with 17,700 jobs or 27%.

The total economic impact of the maritime industry in 2021 (including indirect and induced effects) was roughly **174,000 jobs**. Therefore, for every direct job in maritime, an additional 1.6 jobs were supported through secondary impacts. At the same time, maritime sector activities supported, through multiplier effects, approximately **$41 billion in business revenues** and **$12.6 billion in labor income**.

In 2021, nearly **2% of jobs** in Washington were directly in the maritime sector. Factoring in multiplier effects, the maritime sector supported roughly **5% of jobs** in Washington.

## Green Economy Economic Analysis

State-level data from E2 shows the green economy employment in Washington state totaled nearly **76,000 jobs** in 2020, down from 85,000 jobs in 2019 most likely due to pandemic impacts. Employment includes jobs in energy efficiency (75%), renewable energy (14%), grid and storage (5%), clean vehicles (4%), and clean fuels (2%).

Spending on green investments and sustainable infrastructure are cost-effective opportunities to generate new jobs and these jobs are accessible and well-paying. Several research studies found that **green infrastructure investments are cost-effective opportunities to generate new jobs** and the spending creates more jobs per dollar than traditional infrastructure investments. For instance, one model suggests that every $1.0 million in spending on renewable energy creates 7.5 full-time jobs in renewables infrastructure, and 7.7 in energy efficiency, compared to only 2.7 jobs for investment in fossil fuels[1].

### Greening the Maritime Sector

[1] Garrett-Peltier, H. (2017), "Green versus Brown: Comparing the Employment Impacts of Energy Efficiency, Renewable Energy, and Fossil Fuels Using an Input–Output Model", Economic Modelling, 61, 439–47.

The maritime industry is taking steps to reduce its environmental footprint through **electrification of the maritime fleets and shipping supply chain**, **adoption of clean fuels**, and **entrepreneurship and innovation** to launch new technologies and grow successful cleantech businesses. Through these efforts the maritime industry itself can become more efficient, profitable, and sustainable, and can contribute directly to job growth within the green economy, and to the sustainability and productivity of other businesses and livelihoods which depend on healthy oceans and coasts.

## $CO_2$ Emissions Reduction

If the transportation sector is to be decarbonized, improving efficiency of conventional vehicles is a solid short-term solution, but ultimately most vehicles must produce **zero tailpipe emissions and be fueled by carbon-neutral and renewable energy sources**.

Electrifying heavy-duty vehicles can have significant benefits on air quality, public health, and the climate. An analysis conducted in 2019 by the Union of Concerned Scientists (UCS) found that heavy-duty electric vehicles can reduce global warming emissions by 44% to 79% depending on the vehicles average speed over the course of a trip. In Washington, adopting the Advanced Clean Trucks (ACT) rule can cut the state's annual nitrogen oxide emissions from trucks by 47% and particulate matter pollution by 43% compared to the baseline by 2050, according to a study conducted by M.J. Bradley & Associates.

Another strategy for decarbonizing the transportation sector in the medium term, must involve progressively but rapidly **replacing fossil fuels with renewable fuels**.

- **International Shipping.** Advanced biofuels and biomethane could play a role in the short-term in reducing $CO_2$ emissions for the shipping industry but the role is likely limited. In the medium to long-term, green hydrogen-based fuels will be critical for the decarbonization of international shipping. The ability of hydrogen to impact $CO_2$ emissions depends strongly on both the specific use case where it is implemented and the way it is produced.
- **Aviation.** The use of Sustainable Aviation Fuel (SAF) is currently the aviation industry's best option to lower $CO_2$ emissions.
- **Trucking.** Potential clean fuels that could significantly decrease the industry's emissions include renewable diesel, renewable propane, and renewable natural gas. It is reported that renewable diesel could lower GHG emissions by 75% compared to petroleum-derived diesel.

# Contents

# Introduction

## Background and Purpose

Maritime has long been a core component of Washington's economy. Today, the maritime industry is large, diverse, and an important driver of economic activity and growth in Washington state. In 2013 and 2017, Community Attributes Inc. (CAI) produced a detailed statewide economic assessment of the maritime sector, including fishing and seafood processing, recreational boating, shipyards, port operations, water transportation, and various supporting activities. This study aims to refresh the economic impacts of the maritime industry, leveraging the most recent data from federal and state sources.

In addition to an updated economic impact analysis of the maritime industry, this report contributes new insights by analyzing the intersection between Washington's maritime sector and the green economy, with a focus on decarbonizing transportation. A literature review of clean fuels and their role in reducing $CO_2$ emissions in the maritime sector and other sectors also supports this new analysis.

## Methods

The economic analysis of the maritime sector relies on employment, wage, and revenue data published by the Washington State Employment Security Department (ESD), Washington State Department of Revenue (DOR), and the U.S. Bureau of Labor Statistics (BLS). Economic impacts were calculated through use of the Washington State Input-Output (I-O) Model published by the Washington State Office of Financial Management (OFM).

A review of existing reports and studies on the green economy and clean technology, including national sources, was conducted to define the green economy cluster. The $CO_2$ emissions literature review was supplemented with information gathered through interviews with key stakeholder such as the CHARGE – the Consortium for Hydrogen and Renewably Generated Electrofuels at WSU, Clean Tech Alliance, and the Joint Center for Deployment and Research in Earth Abundant Materials (JCDREAM).

## Organization of Report

The report is organized as follows:

- **Maritime Sector Economic Impacts.** A summary of the jobs, labor income, and business revenues supported throughout Washington State by the maritime sector in 2021.
- **Green Economy Economic Analysis.** This section discusses differing green economy definitions from existing literature, lays out the definition

used for this report, and discusses the growth opportunities that the maritime and green industries present for each other.

- **$CO_2$ Emissions Reduction.** This section reviews existing literature regarding short-term and long-term solutions to lowering emissions generated by the transportation sector.
- **Summary and Conclusions.** Presents a summary of findings and concluding remarks.

## Maritime Sector Economic Impacts

Washington's maritime sector includes six subsectors as defined in the 2017 Washington State Maritime Sector Economic Impact Study:

- **Maritime logistics and shipping.** This subsector includes all activity related to the shipping of goods by water, including container and bulk goods. Trans-ocean, shoreline, and river freighting are included in this category, as is direct transportation by land to the state's ports for exports via water.
- **Shipbuilding, repair, and maintenance.** This category covers all commercial and federal boat and ship building, repair, and maintenance activities. This category also covers activities at the Puget Sound Naval Shipyard (PSNS) and other government shipbuilding, repair, and maintenance.
- **Commercial fishing and seafood products.** This category includes all activity related to the catching and processing of fish, including both finfish and shellfish. This category includes fishing and seafood processing that occurs on Washington vessels operating in Alaskan waters.
- **Maritime support services.** Support services covers technical and professional maritime services, such as engineering and naval architecture, as well as business support, such as legal and accounting businesses and industry associations. Washington's maritime education organizations are also included in this subsector.
- **Recreational boating and boat building.** This subsector includes charter fishing activities around the state, recreational marinas, recreational boat manufacturing, retail boat dealers, and other related activities.
- **Passenger water transportation.** This subsector includes all Passenger Water Transportation, including recreational transportation.

A detailed definition can be found in **Appendix A Exhibit 6.**

## Direct Impacts

Direct impacts represent the jobs, labor income, and business revenues directly supported by the maritime sector, and are presented by subsector in **Exhibit 1**. Throughout Washington State, nearly 67,000 jobs, $6 billion in labor income, and more than $26 billion in business revenues were supported by the maritime sector in 2021 (**Exhibit 1**). The maritime logistics and shipping subsector supported the most jobs and labor income, supporting 34% and 43% respectively. The commercial fishing and seafood products subsector supported the most business revenues, representing about 41% of the sector total.

**Exhibit 1. Maritime Sector Direct Impacts by Subsector, Washington State, 2021**

| Subsector | Jobs | Labor Income (mils 2021$) | Business Revenues (mils 2021$) |
|---|---|---|---|
| Maritime Logistics and Shipping | 22,400 | $2,600 | $7,000 |
| Shipbuilding, Repair and Maintenance | 17,700 | $1,500 | $900 |
| Commercial Fishing and Seafood Products | 12,400 | $900 | $10,900 |
| Maritime Support Services | 9,100 | $700 | $5,400 |
| Recreational Boating and Boat Building | 3,800 | $200 | $2,300 |
| Passenger Water Transportation | 1,300 | $100 | $100 |
| **Total** | **66,700** | **$6,100** | **$26,600** |

*Sources: State Employment Security Department, 2021; Washington State Department of Revenue, 2021; U.S. Bureau of Labor Statistics, 2021; U.S. Census Bureau, 2021; Union Pacific Railroad, 2021; BNSF Railway, 2021; Community Attributes Inc., 2022.*
*Note: Totals may not sum due to rounding.*

## Total Economic Impacts

Total economic impacts include direct, indirect, and induced impacts. Direct impacts represent the jobs, labor income, and business revenues directly attributable to the day-to-day operations within the defined maritime sector. Indirect impacts refer to additional economic activity, measured in jobs, labor income, and revenues, supported by inter- and intra-industry transactions associated with the direct activities being modeled. Induced impacts are additional revenues, wages, and jobs associated by income expenditures among employees supported through direct and indirect impacts.

**Exhibit 2** presents the statewide economic impacts generated by the maritime sector in 2021. In total, the sector supported more than 173,000 jobs, $12.6 billion in labor income, and about $41 billion in business revenues.

**Exhibit 2. Maritime Sector Economic Impacts, Washington State, 2021**

| | Direct | Indirect | Induced | Total |
|---|---|---|---|---|
| Jobs | 66,700 | 36,200 | 70,600 | 173,500 |
| Labor Income (mils 2021$) | $6,100 | $2,400 | $4,100 | $12,600 |
| Business Revenue (mils 2021$) | $20,900 | $7,900 | $12,400 | $41,100 |

*Sources: Washington State Employment Security Department, 2021; Washington State Department of Revenue, 2021; Washington State Office of Financial Management, 2021; Community Attributes Inc., 2022.*
*Note: Totals may not sum due to rounding. Direct business revenue used for total economic impact estimates does not match direct business revenues shown in Exhibit 1 because it includes an adjustment to wholesale industry revenue. This adjustment uses gross margins, which prevents the value of goods sold through wholesale from being counted more than once.*

## Green Economy Economic Analysis

This section provides an overview of the size and breadth of the green economy sector in Washington state, potential economic impacts of green economy investment and opportunities for greening the maritime sector.

### Green Economy Definition

There has been remarkable growth in federal clean energy economy efforts since the Great Recession of 2008. As a result, a flurry of national and regional research efforts attempted to characterize the size and breadth of the "clean" or "green" economy. Efforts to measure the green economy are complicated by the variability of definitions, as each of these efforts provide a different perspective as to which industries and occupations should be included.

At the national level, notable efforts included Pew's 2009 "Clean Energy Economy" report[2], the Bureau of Labor Statistics (BLS) 2010 Green Jobs Initiative[3], and Brookings Institution's "Sizing the Clean Economy" 2011 report[4]. Starting in 2016, the Department of Energy expanded their "U.S. Energy and Employment" reports to include clean energy economy measures[5]. More recent analysis includes studies from the National Association of State Energy Officials and the Energy Futures

[2] Cuttino, Phyllis. "The Clean Energy Economy." Washington, D.C.: The Pew Charitable Trusts, June 10, 2009.
[3] BLS. "Green Jobs : U.S. Bureau of Labor Statistics." U.S. Bureau of Labor Statistics, 2012. https://www.bls.gov/green/.
[4] Muro, Mark, Jonathan Rothwell, and Devashree Saha. "Sizing the: A National and Regional Green Jobs Assessment." Washington, D.C.: The Brookings Institution, July 13, 2011.
[5] United States Department of Energy, "U.S. Energy and Employment Report," 2016.

Initiative[6], the Brookings Institution[7], and E2[8], a national, nonpartisan group of business leaders, investors and others who advocate for smart policies that are good for the economy and good for the environment.

Some efforts to define the green economy have a broader scope than others. For example, the BLS green jobs definition, which includes about 1,300 unique industries classified by 6-digit NAICS codes, includes jobs that either: 1) produce goods or provide services that benefit the environment or conserve natural resources; or 2) involve making their establishment's production processes more environmentally friendly or use fewer natural resources.[9]

Some definitions focus on the clean energy economy transition and build on this rich body of past work to structure a new look at clean energy occupations. The Brookings Institution “Advancing Inclusion through Clean Energy Jobs” 2019 report defines clean energy economy jobs as jobs that are directly involved in: 1) the production, transmission and distribution of clean energy; 2) increasing energy efficiency through the manufacturing of energy-saving products, the construction of energy-efficient buildings, and the provision of services that reduce end-use energy consumption; 3) Environmental management and the conservation and regulation of natural resources.[10] Through this method, Brookings arrived at three major sectors encapsulating NAICS based industries that comprise what they consider clean energy jobs. These major sectors include clean energy generation, manufacturing and construction, energy efficiency, and environmental management, conservation, and regulation.[11] The full detailed definition can be found in **Appendix A Exhibit 8**.

Within this flurry of research, numerous state-level efforts sought to capture the green labor market within Washington state. The Department of Commerce convened a work group in 2020 regarding the development of Washington’s green economy which put together a working definition for green economy: “Washington’s green economy makes, moves and uses good and services for a cleaner footprint”[12]. However, this work did not aim to measure the size of the green economy in Washington.

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[6] National Association of State Energy Officials and the Energy Futures Initiative, “The 2019 U.S. Energy & Employment Report,” 2019.
[7] Muro, Mark, Adie Tomer, Ranjitha Shivaram, and Kane, Joseph. “Advancing Inclusion through Clean Energy Jobs”. Washington, D.C.: The Brookings Institution, April 2019.
[8] E2, “Clean Jobs America 2021”, 2021.
[9] https://www.bls.gov/green/home.htm
[10] “Advancing Inclusion Through Clean Energy Jobs”, Metropolitan Policy Program at Brookings, 2019.
[11] “Advancing Inclusion Through Clean Energy Jobs”, Metropolitan Policy Program at Brookings, 2019.
[12] Washington State Department of Commerce, “Washington’s Green Economy”, June 30, 2020.

The state first attempted to measure employment in the green sectors in 2008 and used a definition developed by the state Department of Community Trade and Economic Development (now Commerce) and the Employment Security Department (ESD). According to this definition, green jobs are "those where employees are directly and predominantly engaged in at least one of four core areas of the economy: 1) increasing energy efficiency; 2) producing renewable energy; 3) preventing and reducing environmental pollution; 4) providing mitigation or cleanup of environmental pollution."[13] Using these four green core areas, ESD reported more than 120,000 green jobs for both public and private employment in 2011, the latest year of available data.

More recent state-level data from E2 shows the green economy employment in Washington state totaled nearly 76,000 jobs in 2020, down from 85,000 in 2019 most likely due to pandemic impacts (**Exhibit 3**). The estimates are based on an analysis of the U.S. Energy and Employment Report, which uses data from the U.S. Bureau of Labor Statistics (BLS) Quarterly Census of Employment and Wages (QCEW), supplemented by a unique survey of 35,000 businesses across the United States.

**Exhibit 3. Green Economy Employment by Industry, Washington State, 2017-2020**

| Industry | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|
| Energy Efficiency | 62,500 | 63,900 | 64,900 | 56,700 |
| Renewable Energy | 11,400 | 11,100 | 11,200 | 10,600 |
| Grid & Storage | 3,400 | 3,500 | 3,600 | 3,400 |
| Clean Vehicles | 2,800 | 3,500 | 3,400 | 3,300 |
| Clean Fuels | 1,700 | 1,800 | 1,900 | 1,700 |
| **Total** | **81,800** | **83,800** | **85,000** | **75,700** |

*Sources: E2, 2021; Community Attributes Inc., 2022.*
*Note: Totals may not sum due to rounding.*

E2's definition focuses on energy production, transmission, and distribution and includes clean vehicles and clean fuels, among the five total subsectors. The full definition is included in **Appendix A Exhibit 7**. Employment includes jobs in solar energy, wind energy, energy efficiency, combined heat and power, bioenergy, non-woody biomass, low-impact hydro power, geothermal, clean vehicle technologies, clean energy storage, smart grid, micro grid, grid modernization, and advanced biofuels. These clean energy jobs can be in traditional industries such as construction, manufacturing, wholesale trade, transmission and distribution, agriculture, and professional services.[14]

[13] Hardcastle, Alan and Kester, Kyra. "Growing Washington's Green Economy: Progress, Opportunities and Challenges". Washington State University Extension Energy Program. October 2011.
[14] https://e2.org/reports/clean-jobs-america-faq/

## Economic Impact of Green Economy Investment

Green economy investments, such as investments to expand the supply of clean renewable energy sources, improve energy efficiency in the state's stock of buildings and industrial production processes, and decarbonize transportation, have significant economic impacts, supporting existing employment levels, expanding job opportunities, and raising average living standards throughout Washington state. Several research studies illustrate the economic benefits and job creation impact of spending on green investments and sustainable infrastructure.

Investments in green infrastructure are cost-effective opportunities to generate new jobs and the spending creates more jobs per dollar than traditional infrastructure investments. One model suggests that every $1.0 million in spending on renewable energy creates 7.5 full-time jobs in renewables infrastructure, and 7.7 in energy efficiency, compared to only 2.7 jobs for investment in fossil fuels[15]. In addition, every $1.0 million invested in transportation electrification could create up to 15 jobs[16].

Another study by the International Monetary Fund (IMF) also finds that the renewable energy industry is more labor intensive compared with fossil fuel technologies, which are typically mechanized and capital intensive[17]. Using an international dataset, the study finds that every dollar spent on key carbon-neutral or carbon-sink activities can generate more than a dollar's worth of economic activity. By contrast, spending on non-eco-friendly energy generation, is found to crowd out other forms of domestic spending to a larger extent.

A recent study prepared at the request of Advanced Energy Economy, a national trade association representing the advanced energy industry, shows the potential economic impact of investment in transportation electrification[18]. The authors found that a hypothetical $274 billion of economic stimulus investment, spread across electric vehicle (EV) purchases, manufacturing, and domestic supply chain to make batteries and EVs, charging infrastructure, workforce training, and research and development for EVs, produces $1.3 trillion added to the

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[15] Garrett-Peltier, H. (2017), "Green versus Brown: Comparing the Employment Impacts of Energy Efficiency, Renewable Energy, and Fossil Fuels Using an Input–Output Model", Economic Modelling, 61, 439–47.

[16] HR&A Advisors, the California Workforce Development Board (CWDB), and City of Los Angeles Workforce Development Board, "Green Jobs in Los Angeles. Opportunities for Economic Recovery through Equitable Workforce Training", Los Angeles Cleantech Incubator (LACI), 2021.

[17] Nicoletta Batini, Mario Di Serio, Matteo Fragetta, Giovanni Melina, and Anthony Waldron, "Building Back Better: How Big Are Green Spending Multipliers?", IMF Working Paper, March 2021.

[18] Hibbard, Paul, and Darling, Pavel, "Economic Impact of Stimulus Investment in Transportation Electrification – An Economic Assessment of Applying Stimulus Funds to Spur Electrification of the Transportation Sector in the United States", Analysis Group, June 2021.

national GDP -  a nearly five-times return on public investment. Additionally, it creates 10.7 million jobs, including positions in vehicle and battery manufacturing, $231 billion of additional tax revenue to federal, state, and local governments, and $19 billion in consumer, governmental, and business savings, annually, from switching to EVs.

Robert Pollin et al. studied the job creation impact in Washington state of clean energy investments at the level of about $6.6 billion per year in energy efficiency and clean renewable energy over 2021-2035[19]. They found that in the first year the investment would create an estimated 41,000 direct plus indirect jobs, equal to about 1.2% of the state's total workforce. Total job creation through $6.6 billion in clean energy investments will be about 36,000 in 2035, assuming a labor productivity growth rate of 1% per year on average. These jobs would include occupations in construction, sales, production, engineering, and administrative support, with average annual compensation ranging from $52,000 to $90,000.

A similar study Build Back Better, Faster from E2 and E4Thefuture, estimates that if Congress directs $99.2 billion in federal stimulus, policy initiatives, and other investments targeting energy efficiency, renewables, and grid modernization nationwide, Washington's workforce would grow by roughly 15,600 jobs per year for at least five years (a total of 78,000 job-years). Additionally, the federal stimulus package would generate $6.4 billion in additional economic activity in Washington state[20].

In a study completed for the Washington State Department of Commerce, a range of potential energy strategies to reach Washington's decarbonization targets were found to produce positive economic impacts for a modeling period spanning from 2020 through 2050. The decarbonization scenarios utilized in the study ranged from fully electrifying Washington's energy grid and sources, to focusing primarily on the transportation sector to achieve decarbonization targets. Across all scenarios, decarbonization was found to be a net creator of jobs. This is driven by two major factors: 1) transitioning the energy sector would benefit the rest of the economy, driving growth in other sectors and offsetting higher energy costs; 2) transitioning the state's energy sector would reduce the import of fossil fuels, which Washington spends about 1.5% of statewide GDP on each year.[21]

Per the economic impact model utilized in the study, the initial investment in the clean energy infrastructure associated with each scenario drives employment growth in the early 2020s, before dipping slightly in the late 2020s and early 2030s, as

[19] Pollin, Robert, Heidi Garrett-Peltier, and Wicks-Lim, Jeannette. "A Green New Deal for Washington State. Climate stabilization, Good Jobs, and Just Transition". Department of Economic and Political Economy Research Institute (PERI) University of Massachusetts-Amherst. December 2017.
[20] "Build Back Better, Faster", E2, E4Thefuture, 2020.
[21] "Economic Impacts of Decarbonization Pathways Modeling 2021 State Energy Strategy", Washington State Department of Commerce, 2020.

the economic impacts of deploying the infrastructure catch up to the initial cost and lower consumer spending associated with a higher cost of living. However, employment is expected to recover strongly and outpace job growth compared to a reference scenario, which assumes current policy is implemented and no decarbonization targets are in place. Depending on the scenario being modelled, employment gains relative to the reference scenario were projected to be anywhere from 0.4% to as much as 1.2% by 2050.

## Greening the Maritime Sector

A transition to a low-carbon, resource-efficient green economy in Washington state would not be possible unless one of the state's key economic sectors, the maritime industry, becomes a part of these urgently needed transformations. As clean technologies continue to develop and become adopted by the maritime industry, the green economy will naturally be relied upon to build-out and sustain the necessary infrastructure; and to maintain and continue innovating around clean technologies. Through this interdependency, the maritime industry will achieve greater environmental friendliness, while the green economy will likely see growth, as its operations within the state expand to further support one of Washington's core industries.

This section of the report highlights opportunities for the maritime industry to reduce the environmental footprint of its economic activities and foster job creation for the green economy.

### Electrification of the Maritime Fleets and Shipping Supply Chain

Arguably, the trucking industry is the nearest to bringing the maritime industry and green economy together, through planned adoption of electric trucks. Trucking plays a vital role in supporting the maritime industry and may have the easiest path towards reaching zero-emissions. Washington is among five other states to approve the Advanced Clean Trucking (ACT) rule, which requires a growing percentage of all medium- and heavy-duty trucks sold to be zero-emission. Nationally, interest in electrifying the industry appears to be high, with billions of dollars invested in pre-orders for heavy-duty electric vehicles (EV).[22] Kenworth, out of Kirkland, Washington, revealed an electric version of its T680E semi-truck earlier this year. While it is not the brand's first heavy-duty EV, it is the largest and heaviest model in their EV fleet.[23] As heavy-duty EV technology continues to advance and more trucking companies invest in electrifying their fleet, the role of Washington's green economy in the maritime industry will only grow.

[22] https://www.bloomberg.com/news/articles/2022-01-06/how-zero-emission-laws-will-reshape-u-s-trucking

[23] https://www.greenbiz.com/article/7-ev-van-and-truck-companies-big-2022-plans

Electric technologies and energy storage are also emerging as alternatives to reduce fossil fuel consumption in the maritime shipping industry. This will play a key role in reaching the International Maritime Organization's global target of cutting annual emissions in maritime shipping 50% by 2050 from 2008 levels. Although internal combustion engines will remain the standard for the time being, electric and battery technologies have matured enough for use in maritime applications, thanks to advancements in the automotive sector.

### Electrification of Port Operations

Ports and harbors offer great potential for decarbonizing shipping, by turning into carbon neutral smart hubs. Port authorities and terminal operators have significantly invested in and deployed shore-to-ship solutions powering docked ships from a shoreside electrical power source to reduce emissions from at-berth vessels. Investments are also being made in electrifying port cranes, cargo handling equipment and drayage trucks.

In Washington, the ports of Seattle, Tacoma, and the combined container operations of The Northwest Seaport Alliance (NWSA) have adopted near-term implementation plans that guide emission reduction efforts across six sectors of port activity: oceangoing vessels, cargo-handling equipment, trucks, harbor vessels, rail, and port administration and tenant facilities. This includes commitments to: 1) complete the Seattle Waterfront Clean Energy Strategy to plan for the transition to zero-emissions equipment, locomotives, vehicles, vessels, and buildings along the waterfront; 2) install shore power infrastructure at all cruise ship berths and achieve a 100% connection rate for homeport cruise ship calls; 3) phase-out fossil natural gas in Port-owned buildings and transition all Port-owned light-duty fleet vehicles to electric or renewable fuels[24].

### Decarbonization of Passenger Transportation

The green economy's impact on Washington's passenger ferry sector is growing as well. Particularly, a goal to electrify the state's fleet of passenger ferries is driving demand for electric and plug-in hybrid technology in Washington. This goal has been set through an ambitious initiative with a 20-year horizon by Washington State Ferries (WSF).[25] WSF will electrify a total of 16 new vessels and convert 3 existing vessels to plug-in hybrid electric propulsion by 2040. Smaller, regional ferry systems are also driving demand for cleaner fleets. Currently, Kitsap Transit is having an electric-powered hydrofoil passenger ferry designed by Glosten and Bieker Boats.[26]

[24] Port of Seattle, https://www.portseattle.org/news/northwest-ports-adopt-plans-phase-out-maritime-emissions, December 8, 2021.
[25] "Washington State Ferries System Electrification Plan", Washington State Department of Transportation and Washington State Ferries, 2020.
[26] https://www.geekwire.com/2021/maritime-blue-wins-500000-for-cleaner-transportation-as-finalist-in-federal-challenge/

## Clean Fuels

Further opportunity for the maritime industry to intersect with the green economy comes through the adoption of clean fuels. For trans-oceanic shipping, numerous fuels, including hydrogen, have been proven to be effective and viable. However, despite success throughout the research phase, wide-scale implementation is likely to occur slowly. One major barrier impacting this is the need to retrofit the ports and ships operating within the maritime industry. This will require a large investment and a long period of time to complete.[27] However, once the conversion to zero-emission begins in earnest, the green economy will be at the forefront of bringing the conversion to fruition through support of the infrastructure build out and retrofitting of the maritime fleet.

### Hydrogen

Hydrogen as a fuel gains an advantage over other alternative fuels given its flexibility. Hydrogen can be utilized to generate power in numerous settings; and can support a range of industries including but not limited to the manufacturing industry, the power grid, and the transportation industry. For example, a hydrogen fuel production facility may be built to support a greater use of fuel cell electric vehicles (FCEVs) in a region but would in tandem be able to support other industries in the region that demand the fuel. In part, hydrogen's high energy density creates this flexibility. The fuel's energy density is also why it has long been considered a strong candidate for helping green the transportation industry. This includes being used in passenger vehicles, public transit, or long-haul activities that require heavy-duty trucks or maritime vessels to travel long periods without refueling.[28]

Hydrogen project plans are beginning to become more common throughout the United States. In late 2021, New York took the first step in building what will become the largest green hydrogen plant in the United States. Power Plug, the company undertaking the project, has committed to creating as many as 68 new jobs to support the facility.[29] Similarly, Washington state has active hydrogen projects of its own. Twin Transit, of Lewis County, has begun purchasing hydrogen fuel cell buses and hopes to have a refueling station built in the county by as early as 2022. [30] Meanwhile, a hydrogen production facility is currently under construction in Douglas County.[31]

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[27] https://www.ship-technology.com/features/fuel-shipping-heading-right-direction/
[28] "Road Map to a US Hydrogen Economy: Reducing emissions and driving growth across the nation", Fuel Cell & Hydrogen Energy Association, 2020.
[29] https://www.governor.ny.gov/news/governor-hochul-announces-construction-start-largest-green-hydrogen-plant-north-america
[30] https://www.chronline.com/stories/twin-transit-eyes-renewables-as-legislature-considers-allocating-funding-for-states-first,262119
[31] https://douglaspud.org/renewable-hydrogen-production-facility-groundbreaking-d30/

Current barriers associated with a transition to hydrogen include high production and fuel costs, in addition to the large infrastructure investment needed to support widespread adoption of hydrogen. However, analysis suggests that the cost of fueling stations can decrease by an estimated 50 percent with higher utilization of retail fueling stations, larger stations, multiyear development programs, increasing network density, and R&D innovations to decrease fueling capital expenditures. Additionally, it is estimated that fuel cell system costs could decline by about 25, if production were to scale from 1,000 to 100,000 systems per year.[32]

Currently, energy generated by hydrogen represents 1% of nationwide energy demand.[33] Given continued investment and adoption, it is projected that hydrogen can help meet 14% of the nation's final energy demand by 2050. A robust hydrogen industry would create U.S. jobs and business revenue. If the U.S. remains a leader in the energy sector, exports to regions looking to further develop their hydrogen industry will also grow U.S. businesses working within the hydrogen industry.[34]

Employment levels in current hydrogen clusters are relatively low but show promise for the potential job creation as the industry continues to grow. According to a national study, Connecticut's hydrogen/fuel cell industry supported 3,400 jobs in 2015. In Florida, it was found that 8,000 advanced transportation jobs were related to the hydrogen/fuel cell industry in 2016.[35] A 2014 study analyzing the economic impact of hydrogen fuel station rollouts in California projected that the production of hydrogen, its sale, and the operation of fuel stations would support a total of 1,120 jobs by 2023, given a network of 123 fuel stations. Annually, an average of 128 jobs were projected to be created as the 123 stations were built from 2015 to 2023.[36]

As wider spread adoption of hydrogen continues throughout the United States, the number of hydrogen related jobs is expected to grow significantly. In a 2008 study conducted by the American Solar Energy Association and Management Information Services, Inc., it was projected that the hydrogen/fuel cell industry could support as many as 1 million jobs nationwide by 2030.[37] In a more recent study, conducted in 2020, it was projected that that widespread adoption of

[32] "Road Map to a US Hydrogen Economy: Reducing emissions and driving growth across the nation", Fuel Cell & Hydrogen Energy Association, 2020.

[33] https://www.shearman.com/Perspectives/2021/10/Hydrogens-Present-and-Future-in-the-US-Energy-Sector

[34] "Road Map to a US Hydrogen Economy: Reducing emissions and driving growth across the nation", Fuel Cell & Hydrogen Energy Association, 2020.

[35] "State of the States: Fuel Cells in America 2016", U.S. Department of Energy, 2016.

[36] "Economic Impacts Associated with Commercializing Fuel Cell Electric Vehicles in California: An Analysis of the California Road Map Using the JOBS H2 Model", Argonne National Laboratory and RCF Economic and Financial Consulting, Inc., 2014.

[37] "The Hydrogen Economy and Jobs of the Future", Roger H. Bezdek, 2018.

hydrogen in the US could generate $140 billion a year in revenue and support 700,000 total jobs across the nation by 2030. By 2050, it is estimated that the hydrogen value chain could generate $750 billion a year in revenue and a cumulative 3.4 million jobs.[38]

Jobs created by the hydrogen value chain are expected to span multiple skill- and education-levels. Historically, high-skilled industries have required almost exclusively highly educated workers with advanced degrees. However, the hydrogen/fuel cell industry is expected to demand a range of occupations requiring various lower levels of schooling. Occupations requiring 2-year degrees, apprenticeships, or trade certifications are expected to be abundant, and will lead to many hydrogen-related jobs that pay above the U.S. average in wages.[39] In a study conducted by the U.S. Department of Energy, it was estimated that hydrogen production jobs alone could see a net increase of as many as 43,000 jobs by 2035, while an additional 8,000 could be supported by 2050. Of the total production jobs created, it was estimated that roughly 80% would represent jobs requiring lower educational levels such as technical or vocational schooling. Total employment gains from this study were projected to reach as high as 675,000 jobs by 2050. These figures consider industry losses associated with hydrogen adoption, thus providing a clear picture of how a hydrogen transition could impact national employment levels.[40]

## Entrepreneurship and Innovation

New technologies created through innovation will play a crucial role in greening the maritime industry. Accompanying this is a need for incubators and accelerators to ensure these technologies do not become stifled in their early stages[41]. While incubator organizations can have strong positive impacts on a new technology's success, they also support job creation by supporting small and growing businesses. The Los Angeles Cleantech Incubator (LACI) is an example of such an organization and works with startups to accelerate the commercialization of clean technologies. As of 2016, LACI's reporting companies supported 318 jobs spread across multiple industries. LACI's reporting companies also received more than $132 million in funding in 2016. Environmentally, their reporting companies reduced greenhouse gas (GHG) emissions by nearly 250 million pounds, saved 23 million gallons of water, and generated nearly 95 million kilowatt hours of renewable energy in the same year.[42]

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[38] "Road Map to a US Hydrogen Economy: Reducing emissions and driving growth across the nation", Fuel Cell & Hydrogen Energy Association, 2020.
[39] "The Hydrogen Economy and Jobs of the Future", Roger H. Bezdek, 2018.
[40] "Effects of a Transition to a Hydrogen Economy on Employment in the United States: Report to Congress", U.S. Department of Energy, 2008.
[41] U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy provides a list of incubators and accelerators at https://www.energy.gov/eere/buildings/incubators-and-accelerators.
[42] "Just Impact Annual Report 2016", LACI, 2016.

Another example is Cleantech Open (CTO), the world's largest cleantech accelerator, providing entrepreneurs and corporate innovators the resources they need to launch and grow successful cleantech businesses. Since 2005, CTO has trained more than 3,500 entrepreneurs from 1,800 early-stage clean technology startups. CTO alumni have gone on to raise over $1.5 billion in equity. In recent cohorts, 39% of founder CEOs self-identified as BIPOC and/or women.

## $CO_2$ Emissions Reduction

The transportation sector is a major consumer of fossil fuels. Pre-pandemic, transport made up 29% of global primary energy use and around 25% of global energy-related carbon dioxide ($CO_2$) emissions[43]. Among transportation sectors, heavy-duty vehicles, including buses, are responsible for more than a third of the $CO_2$ emissions in the transportation sector as shown in **Exhibit 4**, followed by maritime shipping (11%) and aviation (10%) which rank as the third and fourth highest emitters[44].

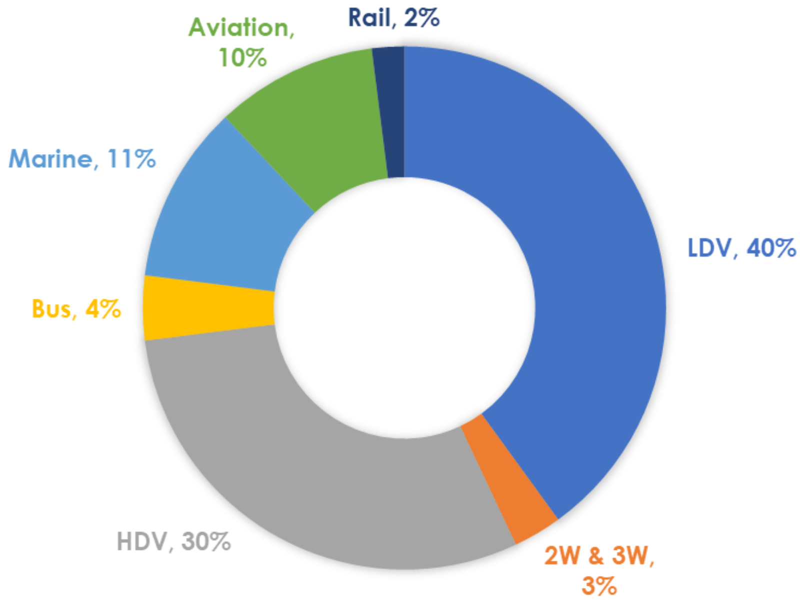
Decarbonization of transportation sector is crucial for sustainable transport, meeting future climate goals, and keeping climate change in check. According to the Intergovernmental Panel on Climate Change, an intergovernmental body of the United Nations, greenhouse gas emissions must be reduced by 50%–85% by 2050 to limit global warming to two degrees Celsius (four degrees Fahrenheit). A mobility system fueled with clean, renewable energy, delivered directly by vehicle electrification, or indirectly by low-carbon, energy dense fuels and renewable hydrogen for those sectors, like marine and aviation, that are harder to electrify can help drive down emissions.

This section of the report summarizes findings from a literature review of the potential for $CO_2$ reduction from a wide range of vehicle and fuel technologies implemented in the heavy-duty vehicles, marine, and aviation sectors.

**Exhibit 4. Share of 2020 $CO_2$ Emissions from Transportation, by Mode**

[43] Gross, Samantha, "The Challenge of Decarbonizing Heavy Transport", The Brookings Institution, October 2020.

[44] "Vision 2050. A strategy to decarbonize the global transport sector by mid-century", The International Council on Clean Transportation, 2020.




*Source: The International Council on Clean Transportation, 2020; Community Attributes, 2022. Note: LDV stands for light-duty vehicles, HDV stands for heavy-duty vehicles, 2W & 3W stands for 2 and 3 wheelers.*

## Electric Vehicles

If the transportation sector is to be decarbonized, while improving efficiency of conventional vehicles is a solid short-term solution, ultimately most vehicles must produce zero tailpipe emissions and be fueled by carbon-neutral and renewable energy sources. The International Council on Clean Transportation estimates that by 2050 electric buses will be 81% of the global bus stock, electric light heavy-duty trucks will make up 69% of the global stock, and electric heavy duty-trucks will be 29% of the global stock[45].

Electrifying heavy-duty vehicles can have significant benefits on air quality, public health, and the climate. Despite being roughly 10% of vehicles on U.S. roads, heavy-duty vehicles contribute 30% of CO2 emissions from the nation's transportation sector. They are also responsible for 45% of on-road NOx emissions (oxides of nitrogen) and 57% of on-road, direct PM2.5 emissions (particulate matter less than 2.5 micrometers in diameter). On-road sources of air pollution disproportionately burden communities of color and low-income communities due to their proximity to roads and vehicular traffic. Asian Americans, African Americans, and Latinos are exposed to 34 percent, 24 percent, and 23 percent more PM2.5 pollution (respectively) from cars, trucks, and buses than the national average[46].

[45] "Vision 2050. A strategy to decarbonize the global transport sector by mid-century", The International Council on Clean Transportation, 2020.
[46] Union of Concerned Scientists, "Ready for Work. Now is the Time for Heavy-Duty Electric Vehicles", 2019.

An analysis conducted in 2019 by the Union of Concerned Scientists (UCS) found that heavy-duty electric vehicles can reduce global warming emissions by 44% to 79% depending on the vehicles average speed over the course of a trip. Additionally, they found that no matter the operating characteristics of the vehicle or electricity grid, battery-electric heavy-duty vehicles have lower global warming emissions than diesel vehicles, ranging from 36% to 88% lower[47].

In Washington, adopting the Advanced Clean Trucks (ACT) rule that requires truck manufacturers to sell an increasing number of zero-emission vehicles, can cut the state's annual nitrogen oxide emissions from trucks by 47% and particulate matter pollution by 43% compared to the baseline by 2050[48]. The study which was conducted by M.J. Bradley & Associates, commissioned by National Resources Defense Council (NRDC) and the Union of Concerned Scientists, also found immense public health benefits. By 2050, Washington is expected to avoid almost 70,000 respiratory cases, nearly 100 hospital visits, and 114 premature deaths.

The electrification of marine shipping and aviation also have significant benefits for cutting carbon emissions, but present distinct challenges compared to vehicles. The main challenges is the heavy weight of batteries which would be required for such large vessels and aircrafts. However, improvements of the design and lighter materials used for the ships and aircrafts will allow larger battery packs on board, together with the technological improvement of batteries.

Today's battery technologies can power many ferry application, especially for short routes and routes that use smaller ferries. Some ferry operators like those in Washington state are transitioning to the intermediary step of hybrid ferries. These ferries can reduce nitric oxide emissions by 146 metric tons/year and carbon dioxide emissions by 16,340 metric tons/year, reducing operating costs, virtually eliminating engine noise and vibration, and reducing maintenance costs[49]. However, successes from ferries operating entirely on batteries such as Denmark's e-ferry Ellen, a Ro-pax ferry operating a 40 km route since 2019, suggest that the all-electric option is workable. With an energy efficiency rating of 85%, the Danish electric ferry Ellen can reduce $CO_2$ emissions by up to 2,250 tons a year[50].

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[47] Ibid.

[48] Dana Lowell, Amlan Saha, Miranda Freeman, Doug MacNair, David Seamonds, and Ellen Robo, "Washington Clean Trucks Program. An Analysis of the Impacts of Zero-Emission Medium- and Heavy-Duty Trucks on Environment, Public Health, Industry, and the Economy", M.J. Bradley & Associates, NRDC, Union of Concerned Scientists, 2021.

[49] Washington State Department of Transportation, https://wsdot.wa.gov/construction-planning/major-projects/ferry-system-electrification.

[50] World Economic Forum, "Could this electric ferry's success herald and era of greener shipping?", 14 July 2020.

## Renewable Fuels

### International Shipping

The shipping industry was responsible for about 3% of global greenhouse gas emissions in 2018. As of 2021, 99% of energy demanded by the international shipping industry was met by fossil fuels.[51] While renewable fuels have begun to be introduced throughout the shipping sector, the sector is still heavily reliant on fossil fuels. In the medium term, the main strategy for reducing emissions in the shipping sector must involve progressively but rapidly replacing fossil fuels with renewable fuels.

The renewable fuels most suited to international shipping are primarily advanced biofuels and e-fuels, such as methanol and ammonia. Each of these are different in terms of their benefits and challenges. Factors such as supply chain, engine technology, environmental impacts, and production costs influence the choice of fuels. The production cost, which will ultimately dictate the deployment of renewable fuels, is determined by the cost and availability of feedstock, the process used for production, and the maturity of the production technology[52].

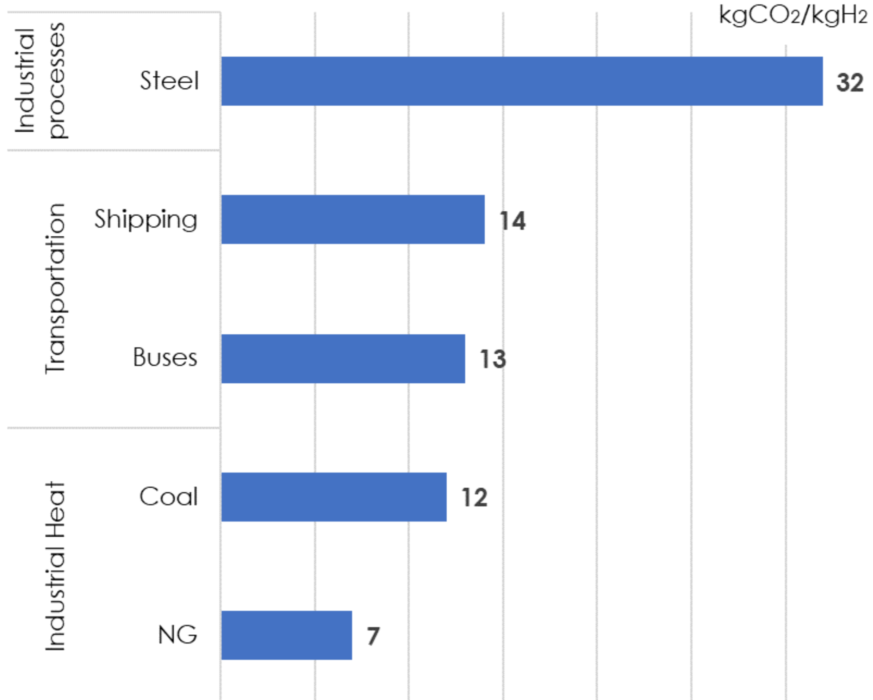
Advanced biofuels and biomethane could play a role in the short-term in reducing $CO_2$ emissions for the shipping industry but is likely limited. In the medium to long-term, green hydrogen-based fuels will be critical for the decarbonization of international shipping. The International Renewable Energy Agency's decarbonization analysis estimates that 46 million tons of green hydrogen will be required by 2050, of which 73% will be used indirectly to produce ammonia, 17% to produce e-methanol and 10% will be used directly via fuel cells (FCs) and internal combustion engines (ICEs) mainly for short sailings.

The ability of hydrogen to impact $CO_2$ emissions depends strongly on both the specific use case where it is implemented and the way it is produced. A study by Rocky Mountain Institute analyzed five different hydrogen use cases and found that the $CO_2$ reduction effectiveness of a kilogram of hydrogen varies quite dramatically, by more than a factor of three[53], as shown in **Exhibit 5**. Today only 4% of hydrogen production is "green" – made by electrolysis powered by renewables. The rest is created using fossil fuels, predominantly through Steam Methane Reform (SMR). Despite lower CO2-intensity than most power grid-based hydrogen sources, there is no long-term role for SMR in

[51] "A Pathway to Decarbonise the Shipping Sector by 2050", International Renewable Energy Agency (IRENA), 2021.
[52] "A Pathway to Decarbonise the Shipping Sector By 2050", International Renewable Energy Agency (IRENA), 2021.
[53] Thomas Koch Blank and Patrick Molly, "Hydrogen's Decarbonization Impact for Industry. Near-term challenges and long-term potential", Rocky Mountain Institute, January, 2020.

decarbonizing industry sectors unless successfully fitted with carbon capture and storage (CCS)[54].

**Exhibit 5. GHG Emission Reduction for Each Consumed Kilogram of Hydrogen**




*Source: Rocky Mountain Institute, 2020; Community Attributes, 2022.*

## Aviation

The use of Sustainable Aviation Fuel (SAF) is currently the aviation industry's best option to lower $CO_2$ emissions. SAF is made from renewable biomass and waste resources and can deliver similar performance to that of petroleum-based jet fuel while significantly lowering the industries carbon footprint. There are numerous sustainable feedstocks that can be used to create SAF, increasing the fuels eco-friendliness. In some cases, SAF can even be a carbon-negative fuel, such as SAF created from wet waste (food waste, animal manure, etc. with high water content).[55] SAF is already being used as a drop-in fuel that can be blended with petroleum-based fuels. Seattle-Tacoma International airport expects to use more than 10% SAF jet fuel blend by as early as 2028. [56] SAF will likely remain an important bridge towards lowered emissions as technology in areas such as electric airplanes, though in preliminary research phases, continues to develop and provide the industry with 100% emission reducing options.

[54] Ibid.
[55] https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuels
[56] "Clean Fuel Forum: 2021 Industry and Policy Forecast for Washington State," Port of Seattle, October 2020."

### Trucking

Electrifying the nation's trucking fleet is underway and appears likely to be the chosen way forward to a zero emissions industry. However, as the technology continues to evolve there are fuel alternatives that can help reduce $CO_2$ emissions in the short-term. Potential clean fuels that could significantly decrease the industry's emissions include renewable diesel, renewable propane, and renewable natural gas. Renewable diesel and renewable natural gas can be used as drop-in fuels, being compatible with current engines in use today. It is reported that renewable diesel could lower GHG emissions by 75% compared to petroleum-derived diesel.[57] These fuels are deemed "renewable" because each fuel can be created using bio-based feedstock.[58] As technology continues to advance, short-term solutions will be important in lowering the emissions of the transportation industry.

## Energy Efficiency

To reduce the sector's carbon footprint, in the near term, rapid implementation of energy efficiency design and operational measures will be key. Energy efficiency in the transportation sector takes several forms. The first is improved efficiency of conventional vehicles, aircraft, and ships through lighter materials, more efficient motors, and other design and operational changes. For example, for the maritime shipping sector such measures include just-in-time arrival and ship speed optimization, reducing onboard power demand from machinery and equipment, integration of high-tensile steel and other composite materials into ship structures to allow for weight reduction, propeller optimization and others. Not only can these measures reduce carbon emissions, but they can also potentially result in important energy savings and thus increase monetary revenue for shipowners and operators.

Emissions can also be reduced through system-wide efficiency gains. For instance, Autonomous vehicles (AV) could potentially allow higher throughout, faster speeds, fewer start-stops, and reduced congestion, leading to a reduction in fuel consumption. However, legal and policy support for AV development is still in early stages[59].

## Clean Fuel and Heavy Transportation in Washington

Regional industry leaders discussed the future of clean fuel in heavy transportation, including key fuels and technologies, timelines, and barriers.

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57 https://www.truckinginfo.com/10152137/making-the-case-for-renewable-fuels-in-trucking#:~:text=While%20the%20trucking%20industry%20seems,and%20available%20for%20adoption%20today.

58 U.S. Department of Energy: Alternative Fuels Data Center, 2022.

59 Ashley Lawson and Fatima Maria Ahmad, "Decarbonizing U.S. Transportation", Center for Climate and Energy Solutions, July 2018.

## Key Fuels and Technologies

Supporting the findings above, green hydrogen was a centerpiece of conversations with regional industry leaders given the potential it possesses for many of Washington's industries. Hydrogen is considered a necessity for working to decarbonize heavy transport in addition to enabling the production of other sustainable fuels such as SAF or green diesel. Industry stakeholders feel Washington is particularly well suited for hydrogen, given the state's large and stable power grid, access to renewable energy sources, and potential widespread use of hydrogen spanning beyond heavy transportation.

In the near term, it is believed hydrogen could be utilized for shorter regional flights and sea voyages while greater use will require re-outfitting current ships, trucks, and aircraft to become more compatible with clean fuels. In addition to re-outfitting, the per kilo price of hydrogen will heavily dictate how quickly industries begin to adopt green hydrogen. For some industries, hydrogen prices are beginning to reach sustainable levels, the trucking being the most noteworthy at the moment. Trucking and maritime are thought to be more easily decarbonized, as reformatting current truck and maritime technologies for compatibility with green hydrogen is considered more attainable. The ability of green hydrogen to decarbonize the aviation industry's longer flights is uncertain, with uncertainty stemming from the inability of current aircraft fuel storage formats to hold enough liquid hydrogen to support longer flights.

Washington's large presence of heavy transportation and the desire to decarbonize these industries are not expected to fully drive hydrogen adoption within the state. Rather, potential uses across multiple industries are expected to help generate increased production and adoption. For example, tech firms have begun showing interest in hydrogen fuel as a back-up fuel for data centers, resulting in large amounts of research investment. Hydrogen could also be used for the power grid itself, replacing reliance on natural gas.

Other fuels and technologies discussed included fusion energy, small modular reactors, high pressure electrolysis, liquefaction, catalysis, formic acid, ammonia, ethanol/methanol, and green diesel. Research surrounding high pressure electrolysis, liquefaction, and catalysis are working to make hydrogen more accessible through eased production, transport, and storage. Meanwhile, fusion energy, small modular reactors, ammonia, formic acid, and ammonia would provide a diverse set of energy production and fuel sources to complement hydrogen.

## Timeline and Barriers

A consensus opinion shared through conversations with industry leaders was that large scale production of hydrogen in Washington may not be far off. The projected timeline spanned from two years to 10 years, but each stakeholder shared a confidence that large amounts of hydrogen will be produced in Washington sooner rather than later. Notable barriers identified throughout the outreach that could impact this timeline are the supply chain, need for critical materials, production ramp up, misconceptions surrounding hydrogen fuel, workforce, and infrastructure.

- **Supply Chain:** Pandemic impacts on the supply chain's ability to transfer goods and materials will continue to impede the clean fuel industry.
- **Critical Materials:** Current reliance for certain metals and materials that are becoming increasingly difficult to obtain will impede the industry's progress.
- **Production Ramp Up:** Production and technology manufacturing ramp up will naturally take many years, though it is thought that many technologies are near financial viability and will begin the process in the next few years.
- **Current Misconceptions:** Misconceptions surrounding clean fuels and hydrogen will act as a barrier as there is a continued need for collaboration between local manufacturers, communities, and municipalities to support greater production.
- **Workforce:** Workforce will be a natural barrier, as the emerging clean fuel industry requires high-skilled workers and has yet to establish a wide-reaching and substantial workforce.
- **Infrastructure:** Infrastructure build out to sustain new fuels and technologies will be a large barrier, requiring large time and capital expenditures.

Many of these barriers are shared with the other clean fuels and technologies discussed above. The supply chain, infrastructure, production ramp up, and workforce barrier will impact all aspects of the clean fuel industry. Meanwhile, fusion energy and small modular reactors are particularly impacted by the current misconceptions surrounding the technologies and could be the greatest barrier to overcome.

While industry stakeholders believe some partially decarbonizing drop-in fuels may be used in the short-term, green hydrogen and the many of the other fuel technologies discussed above are expected to be the short-term and long-term solution for decarbonization. Some believe electrolysis and fuel cell technologies are ready, but the slow process of increasing production will keep green hydrogen from being widely adopted for the next 3-5 years. Meanwhile, the timeline associated with fusion energy is similar to that of hydrogen, while small modular reactors are thought to have potential for nearly immediate impact in decarbonizing Washington's energy production. The timeline surrounding the remaining clean fuels were not discussed in full detail.

## Summary and Conclusions

This study estimates that in 2021, the statewide maritime sector directly employed 67,000 workers, across a variety of sectors ranging from recreational boating to logistics and shipping. The green economy sector employment in Washington state totaled nearly 76,000 jobs in 2020 in energy efficiency, renewable energy, grid and storage, clean vehicles, and clean fuels. Developing the "green" aspects of maritime and the "blue" aspects of the green economy presents job creation opportunities and improvements to environmental, economic, and social sustainability for both sectors.

# Appendix A

**Exhibit 6. Maritime Sector Definition**

| NAICS | Description | Subsector |
|---|---|---|
| 112511 | Finfish farming and fish hatcheries | Commercial Fishing and Seafood Products |
| 112512 | Shellfish farming | Commercial Fishing and Seafood Products |
| 114111 | Finfish fishing | Commercial Fishing and Seafood Products |
| 114112 | Shellfish fishing | Commercial Fishing and Seafood Products |
| 311710 | Seafood product preparation and packaging | Commercial Fishing and Seafood Products |
| 424460 | Fish and seafood merchant wholesalers | Commercial Fishing and Seafood Products |
| 445220 | Fish and seafood markets | Commercial Fishing and Seafood Products |
| 483111 | Deep sea freight transportation | Maritime Logistics and Shipping |
| 483113 | Coastal and great lakes freight transport | Maritime Logistics and Shipping |
| 483211 | Inland water freight transportation | Maritime Logistics and Shipping |
| 488210 | Support activities for rail transportation | Maritime Logistics and Shipping |
| 488310 | Port and harbor operations | Maritime Logistics and Shipping |
| 488320 | Marine cargo handling | Maritime Logistics and Shipping |
| 488330 | Navigational services to shipping | Maritime Logistics and Shipping |
| 488510 | Freight transportation arrangement | Maritime Logistics and Shipping |
| 493120 | Refrigerated warehousing and storage | Maritime Logistics and Shipping |
| Custom | Rail | Maritime Logistics and Shipping |
| Custom | Warehouse | Maritime Logistics and Shipping |
| Custom | Drayage and trucking | Maritime Logistics and Shipping |
| Custom | Geotechnical and environmental | Maritime Support Services |
| Custom | Naval architecture | Maritime Support Services |
| Custom | Law | Maritime Support Services |
| Custom | Accounting | Maritime Support Services |
| Custom | Associations | Maritime Support Services |
| Custom | Education | Maritime Support Services |
| Custom | Marine construction and engineering | Maritime Support Services |
| Custom | Support | Maritime Support Services |
| Custom | Maritime insurance | Maritime Support Services |
| 483112 | Deep sea passenger transportation | Passenger Water Transportation |
| 483114 | Coastal and great lakes passenger transport | Passenger Water Transportation |
| 483212 | Inland water passenger transportation | Passenger Water Transportation |
| 488390 | Other support activities for water transport | Passenger Water Transportation |
| 441222 | Boat dealers | Recreational Boating and Boat Building |
| 487210 | Scenic and sightseeing transportation, water | Recreational Boating and Boat Building |
| 713930 | Marinas | Recreational Boating and Boat Building |
| Custom | Recreational boat builders | Recreational Boating and Boat Building |
| Custom | Charter fishing | Recreational Boating and Boat Building |
| 336611 | Ship building and repairing | Shipbuilding, Repair and Maintenance |
| 336612 | Boat building | Shipbuilding, Repair and Maintenance |
| Custom | Puget Sound Naval Shipyard | Shipbuilding, Repair and Maintenance |

*Source: Community Attributes Inc., 2022.*

## Exhibit 7. Detailed Clean Energy Employment by Industry, Washington State, 2019

| Industry | Description | Jobs, 2019 |
|---|---|---|
| ***Energy Efficiency*** | | ***64,900*** |
| Energy STAR Appliances | Appliances that meet the international ENERGY STAR standard for energy efficient consumer products originated in the United States. Also includes reduced water consumption products and appliances such as high efficiency (HE) washing machines, faucet aerators, low flow shower heads, etc. | 16,400 |
| LED, CFL and Other Efficient Lighting | Energy efficient lighting sources | |
| Traditional HVAC | Heating, ventilation, and air conditioning systems (HVAC), including building retrocommissioning and retrofits connected to heating and cooling. | 19,900 |
| High-Efficiency HVAC | HVAC that meets the international ENERGY STAR standard for energy efficient consumer products originated in the United States or has high Average Fuel Utilization Efficiency (AFUE) rating of 90 or greater or 15 SEER or greater. | 7,800 |
| Renewable Heating and Cooling | Refers to establishments that are involved with heating, ventilation and air conditioning (HVAC) from Renewable Energy sources or work that increases the Energy Efficiency of HVAC systems (solar thermal — uses the sun's energy to generate thermal energy). | |
| Advanced Building Materials/Insulation | All materials that represent advances in efficiency over the traditional materials. | 7,000 |
| Other Energy Efficiency | Includes variable speed pumps, other design services not specific to a detailed technology, software not specific to a detailed technology, energy auditing, rating, monitoring, metering, and leak detection, policy and non-profit work not specific to a detailed technology, consulting not specific to a detailed technology, LEED certification, phase-change materials, etc.. | 13,800 |
| ***Renewable Energy*** | | ***11,200*** |
| Solar Electric Generation | Generating solar power by using mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. | 5,100 |
| Wind Generation | Converting the wind's kinetic energy into electrical power. | 3,300 |
| Geothermal Generation | Using steam produced from reservoirs of hot water found a few miles or more below the Earth's surface to produce electricity. | 200 |
| Bioenergy/Biomass Generation | Generating electricity from materials derived from biological sources or any organic material which has stored sunlight in the form of chemical energy. | 1,200 |
| Combined Heat and Power | Generating electricity and useful thermal energy in a single, integrated system. Heat that is normally wasted in conventional power generation is recovered as useful energy. | |
| Low-Impact Hydroelectric Generation | Similar to traditional, but certification criteria are aimed at ensuring that the certified dam adequately protects or mitigates its impacts in eight key resource areas: river flows, water quality, fish passage and protection, watersheds, threatened and endangered species, cultural resources, and public access and recreation opportunities. | 1,400 |

## Exhibit 7. Detailed Clean Energy Employment by Industry (cont.), Washington State, 2019

| Industry | Description | Jobs, 2019 |
|---|---|---|
| ***Grid & Storage*** | | ***3,600*** |
| Pumped Hydro Storage | Hydroelectric energy storage used by electric power systems for load balancing. The method stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. | |
| Battery Storage | Using a cell or connected group of cells to convert chemical energy into electrical energy by reversible chemical reactions and that may be recharged by passing a current through it in the direction opposite to that of its discharge. | 2,500 |
| Mechanical Storage | Uses kinetic or gravitational forces to store energy. Includes flywheels, compressed air, etc.. | |
| Thermal Storage | Temporary storage of energy for later use when heating or cooling is needed. | |
| Smart Grid | An electricity supply network that uses digital communications technology to detect and react to local changes in usage. | 400 |
| Micro Grid | A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. | 400 |
| Other Grid Modernization | Other modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth. | 400 |
| ***Clean Vehicles*** | | ***3,400*** |
| Hybrid Electric Vehicles | Use two or more distinct types of power, such as internal combustion engine + electric motor. | 1,500 |
| Plug-In Hybrid Vehicles | A hybrid electric vehicle that uses two or more distinct types of power, such as internal combustion engine and an electric motor that is powered by rechargeable batteries, or another energy storage device, that can be recharged by plugging it in to an external source of electric power. | 700 |
| Electric Vehicles | A vehicle which uses one or more electric motors for propulsion with no onboard generator or non-electric motor. | 800 |
| Natural Gas Vehicles | An alternative fuel vehicle that uses compressed natural gas (CNG) or liquefied natural gas (LNG) as a cleaner alternative to other fossil fuels. | 200 |
| Hydrogen Vehicles | Uses hydrogen as its onboard fuel for motive power. | |
| Fuel Cell Vehicles | A type of hybrid vehicle which uses a fuel cell, instead of an engine, in combination with a storage device, such as a battery, to power its on-board electric motor. | 100 |
| ***Clean Fuels*** | | ***1,900*** |
| Other Biofuels | Other fuel derived directly from living matter. | 300 |
| Other Ethanol/Non-Woody Biomass Fuel, including Biodiesel | Fuel made from other materials such as straw, manure, vegetable oil, animal fats, etc. | 1,700 |
| ***TOTAL*** | | ***85,000*** |

*Sources: E2, 2021; Community Attributes Inc., 2021.*
*Note: Totals may not sum due to rounding.*

## Exhibit 8. The Brookings Institution Green Economy Definition

| NAICS | NAICS Title |
|---|---|
| **Clean energy generation, manufacturing and construction** | |
| *Generation utilities* | |
| 221111 | Hydroelectric power generation |
| 221113 | Nuclear electric power generation |
| 221114 | Solar electric power generation |
| 221115 | Wind electric power generation |
| 221116 | Geothermal electric power generation |
| 221117 | Biomass electric power generation |
| 221118 | Other electric power generation |
| 221121 | Electric bulk power transmission and control |
| 221122 | Electric power distribution |
| 221330 | Steam and air-conditioning supply |
| *Grid component manufacturing and construction* | |
| 332410 | Power boiler and heat exchanger manufacturing |
| 333611 | Turbine and turbine generator set units manufacturing |
| 335311 | Power, distribution, and specialty transformer manufacturing |
| 335911 | Storage battery manufacturing |
| 335931 | Current-carrying wiring device manufacturing |
| 237130 | Power and communication line and related structures construction |
| 237990 | Other heavy and civil engineering construction |
| 238210 | Electrical contractors and other wiring installation contractors |
| **Energy Efficiency** | |
| *Manufacturing of energy-efficient products* | |
| 327993 | Mineral wool manufacturing |
| 332321 | Metal window and door manufacturing |
| 332322 | Sheet metal work manufacturing |
| 333415 | Air-conditioning and warm air heating equipment and commercial and industrial |
| 336111 | Automobile manufacturing |
| 336112 | Light truck and utility vehicle manufacturing |
| 336120 | Heavy duty truck manufacturing |
| 336211 | Motor vehicle body manufacturing |
| 336310 | Motor vehicle gasoline engine and engine parts manufacturing |
| 336320 | Motor vehicle electrical and electronic equipment manufacturing |
| 336330 | Motor vehicle steering and suspension components (except spring) manufacturing |
| 336340 | Motor vehicle brake system manufacturing |
| 336350 | Motor vehicle transmission and power train parts manufacturing |
| 336360 | Motor vehicle seating and interior trim manufacturing |
| 336370 | Motor vehicle metal stamping |
| 336390 | Other motor vehicle parts manufacturing |
| 334512 | Automatic environmental control manufacturing for residential, commercial, and appliance |
| 334513 | Instruments and related products manufacturing for measuring, displaying, and controlling |
| 334515 | Instrument manufacturing for measuring and testing electricity and electrical signals |
| 336510 | Railroad rolling stock manufacturing |
| 335110 | Electric lamp bulb and part manufacturing |
| 335121 | Residential electric lighting fixture manufacturing |

### Exhibit 8. The Brookings Institution Green Economy Definition (cont.)

| NAICS | NAICS Title |
|---|---|
| **Energy Efficiency** | |
| *Manufacturing of energy-efficient products* | |
| 335122 | Commercial, industrial, and institutional electric lighting fixture manufacturing |
| 335210 | Small electrical appliance manufacturing |
| 335221 | Household cooking appliance manufacturing |
| 335222 | Household refrigerator and home freezer manufacturing |
| 333413 | Industrial and commercial fan and blower and air purification equipment manufacturing |
| 333414 | Heating equipment (except warm air furnaces) manufacturing |
| 334413 | Semiconductor and related device manufacturing |
| 335312 | Motor and generator manufacturing |
| 335999 | All other miscellaneous electrical equipment and component manufacturing |
| *Construction of energy efficient buildings & provision of energy efficiency services* | |
| 236115 | New single-family housing construction (except for-sale builders) |
| 236116 | New multifamily housing construction (except for-sale builders) |
| 236117 | New housing for-sale builders |
| 236118 | Residential remodelers |
| 236210 | Industrial building construction |
| 236220 | Commercial and institutional building construction |
| 237210 | Land subdivision |
| 238350 | Finish carpentry contractors |
| 238220 | Plumbing, heating, and air-conditioning contractors |
| 238160 | Roofing contractors |
| 238990 | All other specialty trade contractors |
| 541310 | Architectural services |
| 541340 | Drafting services |
| 541320 | Landscape architectural services |
| 541350 | Building inspection services |
| **Environmental management, conservation and regulation** | |
| 541620 | Environmental consulting services |
| 562111 | Solid waste collection |
| 562112 | Hazardous waste collection |
| 562119 | Other waste collection |
| 562211 | Hazardous waste treatment and disposal |
| 562212 | Solid waste landfill |
| 562213 | Solid waste combustors and incinerators |
| 562219 | Other nonhazardous waste treatment and disposal |
| 562910 | Remediation services |
| 562920 | Materials recovery facilities |
| 562998 | All other miscellaneous waste management services |
| 813312 | Environment, conservation and wildlife organizations |
| 924110 | Administration of air and water resource and solid waste management programs |
| 924120 | Administration of conservation programs |
| 925120 | Administration of urban planning and community and rural development |
| 926120 | Regulation and administration of transportation programs |
| 926130 | Regulation and administration of communications, electric, gas, and other utilities |

*Sources: The Brookings Institution, 2022; Community Attributes Inc., 2022.*