Assessment on the Availability of Alternative Fuels for the Offshore Wind Power Fleet

October 16, 2023

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MEMORANDUM

TO:	Office of Air Quality Planning & Standards, U.S. Environmental Protection Agency (EPA)
FROM:	Eastern Research Group, Inc. (ERG)
DATE:	October 16, 2023
SUBJECT:	Assessment on the Availability of Alternative Fuels for the Offshore Wind Power Fleet

Purpose

The U.S. Environmental Protection Agency (EPA) requested information regarding the availability of alternative fuels and associated infrastructure (e.g., vessels, bunkering availability, and refueling infrastructure) for the offshore wind industry. This memorandum is a literature review about the availability and infrastructure requirements for several alternative energy sources for marine vessels used in the construction and operation and maintenance (O&M) of offshore wind farms. The energy sources reviewed include the currently regulated marine fuels, nonroad marine diesel fuels, Liquified Natural Gas (LNG), biofuels/biodiesel, and electricity. The memorandum also includes cost calculations where available, consideration of alternative fuels in the context of port economy, and information gathered from interviews conducted with port personnel. This memorandum is a deliverable under EPA Contract EP-W-15-011 Work Assignment 5-03.

This document reviews general information about the costs, pollution effects, and technical considerations of traditional and alternative energy systems on marine vessels, bunkering and refueling facilities. Note, that these aspects of marine fuel systems will be affected by site-specific variables, such as the age and condition of the vessels and associated equipment, distance to refueling, price and availability of fuels. Therefore, each project would require site-specific analysis of these factors.

Executive Summary

- LNG is probably the most likely candidate as a viable alternative fuel for the offshore wind power fleet as some of the fleet are equipped with dual fuel (LNG/diesel) engines and there are natural gas lines currently near some of the major ports in the Northeast;
- Drop-in biodiesel fuels are also a good candidate but availability of sufficient quantities of biodiesel may limit its use;
- Electrification has limited applications at this time, but in the future, it may be viable to replace diesel-electric engines with battery banks or fuel cells as the power source;
- Requiring very low sulfur fuels such as nonroad marine fuels may also be an effective option, though obtaining sufficient supply of these fuels may be an issue.

Background on Marine Fuels

To better appreciate the value of alternative fuels, it is necessary to understand the marine fuels that are currently in use and their associated fuel sulfur content requirements. Prior to 2010, marine vessels often used heavy residual fuels with extremely high fuel sulfur content (45,000 ppm S). In 2012, the international standard for global operations was set at 35,000 ppm S (3.5% S). This standard was further reduced in 2020 to 5,000 ppm S (0.50% S) and serves as the current fuel standard for most international marine freight operations. Specific regions with air quality concerns and high vessel traffic have established Emission Control Areas (ECA) (e.g., Baltic Sea, North Sea, and North America) with more stringent marine fuel standards. For these ECAs a fuel standard of 1,000 ppm (0.1% S) was established in 2015 (Table 1). The U.S. has an additional and more stringent marine fuel standard, referred to as the nonroad marine fuel standard, for smaller U.S. flagged domestic vessels which has sulfur concentration less than 15 ppm (0.0015% S).

Table 1. International Ship Engine and Fuel Standards (MARPOL Annex VI)

Domain	Year	Fuel Sulfur	NO_x
Emission Control Area	Prior to 2010	15,000 ppm	
	2010	10,000 ppm	
	2015	1,000 ppm	
	2016		Tier III (after treatment)
Global	Prior to 2011		Tier I (engine-based controls)
	2011		Tier II (engine-based controls)
	Prior to 2012	45,000	
	2012	35,000	
	2020	5,000	

Marine vessels use a variety of fuels ranging from light distillates to Heavy Fuel Oils (HFO), that are often referred to as residual fuels. For example, Marine Gas Oils (MGO) are light and highly refined distillates and are typically ECA compliant fuels (less than 0.1% S). These fuels do not require scrubbers, also known as exhaust gas cleaning systems, when used within an ECA.

Global marine fuels that can be used outside of an ECA include Very Low Sulphur Fuel Oils (VLSFO) and must comply with the ISO 8217 marine fuel standard. ISO 8217 defines the fuel parameters related to blending of distillate marine fuels with HFO to produce VLSFO. It is possible for large international vessels to use VLSFO and other higher sulfur fuels such as Marine Diesel Oil (MDO) and Intermediate Fuel Oils (IFO) which are blends that tend to have high residual fuel oil content. MDO and IFO fuels have a maximum sulfur content of 3.5%, and though it is possible to reduce the sulfur content further, the process is too expensive to produce a fuel that could compete with distillate marine fuels. Higher sulfur fuels such as VLSFO, MDOs and IFOs are cheaper and can be used by large international vessels within the NA ECA if the vessel is equipped with a scrubber that reduces SO_x emissions to the level equivalent to an ECA compliant fuel (noted in Table 2).

Table 2. Emission Control Area Status of Marine Fuels

Fuel	ECA compliant	ECA compliant with add on control (e.g., scrubber)
Nonroad Marine Fuel	X	
MGO	X	
MDO		X
IFO		X
VLSFO		X

Methodology and General Findings

Vessel data were obtained from Clarksons Renewables Intelligence Network of more than 2,000 offshore wind project vessels (Clarksons data) in May 2022.[1] Findings indicate that several alternative fuels and energy sources are currently possible for a variety of marine vessel types deployed in the construction and O&M of offshore wind turbines. The Clarksons data includes larger specialized wind turbine installation vessels (WTIV), jack-up vessels and barges, support and supply vessels, as well as smaller crew transfer and walk-to-work vessels. According to the Clarksons data, existing marine vessels deployed in the installation of offshore wind turbines around the world have propulsion and auxiliary power systems utilizing a variety of fuels and energy systems, including:

- Category 3 marine engines (i.e., marine engines with a cylinder displacement greater than or equal to 30 liters) firing ECA compliant marine fuel oils[2];
- Category 1 and 2 engines (i.e., marine engines with a cylinder displacement < 30 liters) firing nonroad marine diesel fuels[3],
- Vessels that use engines capable of firing natural gas from LNG;
- Engines firing biofuels, including biodiesel and biodiesel/diesel blends, as well as alcohols (such as ethanol and methanol);
- Engines firing hydrogen; and
- Motors powered by electricity stored in batteries, generated on board, or provided through high voltage external connection.

[1] Vessel data obtained from Clarksons Research, Renewables Intelligence Network, specified data pull provided May 20, 2022.

[2] Vessels equipped with Category 3 engines must comply with the NA ECA regulations, including requirement of marine fuel sulfur content < 1,000 ppm (0.1%) sulfur. Note there is an exception; large Category 3 vessels involved in international freight movements can use higher sulfur fuels Marine Diesel Oil (MDO) (up to 1.5% S) or Heavy Fuel Oil (HFO) (1.5 to 3.5% S) as long as they operate a scrubber that provides emissions comparable to the 0.1% S standard.
(EPA Designation of North American Emission Control Area to Reduce Emissions from Ships March 2010, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100AU0I.PDF?Dockey=P100AU0I.PDF).

[3] Category 1 and Category 2 engines need to have a fuel sulfur content below 0.0015% (< 15 ppm). Diesel Fuel and ECA Marine Fuel Standards Subpart D Section 1090.305 (https://www.ecfr.gov/current/title-40/chapter-I/subchapter-U/part-1090/subpart-D).

The Clarksons data indicate that worldwide, dozens of wind project vessels are currently using add-on systems to control emissions of airborne contaminants, including 62 wind power support vessels using selective catalytic reduction (SCR) systems to control emissions of oxides of nitrogen (NO_x) and 9 additional vessels using scrubbers to control oxides of sulfur (SO_x). For example, one WTIV has an SCR system for controlling NO_x from a diesel-electric propulsion system[4] burning VLSFO. Similarly, two heavy lift transport and five heavy lift semi-submersible vessels are using scrubber systems to control SO_x from either IFO-fired two-stroke engines or IFO-fired hybrid mechanical/electrical systems.

Of the 75 WTIVs listed in the Clarksons data, 17 are described as non-propelled, including two of the largest and four of the mid-sized vessels, suggesting that they are moved by other vessels which are attached to the WTIVs. Although the Clarksons data do not indicate which types of vessels provide power to those WTIVs, the lack of dedicated power systems on these large non-propelled vessels means that it may be possible to use vessels with alternative energy systems to provide power to such WTIVs.

The Clarksons data do not discuss bunkering or refueling equipment for offshore wind support vessels. However, there are numerous articles and reports available discussing marine energy storage and refueling systems. Generally, bunkering and refueling infrastructure currently exists at various locations along the Eastern U.S. for several of the energy types, including:

- Heavy marine fuel oils,
- ECA compliant fuels,
- Nonroad marine compliant fuels,
- Biofuels, including biodiesel, ethanol, and methanol,
- High voltage transmission lines and substations, and
- LNG.

However, storage and refueling equipment for these energy types are not always located in advantageous locations for the Wind Development Areas (WDA). Depending on the distance from existing bunkering and refueling sites, new or additional infrastructure may be needed. See maps in Appendix B for existing energy infrastructure.

The type of fuel used in marine engines, either individually or in combination with pollution control techniques, significantly impacts the level of air emissions (e.g., NO_x, SO_2, particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs), greenhouse gases (GHGs)). Based on the literature that was reviewed, all the alternative fuel energy systems appeared to reduce air pollutants relative to marine engines burning conventional marine fuels. For example, battery electric propulsion systems are expected to reduce NO_x, SO_x, PM, CO, VOC, and carbon dioxide (CO_2) by 100% compared to standard marine fuels at the vessel, though the source of the electricity used to charge these systems will need to be considered. Switching to LNG-based propulsion systems is expected to reduce NO_x, SO_x, and PM by 85 – 95% from HFO and 80 – 95% from MDO. Similarly, switching to a 20% blend of biodiesel and

4 Diesel-electric systems have a diesel engine that drives a generator which provides electrical power to the ship to run all electrical equipment including electric motors used for propulsion.

diesel fuel is reported to reduce SO_x by as much as 95% from HFO and 20% from MDO, as well as reducing PM by 16%, CO by 13%, and VOC by 21%. Additionally, the Clarksons data indicate that a significant number of wind project vessels are currently using some form of add-on pollution control systems for either reducing NO_x (e.g., by 80%) or SO_x (e.g., by 95%) which may also reduce air pollutants such as PM (e.g., 90%) and VOC.

Regulatory Background

Most of the wind turbine installations to date have been outside of the U.S. therefore, most, if not all, of the construction vessels associated with wind turbine installations are typically from other parts of the world (e.g., European). The following section presents the backdrop of U.S. and international air pollution standards for these vessels accounting for international pressures for replacing fossil fuels in maritime vessels.

International Maritime Organization Sulfur in Fuel Standards

The U.S. participates in the International Maritime Organization (IMO) which is part of the United Nations (UN). The IMO has developed global standards for the prevention of pollution from ships caused by operational or accidental releases. These standards are embodied in the International Convention on the Prevention of Pollution from Ships, better known as MARPOL (abbreviation for Marine Pollution). MARPOL Annex VI defines engine and vessel requirements related to air pollution. These standards include maximum allowable sulfur concentrations in marine fuels, and maximum NO_x emission rates in engine exhaust. MARPOL Annex VI was amended in 2008, and went into effect in 2010, setting more stringent fuel sulfur limits and NO_x emission standards, especially for vessel operations in designated ECAs (Table 1). The NA ECA includes both fuel-sulfur standards and NO_x emission standards covers most waters up to 200 nautical miles from the coasts of the continental U.S. and large portions of coastal waters around Alaska and Hawaii, as well as those in the Caribbean, specifically surrounding Puerto Rico and the U.S. Virgin Islands.

Vessels operating in ECAs must meet fuel-sulfur concentrations that may not exceed 0.10 weight percent (i.e., 1,000 ppm), or vessels may use an approved equivalent method (such as utilizing SO_x scrubbers. Engines above 130 kW installed on vessels built (or modified) since 2000 must be certified to meet appropriate emission standards corresponding to the vessel's build date (or modification date). As of January 1, 2016, engines installed on new and modified vessels are subject to the Annex VI Tier III NO_x standards[5] while those engines are operating in the ECA. The international standards apply to both U.S. vessels and to foreign vessels. Outside the ECA, the standard is 5,000 ppm (0.50 %) sulfur which became effective on January 1, 2020.

Note the above international standards focus on larger vessels that operate in open waters moving international freight. These larger vessels tend to have engines with an individual cylinder displacement equal to or greater than 30 liters referred to in EPA regulations as

[5] 2008 IMO MARPOL Annex VI Amendments introduced manufacturer Tier III NOx emission standards for vessel with a total power output greater than 130 kWs operating within a NO_x ECA such as the NA ECA. The standard varies by engine operating speed (RPM) for slow speed engines with an RPM < 130 the standard is 3.4 g/kW-hr; for medium speed engines with an RPM greater than or equal to 130 or < 2000 the g/kW-hr standard is 9 times $(RPM)^{-0.2}$; and for high-speed engines greater than or equal to 2000 RPM the standard is 1.96 g/kW-hr.

Category 3 engines. Smaller vessels mostly involved in domestic vessel traffic have non-Category 3 engines (referred to as Category 1 & 2 engines) and tend to be registered in the U.S. as Jones Act vessels and are subject to more stringent fuel and engine emission standards that EPA has adopted under the Clean Air Act (CAA). As of 2014, these smaller vessels must use more stringent nonroad marine fuels with a sulfur content less than 15 ppm (< 0.0015 %).[6]

According to the Clarksons data, more than 560 of the global fleet are now using low sulfur fuels directly, or higher sulfur fuels in combination with sulfur scrubbers and/or SCR systems. To meet the sulfur limits, marine vessels may also choose to use alternative fuels such as LNG, biofuels (such as methanol, ethanol, and biodiesel), electricity, or hydrogen.

EPA Air Emissions Control Permitting Requirements for Vessels

Section 328 of the CAA and EPA's implementing regulations at 40 CFR Part 55 establish the framework for application of federal and state air pollution control requirements to Outer Continental Shelf (OCS) sources. CAA section 328(a)(4)(C) defines the "OCS source" to include (in relevant part): "any equipment, activity, or facility which— (i) emits or has the potential to emit any air pollutant…" and states that "emissions from *any* vessel servicing or associated with an OCS source, including emissions while at the OCS source or enroute to or from the OCS source within 25 miles of the OCS source, shall be considered direct emissions from the OCS source." EPA's implementing regulation in 40 CFR Section 55.2 defines "potential emissions" to include "emissions from vessels servicing or associated with an OCS source… while at the source, and while enroute to or from the source when within 25 miles of the source" and specifically states that such emissions "shall be included in the 'potential to emit' for an OCS source." An OCS source's "potential to emit" determines whether the source is a "major" or "minor" stationary source for NSR and title V permitting purposes, which in turn determines the control standards and other requirements that the source must meet under the relevant permitting program(s).

As required by the Prevention of Significant Deterioration (PSD) and Nonattainment New Source Review (NNSR) regulations, OCS sources with emissions that exceed the PSD and NNSR permitting applicability thresholds are required to apply Best Available Control Technology (BACT)[7] and/or Lowest Achievable Emission Rate (LAER)[8] as applicable to their

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[6] U.S. EPA, International Standards to Reduce Emissions from Marine Diesel Engines and Their Fuels; website at: https://www.epa.gov/regulations-emissions-vehicles-and-engines/international-standards-reduce-emissions-marine-diesel

[7] BACT is defined, in relevant part, as an emission limitation based on the maximum degree of reduction of each pollutant subject to regulation… emitted from or which results from any major emitting facility, which the permitting authority, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for such facility through application of production processes and available methods, systems, and techniques, including fuel cleaning, clean fuels, or treatment or innovative fuel combustion techniques for control of each such pollutant. Clean Air Act (CAA) 169(3).

[8] LAER means for any source (in relevant part), that rate of emissions which reflects: (A) the most stringent emission limitation which is contained in the implementation plan of any State for such class or category of source, unless the owner or operator of the proposed source demonstrates that such limitations are not achievable, or (B) the most stringent emission limitation which is achieved in practice by such class or category of source, whichever is more stringent.

NO_x, NO_2, PM, PM_{10}, $PM_{2.5}$, CO, and GHG emissions. These BACT or LAER control technologies are generally considered add-on control technologies.

In addition to add-on controls, EPA can consider inherently lower-emitting processes, practices, and designs within a BACT or LAER analysis (e.g., highest tiered engine available at the "time of deployment", which would have the lowest emissions of the applicable pollutants).

Under EPA regulations, foreign flagged vessels, when operated as OCS sources, are also considered in determining BACT or LAER. Engines on foreign flagged vessels operating within the WDA and within the NA ECA are subject to 40 C.F.R. § 1043 and are not required to operate internal combustion engines certified in accordance with 40 C.F.R. §§ 1042.101, which are regulations for marine engines on US flagged ships. 40 C.F.R. § 1043.30(c) requires engines over 130 kW on foreign flagged vessels to have a valid Engine International Air Pollution Prevention (EIAPP) certification, signifying that the engine meets the applicable MARPOL Annex VI NO_x emission standards, unless the foreign country where the vessel is registered is not part of the IMO. Annex VI, Regulation 1328. It is important to note that marine engines in OCS sources are also subject to other CAA requirements such as Standards of Performance for Stationary Compression Ignition Internal Combustion Engines (NSPS IIII) and National Emissions Standards for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines (NESHAPS ZZZZ).

Overview of Current Fleet Fuel Options and Engine Types

In preparation for meeting the EU's goals to reduce and phase out GHG emissions from international shipping as soon as possible in this century[9]; there have been numerous demonstration projects of alternatives to fossil fuels for maritime applications. The Clarksons data shows that numerous vessels involved in offshore wind turbine installation and O&M are utilizing a variety of inherently lower polluting energy systems and lower carbon fuels (i.e., LNG, biofuels, fuel cells, hydrogen, batteries). Although vessels that use alternative energy systems make up a small portion of the wind installation vessels, the data indicate that such alternative energy systems are currently available.

Current Fuel Types

Based on the Clarksons data, Table 3 below shows the relative distribution of the current fuel types used in offshore wind support vessels:

9 The European Union's report, "Fuel EU Maritime - Sustainable maritime fuels," in 2018 presents the IMO's goal to reduce the average carbon intensity by at least 40% by 2030 and by 70% in 2050, as well as to cut the total emissions by at least 50% by 2050, compared to 2008. To meet the 2050 demands, the EU contends that shipping will need to undergo a global transition to alternative fuels and energy sources. FUEL EU MARITIME - SUSTAINABLE MARITIME FUELS / BEFORE 2021-1. https://www.europarl.europa.eu/legislative-train/carriage/fuel-eu-maritime/report?sid=5801

Table 3. Number of Wind Installation Vessels by Fuel Type

Fuel Type	Number of Offshore Wind Support Vessels*
ECA Compliant fuel or higher sulfur fuels	375
ECA Compliant	256
MGO	2
IFO	67
Biofuel	3
Dual fuel LNG with VLS MGO, MDO, or IFO	6
Hydrogen	1

* The 2022 Clarksons data includes 1,145 offshore wind support vessels of which 710 included fuel data.

Current Engine Power Types

The Clarksons data includes information regarding the type of engine derived power used on offshore wind support vessels (see Table 4). The data indicate that many vessels have engine derived power using a diesel-electric system. These types of systems provide flexibility in load management and fuel efficiency over a wide range of operating loads. Battery storage is also a common feature of this type of configuration. These types of systems which provide indirect power generation and battery storage may also be easier to retrofit with alternative fuels and energy systems.

Table 4. Number of Vessels by Engine Power Type

Engine Derived Power Type	Number of Vessels*
Diesel 4-stroke	706
Diesel/Electric	275
Non-propelled	113**
Batteries & Diesel	22
Diesel 2-stroke	16
Hybrid mechanical/electrical	10
Combined	2

* One vessel did not include engine derived power data.
** Including 12 WTIVs.

Consideration of Different Fuel Standards

One challenge for WTIVs (e.g., jack-up vessels) in the Eastern U.S. is that these vessels need to travel long distances (e.g., from Europe) in order to be utilized for several years near U.S. shores. Consequently, owners of existing long-range capable vessels may face tradeoffs and additional costs to replace existing power systems or add redundant systems capable of utilizing alternative energy sources that can meet both international and U.S. fuel standards. However, these challenges are not insurmountable and numerous offshore wind support vessels already carry multiple fuels to comply with fuel requirements in international ECAs. In addition, due to the number of offshore wind projects planned for the Eastern U.S., costs of retrofits as capital costs could be averaged over a longer timeframe if a vessel is expected to service a particular area for a longer period rather than on a per project basis.

Potential Benefits of Developing Infrastructure for Alternative Fuels

Developing the storage and refueling infrastructure for alternative fuels also has potential utility for the offshore wind power fleet (e.g., component barges, crew boats, and other support and supply vessels). Such development could additionally benefit other non-wind power related marine vessels in the area (e.g., cruise ships, fishing, construction, cargo transport, harbor craft, etc.). If the distribution point for the alternative fuel is within a port, this could also encourage transition of cargo handling equipment and drayage trucks to alternative fuel options.

Construction and ongoing offshore wind power O&M activities ensure a market for alternative fuels that extends over several decades. This also presents opportunities for partnerships with other potential onshore transportation services (e.g., bus, truck, train) which would be a driver to invest in additional storage and refueling infrastructure to meet these additional needs. In this way, upfront costs for port bunkering and refueling systems for alternative fuels such as LNG and plug-in electric systems could be scaled up and considered over longer periods for a wide variety of applications.

Review of Alternatives

Based on available literature and interviews with port personnel, there are numerous marine vessels of a range of sizes and functions currently using alternative fuels, or currently under construction, including WTIVs. It appears that the following alternatives to traditional marine fuel oils are feasible and available, either with additional pollution control systems or by themselves:

- LNG,
- Biofuels, including blends with fossil-fuels,
- Electricity, from either fuel cells, batteries, or with high voltage external connections, and
- Diesel fuel, including expanding used of nonroad marine diesel fuels.

In the sections below, the alternatives are discussed by fuel/energy type, including:

- Current capacity and uses
- Cost and pollutant considerations
- Bunkering capacity
- Other considerations

There was limited project-specific cost information available but some general estimates for the commonly used types were found. Further economic analysis will be required for specific offshore wind power projects.

Liquefied Natural Gas (LNG)

LNG is commercial natural gas that is liquefied at high pressure and low temperature. Liquification increases the fuel density, reducing storage requirements. Use of LNG reduces SO_x and NO_x emissions when compared to petroleum based marine fuels but there are potentially increases in GHG emissions from methane slippage. There are a growing number of LNG powered ships currently in use and several new build orders. To encourage further use of LNG as a marine fuel the existing natural gas infrastructure needs to be expanded to be accessible at ports, including liquification plants and storage facilities.

Current Capacity and Uses

There are several LNG powered ships currently in use and several new builds on order that will be able to support offshore wind. According to SEA-LNG, an international multi-sector industry coalition created to accelerate the adoption of LNG as a marine fuel, there was exponential growth in LNG-fueled deep-sea vessel orders in 2021, including containerships, tankers, cruise ships, bulk carriers, car carriers, and ferries, as well as offshore wind support vessels.[10]

As discussed in the New England Wind Phase 1 OCS Air Permit Application, dated October 7, 2022, submitted by Park City Wind LLC to EPA Region 1, "As of 2021, there were over 200 vessels operating on LNG, with close to another 200 LNG-fueled vessels either on order or capable of using LNG (SEA-LNG 2022). Although the majority of LNG-fueled vessels are LNG tankers, there are also some LNG-fueled ferries, cruise ships, containerships, platform supply vessels, cable laying vessels, dredging vessels, and tugboats (MI News Network 2019; DEME 2020)." Additionally, the application mentions "two operational LNG-fueled vessels capable of installing offshore wind components: the Orion, a dynamic positioning (DP) vessel, and the Apollo, a jack-up vessel (Offshore Energy 2018). Three other LNG-ready WTIV have been ordered with an expected delivery date in 2025 or later (LNG Prime 2021; Blenkey 2021)."[11]

There are several LNG powered container ships currently in use in North America. Two companies, TOTE Maritime and Crowley Maritime, have switched to LNG as fuel for some of their container operations. TOTE built two LNG-powered, 764-foot Marlin-class containerships for its Florida to Puerto Rico operations and is currently converting its 839-foot Orca-class ships to LNG for its Puget Sound to Alaska operations. TOTE's and Crowley's ships all operate with dual-fuel engines and can burn fuel oil or LNG. However, building LNG infrastructure can be a challenge in an existing port area. The TOTE project discussed above for Puget Sound to Alaska service was granted a temporary exemption from the fuel sulfur requirement in 2012, with the expectation that the vessels would be expeditiously converted and that LNG fueling infrastructure would be constructed by Puget Sound Energy and made broadly available for vessel fueling within a few years. To date, the vessels have not been converted (although one apparently has been fitted with LNG tanks), and the LNG fueling facility only became operational in 2022.

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10 Sea- LNG, LNG – A Fuel In Transition, A View From The Bridge, SEA-LN, January 2022. https://sea-lng.org/wp-content/uploads/2022/01/LNG-2022_A-view-from-the-bridge_V937.pdf

11 New England Wind Phase 1 Outer Continental Shelf Air Permit Application, dated October 7, 2022, submitted by Park City Wind LLC to EPA Region 1.

In British Columbia, Canada, the company, BC Ferries, has four dual-fuel, LNG-powered 350-foot car ferries. BC Ferries has also converted two 550-foot Spirit-class ferries to LNG operations in 2018 and 2019. They also have plans for six new diesel-electric hybrid ferries. In British Columbia, Seaspan Ferries has two LNG/hybrid-electric, 488-foot freight ferries that service Vancouver Island. They reported that the LNG hybrid vessels had overall emissions reductions of over 50% compared to traditional vessels.[12] Vessels of this size would be comparable to typical offshore wind operation and maintenance and support vessels.

The New England Wind 2022 application also notes that some existing diesel engines can be converted to dual-fuel diesel-gas operation. They note that Wärtsilä, offers conversion kits for a limited number of engines but cautions, "converting a vessel from diesel to natural gas requires extensive additions to the vessel such as LNG fuel storage containers, piping, and related safety systems."[13]

Wärtsilä's website provides the following information: "Converting a vessel to operate on LNG depends on the vessel type and space available. In most cases, the most economical option is to convert the existing engines of a vessel, but installation of a new dual fuel engine is in some cases a feasible option as well. The fuel gas handling system needs to be installed including the bunkering station, LNG tanks and related process equipment as well as the control and monitoring system." The website also discusses a conversion project, "In 2011 Wärtsilä achieved a world first when it finalized an LNG conversion project on the 25,000 dead weight tonnage (dwt)[14] tanker Bit Viking, owned and operated by the Swedish company Tarbit Shipping AB. The vessel was the first marine installation in the world to convert Wärtsilä 46 engines to Wärtsilä 50DF engines. The scope included deck-mounted gas fuel systems, piping, engine conversion including the related control systems, and all necessary adjustments to the ship's systems." Further, "The Bit Viking utilizes the Wärtsilä LNGPac system, which enables the safe and convenient onboard storage of LNG. The two 500 m^3 storage tanks provide the vessel with 12 days of autonomous operation at 80 percent load, with the option to switch to marine gas oil if extended range is required."[15]

Liquid Petroleum Gas

Though Liquid Petroleum Gas (LPG), a mixture of propane and butane, is very different from LNG, both are gases under normal pressure and temperatures, and both have similar energy densities. Unlike LNG, LPG is liquefied under relatively low pressure, reducing the cost requirements to maintain liquification. Currently, 15 Very Large Gas Carriers (VLGC) are being converted to a dual fuel system burning LPG and traditional marine diesel fuels. According to engine manufacturer MAN PrimeServe, LPG can reduce SO_x emissions by 99%, CO_2 by 15%,

12 Bruce Buls, Industry Updates, LNG marine fuel usage for ships is growing, Workboat, April 7, 2022. https://www.workboat.com/lng-marine-fuel-usage-for-ships-is-growing

13 New England Wind Phase 1 Outer Continental Shelf Air Permit Application, dated October 7, 2022, submitted by Park City Wind LLC to EPA Region 1.

14 Deadweight tonnage (dwt) is a measurement of total contents of a ship including cargo, fuel, crew, passengers, food, and water aside from boiler water. It is expressed in long tons of 2,240 pounds.

15 Wartsila, LNG Conversion, https://www.wartsila.com/services-catalogue/environmental-services/wartsila-marine-lng-conversion

NO_x by 10% and PM by 90% compared to fuel oil.[16] A safety concern associated with LPG is that it is denser than air, therefore, propane could accumulate in the bilge of the vessel. Additionally, LPG has a lower explosion limit (LEL) of 2%, requiring leak detection monitors and ventilation.[17] Despite this, LPG is seen as a new and promising entry to the marine fuel sector, as current energy cost for LPG range from USD $50-100/MWh shaft output.[18] As the current fleet of LPG vessels is primarily LPG gas carriers, and given that there are no existing offshore wind power support vessels operating with LPG, additional details about LPG was not included in this assessment.

Cost and Pollutant Considerations

Cost Considerations

The price to convert a vessel to LNG includes costs for tanks, bunker station, gas preparation, gas line, engines, and generator sets. The largest share of the additional investment is related to the installation of pressurized/cooled LNG tanks. Specific cost information regarding the conversion of the offshore wind power fleet to LNG can vary by vessel type and space limitations and would need to be evaluated on a case-specific basis. Some reports discuss that even in the absence of a regulatory driver, there is a relatively short return on investment for switching to LNG from IFO. Some indicate payback time for the added LNG investment is estimated at 5-10 years.

One analysis specific to a WTIV found that, "The LNG capacity for a NG-14000X wind turbine installation jack-up is sized for a 20- to 23- day single roundtrip autonomy, with a single roundtrip consisting of the vessel loading wind turbine components to capacity, at the shore base and installing these offshore. For a fuel price advantage of $4/GJ the payback time for the added LNG investment is approximately 8 years."[19] Another report indicated that using comparative costs of HFO and LNG based on the energy content, the payback time for changing larger vessels to LNG could be more than 5 years. According to BE&R Consulting, it appears that for a 2,500 twenty-foot equivalent unit (TEU) vessel, a comparison of payback times for a scrubber and a LNG system indicates that an LNG system is attractive as long as LNG is as expensive as or cheaper than HFO, when the fuels are compared on their energy contents.[20]

Wärtsilä's website offers a case example showing the impact of fuel type and technology on levelized cost of energy. The example is based on a 100 MW power plant, with six W18V46 engines. However, Wärtsilä cautions that for any given power plant, the actual values will vary. Wärtsilä's website indicates that the levelized cost of energy using its conversion kit for certain types of diesel or spark ignition engines, averaged over 10 years, can be 17 – 20% of the energy

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16 International Registries, Worlds First Fleet of Dual-Fuel LPG Powered Ships (25 May 2021) https://www.register-iri.com/blog/worlds-first-fleet-of-dual-fuel-lpg-powered-ships/

17 Hellenic Shipping News, Make Room for LPG as a Marine Fuel (January 25, 2020) https://www.hellenicshippingnews.com/make-room-for-lpg-as-a-marine-fuel/

18 DNV-GL Comparison of Alternative Marine Fuels (Sept 25, 2019). https://sea-lng.org/wp-content/uploads/2020/04/Alternative-Marine-Fuels-Study_final_report_25.09.19.pdf

19 Power and Energy Solutions, PES ESSENTIAL, PES Wind, Powering offshore wind developments by LNG,. http://cdn.pes.eu.com/v/20160826/wp-content/uploads/2017/05/PES-W-2-17-Gusto-PES-Essential-1.pdf

20 BE&R Consulting, Marine Fuel Oil To LNG Conversion, Advantages of LNG as a Marine Fuel, July 16, 2020. https://berconsulting.com.au/2020/07/16/marine-fuel-oil-to-lng-conversion/

costs of an HFO fired engine.[21] Considering that vessels may be coming from Europe, Wärtsilä also discusses the possibility of the EU's Innovation Fund paying for some of the capital expenditures ("CAPEX") but not the operational expenditures ("OPEX"). The website states that "through the EU Innovation Fund it can be possible to secure financing for up to 60 percent of the CAPEX for the conversion project itself as well as the resulting increased OPEX depending on how much the project will reduce the vessel's emissions. There are also country-specific or regional funding sources such as the Norwegian NO_x Fund, which can cover up to 80 percent of the CAPEX costs."[22]

LNG prices per metric tonne cannot be compared directly to oil bunker prices because the fuels have differing energy densities. To make simple comparisons possible, Ship & Bunker expresses LNG prices in terms of the energy equivalent of one tonne of conventional oil bunkers. This comparison used the prices from the city of Rotterdam, Netherlands because it has data on all four fuel types.

LNG-380e is the price for an amount of LNG that delivers the energy equivalent of one metric tonne of IFO 380 bunker fuel. Over the 52-week period of September 23, 2022 through September 21, 2023 the prices at Rotterdam were the following:

- LNG-380e was USD$ 591.50/mt (September 21, 2023) averaged $475/mt with a 52-week low of $384/mt and 52-week high of $598.50.
- IFO 380 was USD $588/mt (September 21, 2023) averaged $448/mt with a 52-week low of $353/mt and 52-week high of $612.50.[23]

LNG-MGOe is the price for an amount of LNG that delivers the energy equivalent of one metric tonne of MGO. Over the 52-week period of September 23, 2022 through September 21, 2023 the prices at Rotterdam were the following:

- LNG-MGOe was USD$ 593/mt (September 21, 2023) averaged $1,007.50/mt with a 52-week low of $461/mt and 52-week high of $2,451.
- MGO was USD $971/mt (September 21, 2023) averaged $844/mt with a 52-week low of $643.50 and 52-week high of $1,121 and.[23]

Pollutant Considerations

LNG has several advantages as a marine fuel with inherently low sulfur. Compared to burning HFO some reports show natural gas can result in a SO_x reduction of 95 – 98%, NO_x reduction of 85 – 95%, PM reduction of 98%, as well as 100% reduction in heavy metal emissions. Compared to MDO, natural gas firing can result in up to a 99% reduction in SO_x, 80% reduction in NO_x, 99% reduction in PM, as well as 100% in metals. CO and VOC (including methane) are products

21 Wartsila, Converting engine to run on gas and beyond, https://www.wartsila.com/services-catalogue/service-projects/gas-conversion-for-power-plants

22 Wartsila, Time to take another look at LNG conversion? https://www.wartsila.com/insights/article/time-to-take-another-look-at-lng-conversion

23 Ship and Bunker. Rotterdam Bunker Prices. Accessed September 22, 2023. https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam

of incomplete combustion and can be specific to the condition, age, and tuning of the LNG-firing equipment.[24,25]

Regarding GHGs, several studies have concluded that the use of LNG as a marine vessel fuel increases the amount of CO_2 equivalents (CO_2e) emitted relative to the use of MDO by 10 – 50%. Other studies show that using LNG as a marine fuel reduces CO_2e emissions by 10 – 15%. Factors affecting the results include the types of engine technologies tested as well as the working assumptions about the source of fuel and the scope of the analysis.[26] For example, a 2020 study of climate implications of using LNG as a marine fuel by the International Council on Clean Transportation (ICCT)[27] found that, "Over a 100-year time frame, the maximum life-cycle GHG benefit of LNG is a 15 percent reduction [in CO_{2e} emissions] compared with MGO, and this is only if ships use a high-pressure injection dual fuel (HPDF) engine and upstream methane emissions are well-controlled. However, the latter might prove difficult as more LNG production shifts to shale gas, and given recent evidence that upstream methane leakage could be higher than previously expected. Additionally, only 90 of the more than 750 LNG-fueled ships in service or on order use HPDF engines."[28] However, the ICCT study indicates that considering a 20-year global warming potential (GWP), "HPDF engines using LNG emit 4 percent more life-cycle GHG emissions than if they used MGO. The most popular LNG engine technology is low-pressure injection duel fuel (LPDF), four-stroke, medium-speed, which is used on at least 300 ships and it is especially popular with LNG fueled cruise ships. Results show this technology emitted 70 percent more life-cycle GHGs when it used LNG instead of MGO and 82 percent more than using MGO in a comparable medium-speed diesel (MSD) engine."

Regarding the emissions associated with burning the fuels in specific engine types from LNG and conventional marine fuels, the ICCT study indicated that modeled CO_2 combustion emissions, "are a function of the carbon content of each fuel except for VLSFO, which we calculate as a 20:80 ratio of HFO and MGO, and for each fuel a portion of the carbon is emitted as VOCs and carbon monoxide (CO). Burning LNG generates the lowest amount of CO_2 on a per-MJ basis; conversely, HFO has the highest combustion emissions. Fossil fuel combustion also emits small quantities of nitrous oxide and methane, both of which are potent climate-forcing agents."

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24 Styliani Livaniou, Georgios Chatzistelios, Dimitrios V. Lyridis and Evangelos Bellos, g., LNG vs. MDO in Marine Fuel Emissions Tracking, Sustainability 2022, 14, 3860. https://doi.org/10.3390/su14073860

25 Clean Energy Compression. https://www.cleanenergyfuels.com/compression/blog/natgassolution-part-1-clean-natural-gas-stack-race-reduce-emissions/

26 Elizabeth Lindstad, Gunnar S. Eskeland, Agathe Rialland and Anders Valland; Decarbonizing Maritime Transport: The Importance of Engine Technology and Regulations for LNG to Serve as a Transition Fuel; Published: 22 October 2020. https://www.mdpi.com/2071-1050/12/21/8793

27 International Council on Clean Transportation; Nikita Pavlenko, Bryan Comer, PhD, Yuanrong Zhou, Nigel Clark, PhD, Dan Rutherford, PhD WORKING PAPER 2020-02, The Climate Implications of Using LNG as a marine fuel, January 2020. https://theicct.org/sites/default/files/publications/Climate_implications_LNG_marinefuel_01282020.pdf

28 Nikita Pavlenko, Bryan Comer, PhD, Yuanrong Zhou, Nigel Clark, PhD1, and Dan Rutherford, PhD. WORKING PAPER 2020-02, JANUARY 2020, The Climate Implications of Using LNG as a marine fuel, January 2020. https://theicct.org/sites/default/files/publications/Climate_implications_LNG_marinefuel_01282020.pdf

ICCT's 2020 study also looked at emissions from crankcase leakage and noted that there is variation in the leakage estimates in different studies, indicating that, "Recent research suggests that methane leakage may be higher for shale gas than for conventional natural gas, largely due to the increased gas venting following high-volume hydraulic fracturing (Howarth, 2015)." Peer-reviewed analyses[29] suggested the EPA assumptions about the upstream methane leakage from shale gas may understate actual emissions." A recent analysis[30] used surface monitoring at facilities in conjunction with aircraft observations to assess methane leakage assumptions and found that the U.S. natural gas industry overall has a leakage rate of 2.3% which is higher than the EPA's assumption of 1.4%.

The ICCT study used the higher leakage assumptions and found that upstream LNG emissions increased by nearly 15% relative to the baseline EPA case[31]. However, regarding emissions from the gas well to vessel use, or well-to-wake (WtWa) emissions, they point out that as combustion emissions are much larger than upstream emissions, "this change only increases WtWa emissions (without methane slip) for LNG systems by 4 percent relative to the baseline case." Additionally, there are concerns that some low-pressure engines may have open crankcases that allow methane to escape without being burned.

ICCT's study concluded that using a 100-year GWP and assuming that upstream methane leakage and downstream methane slip are well-controlled, "HPDF engines and slow-speed, two stroke LPDF engines emitted fewer life cycle GHGs when using LNG than when they used conventional fuels. Combined, these engines power at least 140 ships, including LNG carriers, container ships, and other cargo ships. These results are consistent with Thinkstep (2019)[32]." Further, ICCT stated that, "Lindstad (2019)[33] also found lower life cycle GHG emissions for HPDF engines when they used LNG instead of conventional fuels," but not for slow-speed, two-stroke LPDF engines. However, Lindstad (2019) shows that using MGO in an HPDF engine or an slow speed diesel (SSD) engine would emit fewer life-cycle GHGs than using LNG in an LPDF, slow-speed, two-stroke engine.[34]" They add, "Considering the medium-speed, four-stroke LPDF engines that power at least 300 ships, including LNG carriers, offshore supply vessels, car and passenger ferries, and cruise ships, we found that they emitted more life-cycle GHGs when using LNG than conventional fuels. This is consistent with Lindstad (2019), but not with

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29 Robert W Howarth; Department of Ecology and Environmental Biology, Cornell University, Ithaca, NY, USA; Methane emissions and climatic warming risk from hydraulic fracturing and shale gas development: implications for policy. Dove Press Journal; October 8, 2015.

30 Ramon A. Alvarez, Daniel Zavala-Araiza, David R. Lyon, David T. Allen, Zachary R. Barkley, Adam R. Brandt, Kenneth J. Davis, Scott C. Herndon, Daniel J. Jacob, Anna Karion, Erica A. Kort, Brian K. Lamb, Thomas Lauvaux, Joannes D. Maasakkers, Anthony J. Marchese, Mark Omara, Stephen W. Pacala, Jeff Peischl, Allen L. Robinson, Paul B. Shepson, Colm Sweeney, Amy Townsend-Small, Steven C. Wofsy, and Steven P. Hamburg; Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain. Science, 21 Jun 2018, Vol 361, Issue 6398, pp. 186-188.

31 Wartsila, Methane slip Reduction Solutions, https://www.wartsila.com/marine/services/lifecycle-upgrades/methane-slip-reduction-solutions#:~:text=When%20you%20burn%20LNG%20as,30%20times%20that%20of%20CO2.

32 Thinkstep, Dr. Oliver Schuller, Principal Consultant, Stefan Kupferschmid, Jasmin Hengstler, Simon Whitehouse; Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel. 10/04/2019.

33 Chief Scientist, Dr. Elizabeth Lindstad SINTEF Ocean AS, Increased use of LNG might not reduce maritime GHG emissions at all. Norway; June 2019.

34 Slow speed diesel, SSD, generally refers to an engine operating at speeds below 200 revolutions per minute.

Thinkstep (2019), which found a 5 percent life-cycle benefit of using this engine on LNG instead of MGO. Using 100-year GWP and assuming higher upstream emissions, we found that only the HPDF engine had a life cycle GHG reduction compared with using MGO in that same engine, and the reduction was 12 percent."

Consistent with Lindstad (2019), the ICCT study notes that on a shorter time frame using a 20-year GWP "only one engine technology, HPDF, reduced life-cycle GHG emissions when using LNG instead of conventional fuels. Even then, the benefit was 3 percent and only if upstream emissions were well-controlled. Unfortunately, well-controlled emissions may not be the case as we see a trend toward shale gas, which releases more methane when extracted than other natural gas sources, as well as evidence that actual methane leakage upstream may be higher than expected (Alvarez et al., 2018)."

Bunkering Capacity

Natural gas is plentiful in the U.S. but to load LNG into a ship, it must be liquified and stored at a very low temperature of -260°F. Once a liquid, LNG can be transferred from onshore facilities to vessels, vessels to vessels, truck to vessels, train to vessels, etc., or even in reverse. There are several options currently available which could be adapted depending on the geographic area, including:

- Onshore storage tanks,
- Use of an LNG bunker vessel, either inshore or offshore,
- Truck-to-ship or rail-to-ship bunkering, and
- Local onshore buffer supplied by a docked bunkering vessel, railcar, or truck.

LNG Bunkering Equipment

According to Cryostar's website, LNG bunkering requires additional specialized equipment including cryogenic cooling equipment, compressors, fuel lines, high pressure tanks, pumps, valves, piping, heaters and vaporizers.[35] The American Bureau of Shipping (ABS) issued an equipment advisory in 2021[36] which discussed equipment and safety needs for LNG bunkering on the vessel as well as onshore. The ABS advisory explains that "Vessels transferring or receiving low flashpoint flammable liquids, such as LNG, need to take additional precautions against ignition resulting from electrical arcing. An effective way of preventing arcing is to isolate the ship and the bunker supplier using an isolating (insulating) flange fitted at one end of the bunker hose only, in addition to an electrically continuous bunker hose."

Additionally, the ABS advisory discusses additional outfitting requirements for some vessels. "For example, ships bunker stations are sometimes located below the weather deck. These normally require a suitable watertight door in the side shell, which prevents waves and weather from entering the space, but can be opened to allow the ends of the bunker hoses to enter the

[35] Cryostar, Marine LNG Fueling and Bunkering; https://cryostar.com/datas-pdf/booklet/en/Marine-LNG-fuelling-and-bunkering.pdf

[36] ABS, LNG Bunkering Technical and Operational Advisory: https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/ABS_LNG_Bunkering_Advisory.pdf

bunker station. Furthermore, for such enclosed bunker stations an air lock will be required to separate the bunker station from adjacent non-hazardous areas."

The ABS advisory also discusses additional ventilation needs of vessels using LNG. "For bunker stations located within the ship's hull or elsewhere that is not an open deck, a forced ventilation system will be required." Additionally, gas detectors would be necessary for enclosed or semi-enclosed bunker stations to detect the release of methane vapors. The advisory describes other equipment that would be needed, such as piping, fitted joints, and special deck and bulkhead penetrations that are designed for cryogenic temperatures. "Pipes, valves, and other fittings used for handling LNG should have a minimum design temperature of -165°C (-265°F). Typically, these pipes are stainless steel and have to pass an impact test at a colder temperature than the design temperature."

The ABS advisory noted other requirements when handling LNG. For example, "To protect the crew from exposure to extreme cold, and to minimize heat influx and subsequent warming of the LNG leading to potential boil-off while bunkering, the bunker lines are typically insulated. Rigid foam or other types of insulating materials may be used, or the pipes can be vacuum insulated." Similarly, the report notes that, "LNG and vapor piping may not pass through accommodation spaces, service spaces, or control stations, but they can pass through certain enclosed spaces, such as machinery spaces, if the pipes are protected by a secondary enclosure, either double walled or installed in a ventilated pipe or duct." The advisory also notes that vessels with LNG bunkering need an Emergency Shutdown System which is critical to the safety of the vessel.

The ABS advisory discusses additional safety measures that would be needed for LNG bunkering and transfer, including: insulated mooring lines and fenders to prevent electrical arcing; drip trays and water curtains to prevent damage occurring from cryogenic liquid spills; special bunker hoses and fittings, such as quick connect and break- away couplings; bunker loading arms; emergency monitoring and shutdown systems; fire protection systems; and hose and pipe purging systems. The advisory also notes that in the U.S. there are numerous Coast Guard requirements for a planned LNG bunkering operation.

Existing LNG Onshore Storage

Onshore large-scale LNG storage currently exists in few locations in the Eastern U.S., such as the existing import-export facilities in Lusby, MD and the import facility in Everett, MA (see maps 5 and 6 in Appendix B). But there are also a significant number of existing smaller LNG facilities in the area, including: the Greenpoint Energy facility in Brooklyn, NY; the Avangrid/Southern Connecticut Gas Company facility in Milford, CT; and the Yankee Gas Services Company in Waterbury, CT.

According to the Connecticut Department of Energy and Environmental Protection (CTDEEP) website, LNG is generally stored in large-volume above-ground low-pressure (< 5 pounds per square inch gauge) tanks. The tank is double-walled, with a carbon steel outer wall and a nickel-steel inner tank, separated by a large blanket of insulation to help maintain the cryogenic temperatures. Smaller LNG tanks, generally < 70 thousand gallons, store LNG in higher pressure (up to 250 pounds per square inch gauge) vacuum-jacketed double wall tanks with an inner wall of aluminum.[37]

As shown in Table 5 below there are at least 11 other LNG facilities of various sizes in eastern Massachusetts, as well as four in Connecticut, in addition to the large-scale facility in Everett.

Table 5. LNG Facilities in Eastern Massachusetts and Connecticut

Facility	Address	City	State
Boston Gas LNG Facility	20 Pierce St	Salem	MA
Boston Gas LNG Facility	255 Blossom St	Lynn	MA
Colonial Gas South Yarmouth LNG	127 Whites Path	South Yarmouth	MA
Columbia Gas Brockton Meadow LN LPG	Meadow Lane	Brockton	MA
Columbia Gas Easton LNG Plant	102 Eastman St	South Easton	MA
Columbia Gas Ludlow LNG Plant	5 Ravenwood Dr	Ludlow	MA
District Gas LNG Facility	18 Rover St	Everett	MA
Essex Gas Company LNG Facility	373 North Ave	Haverhill	MA
Hopkinton Liquefied Natural Gas Facility	52 Wilson St	Hopkinton	MA
National Grid LNG Facility	220 Victory Rd	Boston	MA
National Grid LNG Facility	50 Chapman Rd	Tewksbury	MA
Until Westminster LNG Plant	12 LNG facilities 2 State Rd West	Westminster	MA
CNG Liquified Natural Gas Plant	1376 Cromwell Ave	Rocky Hill	CT
Southern Connecticut Gas Company	775 Oronoque Rd	Milford	CT
Yankee Gas LNG Plant	633 S Leonard St	Waterbury	CT
Stamford Natural Gas Storage Facility	32 Washington Blvd	Stamford	CT

CTDEEP's website describes the LNG tanks at the Connecticut Natural Gas in Greenwich, Southern Connecticut Gas Company in Orange, and Yankee Gas Services Company in Waterbury facilities. Two are 96 feet 11.5 inches high, outer tank made of carbon steel, 101 feet 9 inches high and 173 feet 4 inches in diameter. Each tank holds 348 thousand barrels of liquid (14.6 million gallons), the equivalent 1.2 billion cubic feet of gas. Each tank is surrounded by a dike to retain any LNG in case of failure. The facilities can liquify LNG from natural gas, store LNG, and vaporize it for later use. Imported LNG may be purchased and trucked to the site. Additionally, the website describes another tank which is 146 feet in diameter and 117 feet high, with an outer tank wall 150 feet high and 158 feet in diameter, holding 348 thousand barrels (14.6 million gallons) of liquid, the equivalent 1.2 billion cubic feet of gas. Because of the concrete outer tank (surrounding the double walled tank) there is no requirement for a large dike. The initial fill was largely accomplished by trucking in liquid. The City of Norwich Department of Public Utilities also has a small (55 thousand gallons) LNG satellite facility with vaporizers for converting the liquid back into gas.[38]

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[37] Connecticut Department of Energy and the Environment (CTDEEP), What is LNG?, https://portal.ct.gov/PURA/Gas-Pipeline-Safety/What-is-LNG

[38] Connecticut Department of Energy and the Environment (CTDEEP), What is LNG?, https://portal.ct.gov/PURA/Gas-Pipeline-Safety/What-is-LNG

However, as described below, given the potential annual LNG needs of a large WTIV, the current LNG bunkering capacity in the Northeast may not be sufficient to support the number of offshore wind power support vessels required for simultaneous construction projects. During periods of peak natural gas demand such as the winter season, it would be difficult to maintain regional supply and support a large number of offshore wind energy support vessels. Therefore, additional LNG infrastructure would be needed.

Estimated LNG Bunkering Need

The following example estimates the volume of LNG storage needed for the largest WTIVs. According to the U.S. Energy Information Administration (EIA), the annual average amounts of natural gas used to generate a kilowatt-hour (kWh) of electricity by U.S. electric utilities and independent power producers in 2021 was 7.40 cubic feet/kWh.[39] Based on the Clarksons data, the largest self-propelled WTIVs ranged from approximately 20 MW to 46 MW of total power capacity (engine derived mechanical capacity plus electrical power capacity). Assuming these WTIVs were operating at maximum capacity continuously year-round (8,760 hours per year), they would produce approximately 175 thousand to 400 thousand MWh respectively. At capacity, they could consume approximately 1 to 3 billion cubic feet of gas. As noted above, assuming the LNG capacity for a NG-14000X wind turbine installation jack-up is sized for a 20- to 23- day single roundtrip, such a vessel would need to refuel approximately 15 to 18 times per year. Using these assumptions, these vessels could require storage capacity of between 56 million cubic feet and 200 million cubic feet per vessel for refueling. Actual load conditions and power usage would likely be less than these values, particularly if work in winter is stopped for weather reasons.

According to the CTDEEP website, at 14.73 lbs. of pressure per square inch (psi) and 60°F, 1 cubic foot natural gas equals 0.012 gallons natural gas (83.33 cubic feet per gallon natural gas).[40] Therefore, each refueling per vessel could require as much as 700 thousand to 2 million gallons of LNG. Again, these approximations are over-estimates based on all engines running on full power every hour of every day. The actual power requirements and hours, and therefore fuel consumption and storage need, would likely be a fraction of the capacity.

One report discussed development costs for an LNG storage facility in Fairbanks, Alaska. The report estimated that construction of an LNG tank with a capacity of 7.5 million gallons would cost approximately $60 million while a 44-million-gallon tank would cost $135 million.[41]

Truck-to-ship bunkering is a proven method of LNG transfer but may not be practical for the number and size of wind power support vessels expected for future projects. However, LNG truck-to-ship or rail-to-ship bunkering could play an important role in the near-term while other

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[39] U.S. Energy Information Administration (EIA); Frequently Asked Questions (FAQS), https://www.eia.gov/tools/faqs/faq.php?id=667&t=6

[40] Connecticut State Department of Revenue Services, PS 92(10.1) Tables and Equivalents for Natural Gas and Propane for Motor Vehicle Fuels Tax Purposes. https://portal.ct.gov/DRS/Publications/Policy-Statements/1992/PS-92-10-1#:~:text=1%20gallon%20natural%20gas%20%3D%2082.62%20cubic%20feet%20natural%20gas

[41] Michael Baker Jr., Inc. Basis of Estimate, Interior Gas Utility, Fairbanks Gas Distribution Advancement Project, Task 3: LNG Storage Tank Cost Analysis, July 19, 2013, https://www.interiorgas.com/wpdm-package/lng-storage-tank-cost-analysis/?wpdmdl=4912&ind=1457742409200

options are developed. As CTDEEP's website explains, LNG trucks or trailers can maintain low temperatures through double-walled trailers with vacuum and insulation between the outer (carbon steel) and inner (aluminum) tank. The trailers are approximately 42 or 48 feet long and contain 11 thousand to 13 thousand gallons of LNG. In addition to being used to transport LNG, LNG trailers can be connected to mobile vaporizers to provide temporary supply when needed for O&M on pipeline facilities or other contingencies.[42] For the Fairbanks project, the report noted above included estimates for new LNG truck tankers with a nominal capacity of 10,500 gallons of LNG, with an estimated cost of $400 thousand per truck.[43]

Other bunkering options have been developed and are being implemented in the U.S., including the use of barges and railcars as portable bunkering facilities. The option of using LNG bunker vessels will depend on the availability of vessels and the distance needed to its resupply location. According to Power and Energy Solutions, LNG bunker vessels should be feasible for both a support vessel and a jack-up given sufficient supply volume and proximity to an existing delivery location. But they note that an onshore buffer might be required to achieve the necessary conditions.[44]

Recently, there have been several examples of LNG bunkering vessels being built and used in the Eastern U.S. One example is the LNG bunkering vessel owned by Harvey Gulf International Marine (HGIM), Q-LNG 4000, which has a 4,000 cubic meters storage capacity. The vessel is an articulated tug barge (ATB) that bunkers LNG for cruise ships but has the flexibility to handle a variety of ship-to-ship transfers. Other companies are also planning the construction of several larger capacity LNG bunkering vessels to meet growing demands.[45] For example, the construction of a 416-foot-long LNG bunkering vessel, which will have the capacity for 12,000 m^3 (3.17 million gallons) of LNG began in January 2022. The barge will be operated under a long-term charter with Shell NA LNG and is scheduled for delivery in late 2023. The barge is set to be deployed on the U.S. East Coast.[46] These barges are designed to deliver and transfer fuel directly to cruise ships, container vessels, bulk carriers, car carriers and tankers. For example, Crowley in Florida has a contract with Shell who has a contract with Carnival Cruise line.[47] One

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42 Connecticut Department of Energy and the Environment (CTDEEP). What is LNG?, https://portal.ct.gov/PURA/Gas-Pipeline-Safety/What-is-LNG

43 Michael Baker Jr., Inc. Basis of Estimate, Interior Gas Utility, Fairbanks Gas Distribution Advancement Project, Task 3: LNG Storage Tank Cost Analysis, July 19, 2013, https://www.interiorgas.com/wpdm-package/lng-storage-tank-cost-analysis/?wpdmdl=4912&ind=1457742409200

44 Power and Energy Solutions, PES ESSENTIAL, PES Wind, Powering offshore wind developments by LNG,. http://cdn.pes.eu.com/v/20160826/wp-content/uploads/2017/05/PES-W-2-17-Gusto-PES-Essential-1.pdf

45 John Snyder, Riviera Maritime Media Ltd. Large-capacity LNG bunker vessels to serve 'XL-size' ships, 22 Apr 2020 https://www.rivieramm.com/news-content-hub/news-content-hub/large-capacity-lng-bunker-vessels-to-serve-lsquoxl-sizersquo-ships-59059#:~:text=Named%20Q%2DLNG%204000%2C%20the,HGIM)%20chief%20executive%20Shane%20Guidry.

46 Mike Schuler, Bay Shipbuilding Kicks Off Construction on Large LNG Bunkering Barge for Crowley, January 11, 2022, Captain. https://gcaptain.com/bay-shipbuilding-kicks-off-construction-on-large-lng-bunkering-barge-for-crowley/#:~:text=Fincantieri%20Bay%20Shipbuilding%20in%20Sturgeon,upon%20delivery%20in%20late%202023.

47 Carnival News Room, Carnival Cruise Line Signs Agreement with Shell to Fuel North America's First LNG-Powered Cruise Ships, Nov 8/2017. https://carnival-news.com/2017/11/08/carnival-cruise-line-signs-agreement-with-shell-to-fuel-north-americas-first-lng-powered-cruise-ships/

article found estimates that it could cost approximately $100 million to construct a vessel like the Q-LNG 4000.[48]

Additionally, the Port of Providence is currently considering a mobile skid-mounted LNG system that could facilitate minor new source permitting under the CAA and space constraint issues, though the feasibility of such a system is dependent on the port being somewhat near existing LNG infrastructure. This system could likely fill bunker vessels that go out to foreign flagged vessels and at minimum it could fill vessels directly calling into a port. See Appendix A for additional information.

Other Considerations

LNG Refueling Infrastructure

There is significant existing natural gas pipeline infrastructure in the Eastern U.S. coastal area (see maps 1 – 4 in Appendix B).[49] But converting pipeline gas to liquid form requires a significant amount of energy and special equipment, such as cryogenic cooling equipment and specialized insulated tanks that are designed to maintain LNG under the necessary temperatures and pressures. Liquefaction takes place through cooling of the gas using heat exchangers. In these vessels, gas circulating through aluminum tube coils is exposed to a compressed hydrocarbon-nitrogen refrigerant. Heat transfer is accomplished as the refrigerant vaporizes, cooling the gas in the tubes before it returns to the compressor. The liquefied natural gas is pumped to an insulated storage tank where it remains until it can be loaded onto a tanker.[50]

The type of cryogenic equipment needed to convert pipeline natural gas to LNG, as well as the storage and refueling equipment needed to refuel LNG ships, is currently available but limited to existing storage and distribution facilities. Serving a fleet of offshore wind power support vessels would likely require additional equipment. However, as noted above, truck-to-ship and ship-to-ship refueling capacity exists and is growing but may not be sufficient to meet the growing demands of the offshore wind power fleet, without additional investment in capacity closer to the WDAs.

Biofuels/Biodiesel

Biodiesel blends are seen as a drop-in fuel that easily replaces traditional marine fuels for most applications without requiring changes to a vessel's engine. Biodiesel is made by reacting a vegetable oil or animal fat with alcohol, through a process called transesterification, in the presence of a catalyst to produce the mono-alkyl esters. These mono-alkyl ester biofuels reduce sulfur and GHG emissions. To expand use of biofuels for marine fuels, more biofuel refineries are needed to meet the total energy demand.

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[48] American Tugboat Review, Professional Mariner. World's first LNG bunkering ATB enters service, July 8, 2021, https://professionalmariner.com/worlds-first-lng-bunkering-atb-enters-service/

[49] GIS layers were obtained from the U.S. Energy Information Service (EIS) at: https://www.eia.gov/maps/layer_info-m.php

[50] U.S. Department of Energy, Office of Fossil Energy Liquefied Natural Gas: Understanding the Basic Facts, https://www.energy.gov/sites/prod/files/2013/04/f0/LNG_primerupd.pdf

Current Capacity and Uses

There are several potential positive and negative impacts to using biofuels in marine vessels. These need to be considered in the context of individual vessel design and equipment. One advantage to burning biofuels is that they tend to emit small amounts of sulfur and are associated with low GHG emissions. However, according to IEA Bioenergy, the volume of biofuels required for a single large ship may consume the annual production from a single medium sized biofuel facility (e.g., 100 million liters). The current renewable diesel type fuels are mainly produced from plant-based oils, including used cooking oil. Of the current biofuels commercially available, only biodiesel derived from plant oil or pulping residues and bioethanol are produced at a level where they can supply significant volumes of fuel.

Ethanol and methanol are capable of replacing fossil fuels in the shipping sector. Recently, a Dutch company, Van Oord, commissioned a new jack-up vessel for 20 MW turbines that can operate on methanol.[51] However, ethanol and methanol are not compatible with many current marine diesel engines and therefore cannot be used readily as a replacement fuel. It is for this reason that this section focuses on biodiesel.

Most diesel-powered engines can readily burn biodiesel blends. There are several studies of the effects of biodiesel or biodiesel blends used in compression ignition (e.g., diesel) engines, including those used on marine vessels. The National Biodiesel Board indicates that blends of biodiesel and diesel fuel up to 5% (B5) and from 6% to 20% (B20) can be used in conventional diesel engines without voiding the warranties.[52]

Caterpillar's document, "Caterpillar Machine Fluids Recommendations," provides information regarding the use of biodiesel, including the 3500 series Caterpillar diesel engines and indicates that biodiesel that meets the requirements listed in the Caterpillar Specification for Biodiesel Fuel, ASTM D6751, or EN 14214 are acceptable blend stocks and that biodiesel may be blended in amounts up to a maximum of 30% (B30) with an acceptable diesel fuel.[53]

However, one issue with using pure biodiesel (B100) is that it acts as a solvent and can degrade certain elastomers and natural or butyl rubber compounds such as those in some fuel lines and gaskets.[54] Some studies also claim that the use of biodiesel results in reduced power and fuel efficiency of engines which could affect the ability to safely maintain the vessel's position and perform other functions related to the proposed offshore operations such as drilling, cementing,

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[51] Bartolomej Tomic, Editor, Offshore Engineer, Van Oord Orders WTIV for 20 MW Offshore Wind Turbines, October 1, 2021. https://www.oedigital.com/news/491007-van-oord-orders-wtiv-for-20mw-offshore-wind-turbines

[52] Biodiesel Issues and Utilization for Marine Diesel Engines found at: https://utw10356.utweb.utexas.edu/sites/default/files/biodiesel%20issues.pdf

[53] Biodiesel Issues and Utilization for Marine Diesel Engines, found at: https://utw10356.utweb.utexas.edu/sites/default/files/biodiesel%20issues.pdf

[54] Salete Martins Alves, Valdicleide Silva e Mello and Franklin Kaic Dutra-Pereira, Biodiesel Compatibility with Elastomers and Steel; Submitted: May 26th, 2016 Reviewed: September 5th, 2016 Published: January 25th, 2017. https://www.intechopen.com/chapters/52689

and wireline.[55] Additionally, biodiesel can gel at low temperatures and may require special handling in cold climates. Pure biodiesel has a higher freezing point than conventional diesel, which requires consideration when operating in cold weather environments but B20 blends of biodiesel will have a cold-filter plugging point of only 1.5 – 3°C higher than pure petroleum diesel.[56]

Cost and Pollutant Considerations

Cost Considerations

Global biofuel production has increased by 56% from 2011 to 2021. Biofuel prices have climbed by 70 to 150% in the US, Europe, Brazil, and Indonesia during the pandemic; compared to crude oil which has risen by roughly 40% as of 2021. The cost gap between biofuels and fossil-based fuels is shrinking because of the rising production costs of fossil fuels.[57] As marine biofuels technologies are still under development, bunker market prices are not tracked.

Pollutant Considerations

Biodiesel is generally cleaner burning than petroleum diesel and reduces most regulated pollutants, reducing PM by 47% and CO by 48%. According to the National Biodiesel Board, NO_x emissions with pure biodiesel can increase by 10%, but other articles have shown that increases in NO_x may be load dependent and some have even reported a decrease in NO_x emissions. Also, the low sulfur content in biodiesel allows for the use of NO_x control technologies that cannot be used with diesel fuels with higher S content. In addition to the regulated criteria pollutant emissions, biodiesel can also decrease sulfates and polycyclic aromatic hydrocarbons.

Some studies have shown higher NO_x emissions relative to petroleum diesel in traditional direct-injection (DI) diesel engines. NO_x emissions with B20 biodiesel blends are typically increased by 1-7%. The NO_x increase depends on the type of biodiesel feedstock; with the highest NO_x emissions being reported for the most highly unsaturated fuels (soybean, rapeseed, and soap stock-based). Biodiesel from more saturated feedstocks, such as animal fats, yields a smaller NO_x increase. The NO_x increase also appears to depend on the engine technology. The difference in NO_x emissions between diesel fuel and biodiesel blends has been shown to correlate very well with average cycle power regardless of whether the test is carried out on a chassis or engine dynamometer. As average drive cycle power increases, the NO_x emissions increase for biodiesel. This is consistent with steady state tests with biodiesel blends, which show that NO_x emission increases with biodiesel are highest at high loads. At low loads, increases are much smaller, and in some cases NO_x emissions can be lower than with diesel fuel.
Some studies also found that while using biodiesel, retarding the injection to post-top dead center can effectively reduce NO_x emissions. There are claims that on average, there is no increase in

55 Salete Martins Alves, Valdicleide Silva e Mello and Franklin Kaic Dutra-Pereira; Biodiesel Compatibility with Elastomers and Steel; Submitted: May 26th, 2016 Reviewed: September 5th, 2016 Published: January 25th, 2017. https://www.intechopen.com/chapters/52689

56 Biodiesel Issues and Utilization for Marine Diesel Engines found at: https://utw10356.utweb.utexas.edu/sites/default/files/biodiesel%20issues.pdf

57 Murat Bayraktar, Murat Pamik, Mustafa Sokukcu and Onur Yuksel, Clean Technology and Environmental Policy. A SWOT-AHP Analysis on Biodiesel as an Alternative Future Marine Fuel, March 15,2023.

NO_x emissions up to blend levels as high as B20. One study showed that for both conventional and late-injection strategies, the levels of NO_x of B20, B50, and B100 all with post-top dead center (TDC) injection are 68.1%, 66.7%, and 64.4%, respectively, lower than pure European low-sulfur diesel in the conventional injection scenario. Another study showed when a low heat release (LHR) engine was operated with the injection timing of the 38 crank angle (CA), the optimum value of the STD engine, NO_x emissions increased about 15%. But, when the injection timing was retarded to 34° CA (4 degrees from standard), there was a decrease of NO_x emissions of approximately 40%.

Bunkering Capacity

In the northeastern coastal region of the U.S., there are several biodiesel manufacturing, storage, and distribution facilities near the coast. See maps 7 - 9 in Appendix B. The EPA considers existing tanks, pipes, and associated underground equipment to be compatible with the biodiesel blend B20.[58] Therefore, such blends could be stored in storage tanks currently used to store distillate fuels, such as diesel fuel and home heating oil. However, the supply of biodiesel for a fleet of offshore wind project vessels could pose capacity challenges for the industry.

Other Considerations

In the northeastern coastal region of the U.S., there are several biodiesel manufacturing, storage, and distribution facilities, including a number that store biodiesel in storage and distribution facilities accessible by water near the WDAs (See maps 7 – 9 in Appendix B). Refueling infrastructure currently exists for ship-to-ship, truck-to-ship, or rail-to-ship refueling, although additional equipment would likely be necessary to serve a marine vessel fleet supporting the wind turbine installations. Biodiesel blends can be stored in existing storage tanks that are used to store distillate fuels, such as diesel fuel and home heating oil. See maps 18 - 20 in Appendix B for locations of existing petroleum terminals.

A challenge in using biodiesel is the lack of standardization. Biofuels can be produced from different feedstocks and processes which can affect fuel characteristics and engine performance, meaning that not all biodiesels can be used as a replacement fuel for conventional fuels. Although biodiesel can be chemically compatible with conventional fuel, there are issues with biological stability during transport and long-term storage.

Additionally, using biodiesel in marine engines may present regulatory challenges. According to DNV GL, to comply with MARPOL Annex VI, vessels must provide evidence that the diesel engine complies with the applicable NO_x emission limits, including when biofuels are used. Depending on the biofuel used, it may be a challenge to demonstrate compliance through complex on-board emissions testing.[59] Additionally, according to EIA Bioenergy, current international regulations do not allow for biodiesel blending with marine distillate or residual fuels. The addition of biodiesel to a diesel fuel is seen as a contaminant; the fatty Acid Methyl

58 U.S. Department of Energy; Energy, Efficiency and Renewable Energy; Alternative Fuels Data Center; "Biodiesel Equipment Options". https://afdc.energy.gov/fuels/biodiesel_equip_options.html#:~:text=The%20U.S.%20Environmental%20Protection%20Agency,%2C%20blended%20with%20petroleum%20diesel).

59 DNV, Using biodiesel in marine diesel engines: new fuels, new challenges, 14 October 2020. https://www.dnv.com/news/using-biodiesel-in-marine-diesel-engines-new-fuels-new-challenges-186705

Ester (FAME) content in marine fuels cannot exceed 0.1 volume percent in distillate fuels.[60] Separate storage for biodiesel on vessels that are not located within the NA ECA might be necessary.

Electricity: Battery, hybrid and fuel cell options

Battery powered plug-in vessels are currently few and their applications are limited but there is a growing use of diesel-electric systems that could be converted to hybrid or fully battery powered systems. In plug-in technology were to be more readily available, the power supply to recharge plug-in vessels used in offshore wind power O&M vessels could be located on an offshore substations using wind powered-derived electrical energy.

Current Capacity and Uses

A significant number of vessels used in support offshore wind power are partly electrified using diesel-electric propulsion systems. The Clarksons data indicate that more than 40 vessels have engine derived power that is listed as diesel-electric, including 18 WTIVs. These diesel-electric configurations use diesel engines to produce electric power that energizes the electric motors connected to the propulsion systems and provide power to other electric equipment on the ship. Battery storage is a common feature of this type of configuration. The Clarksons data indicates that more than 40 other offshore wind power support vessels list their engine derived power as batteries and diesel. These diesel-electric systems provide flexibility in load management and can allow fuel efficiency over a wide range of loads. The indirect power generation and battery storage of these systems may provide for easier future retrofitting with alternative fuels and energy systems.[61]

Almost all new cruise ships use diesel-electric propulsion. The main advantage of the diesel-electric cruise ship engine systems is efficiency, as they allow main engines to operate near the most efficient speed, regardless of whether the ship is moving at 5 or 25 knots.[62] Diesel-electric ships are expected to become more common in the future, as energy storage technology improves. The major disadvantage of electrification via batteries is that they take up more space and volume than diesel engines.[63]

For non-self-propelled vessels, including some WTIVs, propulsion, stabilization, and onboard electric needs could be supplied with onboard power sources or from electricity provided by support vessels using alternative energy systems, such as rechargeable batteries, fuel cells, or

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[60] Chia-wen Carmen Hsieh, University of Copenhagen, Claus Felby, University of Copenhagen, IEA Bioenergy: Task 39: Biofuels for the marine shipping sector, An overview and analysis of sector infrastructure, fuel technologies and regulations, https://www.ieabioenergy.com/wp-content/uploads/2018/02/Marine-biofuel-report-final-Oct-2017.pdf

[61] Infineon Technologies, Why ships of the future will run on electricity, https://www.infineon.com/cms/en/discoveries/electrified-ships/

[62] CruiseMapper, Cruise Ship Engine Power, Propulsion, Fuel. https://www.cruisemapper.com/wiki/752-cruise-ship-engine-propulsion-fuel

[63] Chia-wen Carmen Hsieh, University of Copenhagen, Claus Felby, University of Copenhagen, IEA Bioenergy: Task 39: Biofuels for the marine shipping sector, An overview and analysis of sector infrastructure, fuel technologies and regulations, https://www.ieabioenergy.com/wp-content/uploads/2018/02/Marine-biofuel-report-final-Oct-2017.pdf

external power sources. For vessels currently using 2-stroke and 4-stroke engines, partial or complete retrofitting would be necessary to utilize electricity as a power source.

There are several examples of battery powered electric vessels in use or on order in the U.S. In May 2019, the company, “Maid of the Mist" ordered from ABB two new all-electric vessels for their Niagara Falls tours. Both catamarans are 100% emission-free and powered by high-capacity batteries. Each ship is fitted with two battery packs (combined capacity 316 kWh / 563 HP output) and charging is estimated to take 7 minutes per ship. In addition to the shoreside charging connection, ABB supplied the newbuilds with switchboards, motors, integrated control systems and ABB Ability’s Marine Remote Diagnostic System (24-hour equipment monitoring and predictive maintenance).[64]

Washington State Ferries (WSF) operates the largest ferry system in the U.S. and is transitioning to an emission-free fleet by developing a hybrid electric ferry system. This includes building new vessels, converting older vessels, and electrifying the terminals. As of August 2023, WSF awarded a contract to convert the three largest ferries (Jumbo Mark IIs) to hybrid electric. They will open bidding for retrofitting their Olympic Class vessels in the fall of 2023.

Similarly, the Maine State Ferry Service will put one electric island ferry, M/V Almer Dinsmore, into service in 2023, and their capital plan calls for 3 others between 2027 and 2032.[65] The Maine Department of Transportation will receive $28 million from the federal government for the hybrid-electric vessel which will serve the 600 residents of Islesboro, an island in upper Penobscot Bay.[66]

Cost and Pollutant Considerations

Cost Considerations

According to the National Renewable Energy Laboratory (NREL), a utility-scale battery storage using lithium-ion battery systems with a four-hour duration are projected to have a range of capital cost for storage of $143/kWh to $248/kWh in 2030, and $87/kWh to $248/kWh in 2050. Given that these projections are for four-hour systems, the equivalent costs per kW are $572 to $992 in 2030. NREL explains that the inverter costs scale according to the power capacity (i.e., kW) of the system, and some cost components such as the developer costs can scale with both power and energy. They also point out that battery storage costs have evolved rapidly over the past several years and project a decline in capital costs by 2025 of 14 to 38 percent.

Using the same approximations described above to estimate bunkering needs of the largest LNG-powered WTIVs, the potential battery needs of such a vessel can be estimated. Assuming 20 MW to 46 MW of total power capacity (engine derived mechanical capacity plus electrical power capacity), a ballpark estimate of the 2030 projected costs would be approximately $11 to $44 million. However, as noted above, these approximations are overestimates based on all

64 CruiseMapper. Cruise Ship Engine Power, Propulsion, Fuel; https://www.cruisemapper.com/wiki/752-cruise-ship-engine-propulsion-fuel

65 Spectrum News https://spectrumlocalnews.com/me/maine/news/2023/01/26/maine-to-replace-islesboro-ferry-with-hybrid-electric-vessel

66 Washington State Department of Transportation, Ferry System Electrification, https://wsdot.wa.gov/construction-planning/major-projects/ferry-system-electrification

engines running on full power every hour of every day. The actual power requirements and hours, and therefore energy consumption and storage needs, would be a fraction of the installed capacity. Additionally, NREL also projects that the lifetime for grid connected lithium-ion batteries can be seven to ten years. Other companies, such as Sun Run Solar, project battery life of approximately five to fifteen years. Therefore, even these overestimates could be annualized to a tenth of these costs.

Further, the projected cost of installing battery systems on wind power support vessels could be considered as the differential cost between the cost of installing batteries and the cost of installing engines with equivalent capacity. For example, if the current engines on a wind power support vessel, ranging from 20 MW to 46 MW installed capacity, were replaced with diesel-fired Tier 3 1800 hp Caterpillar C32 marine engines, at an approximate cost of $200 thousand per engine, compare to an approximate total costs for battery power would be $3 to $7 million.

An alternative way to view cost of vessel electrification is to consider investments currently being made for alternative marine power (AMP), also referred to as shore power or "cold ironing," uses electricity from the local grid to reduce diesel-engine emissions from ships while they are in port.[67] These systems require significant investments, both shipboard and onshore. For example, they estimated retrofitting container vessels for cold ironing can run from $200 thousand to $2.9 million per ship.[68,69]

A report on cost-effectiveness of cold ironing that was prepared by ENVIRON International for the Port of Long Beach, California, discusses a large-scale cruise vessel cold ironing installation in Juneau, Alaska. The report indicates that Princess cruise lines spent approximately $5.5 million to construct the shore side facilities and to retrofit the vessels (about $500 thousand each) and that Princess estimated the cost of the shore power to be approximately $1,000 per vessel per day more than the cost of running the on-board diesel generators.[70]

Project-specific costs of marine recharging equipment for offshore wind project vessels were not readily available in our initial search. However, there are currently infrastructure projects underway near the WDA off the coast of Massachusetts that would facilitate use of electric propulsion vessels. For example, there is significant development occurring at the former Brayton Point power plant site in Somerset, Massachusetts. Anbaric will spend $650 million to convert the former Brayton Point Power Station into a Massachusetts offshore wind platform with 400 MW energy storage. The central element of the project will be a 1,200 MW high-

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[67] U.S. EPA Shore Power Technology Assessment at U.S. Ports, December 2022. https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports#assessment

[68] The Professional Mariner, Cold ironing: An approach to ship ATM power whose time has come; April 10, 2008; https://professionalmariner.com/cold-ironing-an-approach-to-ships-power-whose-time-has-come/#:~:text=But%20it%20does%20require%20significant,%24200%2C000%20to%20%24500%2C000%20per%20ship.

[69] CARB Control for Ocean-Going Vessels at Berth – Cost Analysis Inputs and Assumptions for Regulatory Impact Assessment (March 10, 2019)

[70] Port of Long Beach VOLUME I – REPORT COLD IRONING COST EFFECTIVENESS, PORT OF LONG BEACH, 925 HARBOR DRIVE, LONG BEACH, CALIFORNIA; ENVIRON International Corporation, Los Angeles, California; March 30, 2004. file:///C:/Users/SRapp/Downloads/Cold-Ironing-Cost-Effectiveness-Study-Volume-I-and-II-100710.pdf

voltage direct current converter and 400 MW of battery storage on site. The project was announced in 2019. The estimated cost of the 400 MW battery storage system was $400 million dollars.[71]

Pollutant Considerations

Electric engines generate zero emissions at the point of use but the sources of the electricity needed to charge them must be considered. Critical to this assessment is the observation that landside electric generating units (EGUs) tend to have lower emissions than the associated combustion of typical marine fuels based on the data from the Emissions and Generation Resource Integrated Database (e-GRID). This is due to greening of the electrical grid which includes a mix of low emission sources such as natural gas turbines, and renewables such as hydroelectric, wind, solar, and also nuclear[72]. An exception was observed in Alaska, Hawaii, Michigan, and the Mississippi Valley, where emissions for specific pollutants are higher (Table 6).

Table 6. Comparison of Regional eGRID Emission Factors.[73]

eGRID/NERC Subregion Name	Regional Emission Factors			
	NOx	SO2	CO2eq	PM2.5
Alaska Grid: Alaska Systems Coordinating Council (ASCC)	2.48	0.50	474.00	0.093
Alaska Miscellaneous: (ASCC)	3.50	0.31	239.03	0.355
California: Western Electricity Coordinating Council (WECC)	0.21	0.02	226.20	0.014
Electric Reliability Council of Texas(ERCOT)	0.25	0.38	424.60	0.021
Florida: Florida Reliability Coordinating council (FRCC)	0.16	0.13	424.63	0.029
Hawaii Miscellaneous: Hawaii Electrical Coordinating Council (HICC)	3.46	1.80	507.60	0.420
Oahu: HICC	1.59	3.63	763.21	0.262
New England: Northeast Power Coordinating Council (NPCC)	0.18	0.06	239.30	0.021
Northwest: WECC NWPP	0.26	0.17	291.82	0.017
Upstate NY: NPCC NY	0.06	0.04	115.16	0.008
East: Reliability First Corporation (RFC)	0.15	0.22	326.58	0.022
Michigan: RFC	0.36	0.59	599.28	0.029
West: RFC	0.37	0.42	532.53	0.048
Mississippi Valley: Southeast Reliability Corporation (SERC)	0.28	0.44	389.35	0.020
South: SERC Southeast	0.22	0.13	468.77	0.016
Virginia/Carolina: SERC East	0.20	0.12	339.07	0.023

[71] Anbaric to flip Massachusetts coal plant site into offshore wind facility with 400 MW storage, Iulia Gheorghiu, Published May 14, 2019, Dive Wire, Utility Dive. https://www.utilitydive.com/news/anbaric-to-flip-brayton-coal-plant-site-into-massachusetts-offshore-wind-fa/554725/

[72] For more information about eGRID go to https://www.epa.gov/egrid

[73] U.S. EPA/Office of Transportation and Air Quality Shore Power Technology Assessment at U.S. Ports: 2022 Update (EPA-420-R-22-037) December 2022.

eGRID/NERC Subregion Name	Regional Emission Factors			
	NOx	SO2	CO2eq	PM2.5
Marine Engine Emission Factors				
Higher than NOx Tier III	2			
Higher than MGO (0.10%S)	7.7	0.424	705	0.174
Higher than MDO (0.50%S)	7.7	2.121	705	0.299

Bunkering Capacity

Bunkering and Refueling/Recharging

The electricity distribution system (i.e., the "grid"), including high voltage transmission lines and substations, is well developed in the Eastern U.S. near the WDAs (See maps 10 - 17 in Appendix B). In effect, the grid acts as a large bunkering facility for electricity. However, to ensure dedicated electric supply for marine vessels supporting offshore wind power, developers may need to upgrade and augment existing equipment. For example, developers may need to construct onshore or barge mounted energy storage systems such as batteries and recharging equipment.

Additionally, based on interviews of personnel at a few ports in the Northeast (see Appendix A), there are several considerations to developing vessel electrification infrastructure:

- Space is an issue for infrastructure at ports that are more developed and have less open space.
- Planning for sea level rise adds another layer of planning and complexity for Providence Port, who will prioritize adaptation measures before investing in electrification.
- Several ports that are considering electrification for cold ironing or other shoreline uses (e.g., electrified cranes) found that the costs outweigh the benefits due to the size and vessel types that currently come to their ports.
- Some ports are considering setting up infrastructure for future use of electrified barges that could ferry components between the port and foreign WTIVs.
- Upgrading or designing a port for electrification can be complex, time-consuming, and costly. Private-public partnerships appear to be key to helping finance shoreline electrification.
- There is a lot of ambiguity about what U.S.-flagged WTIVs' electrification needs would be and ports do not feel that there is enough transparency from all involved. Much of the technology is not where it needs to be to plan for electrification beyond shore power.
- Costs are difficult to conceive because of uncertainty on voltage needed for larger vessels. There is some concern about needing to upgrade distribution significantly and possibly transmission lines.

Other Considerations

Charging Systems

Generally, there are two types of charging systems, manual and automated. In manual systems, an operator connects the shore charging station with the vessel. In automated systems, charging can begin as soon as the vessel comes into range of a wireless charging station, not requiring any operator action. Depending upon the characteristics of the site and the vessel to be charged, the charging unit can be located on an existing concrete foundation or on custom designed beams. For all types of charging, some jetty infrastructure work and high-power supply is necessary.[74]

According to the Wärtsilä website, a "2.5 MW system will fully charge a 1 MWh battery in 24 minutes. Normally, only a smaller part of the onboard battery is charged and discharged for each trip. For instance, 170 kWh of energy will be transferred in 4 minutes. It is also possible to charge with more than one 2.5 MW system at the same time, if necessary. Heat dissipation (losses) is dependent upon the actual power used for charging. Since wireless charging provides longer available charging time, a lower rate of charging power is necessary, and therefore the losses are also lower. The number of cycles and the battery life depend mostly on the ship's operational profile."[75]

According to the Institute of Electrical and Electronics Engineers (IEEE) article, "Shore charging for plug-in battery-powered ships: power system architecture, infrastructure and control," published in 2020, there are specific equipment needs for shore power to be able to supply marine vessels with electric power. The article notes that, "solutions for power supply from shore consist of an interface to the main grid by a step-down transformer, possibly an energy storage system typically based on [Lithium-ion] batteries, power electronics converters responsible for alternating current (AC) to direct current (DC) and DC to DC conversion, transformers for maintaining the galvanic isolation as well as voltage level adjustment, circuit breakers and cable management systems."[76]

The IEEE article discusses categories of shore-to-ship charging technologies, including conductive or wired charging systems, wireless charging systems, and battery swapping mechanisms. For wired charging systems, wired charging solutions are categorized into two types: AC charging systems and DC charging systems. For AC charging systems, an AC-DC converter is needed. The article notes that for vessels which require more power to recharge onboard batteries, an infrastructure or a dedicated substation may be needed. Additionally, the article discusses the need for other electrical equipment, such as battery storage systems, transformers to step down grid voltage, converters, rectifiers, and inverters. The article noted that "the main battery charger either can be installed onboard or can be located offboard, in a dedicated charging station. Although onboard chargers make it easy to charge by a regular AC

74 Wartsila, Charging Marine Vessels. https://www.wartsila.com/marine/products/electrical-and-power-systems/shore-power/charging

75 Wartsila, Vessel Battery Charging, https://www.wartsila.com/marine/products/ship-electrification-solutions/shore-power/charging

76 Siamak Karimi, Mehdi Zadeh, Jon Are Suul; IEEE Electrification Magazine, Shore charging for plug-in battery-powered ships: power system architecture, infrastructure and control, Volume: 8, Issue: 3, September 2020; https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/2736779/IEEE_EM_Shore_to_ship_charging_Submission.pdf?sequence=2

plug everywhere, there would be several limitations for the size, weight and cost of the onboard equipment, resulting in a constraint for the charging power. In contrast, dedicated offboard charging stations can provide high power for charging since the weight and the size of the charger are not limited, enabling fast charging and reduced charging time. In marine vessels, there can be size and weight restrictions in the design such as weight and volume-sensitive ships, for instance in the case of high-speed ferries where the weight of onboard equipment can highly affect the operation range and the performance of the vessel."

Another option discussed in the article is battery swapping. In this method, discharged onboard batteries are exchanged with fully charged batteries while the vessel is at berth. The article notes that battery swapping, "can reduce adverse impacts of charging stations on local power grid, since onshore battery packs are not being charged in a short time, rather they can be charged at off-peak with a cheap electricity or transferred to a central station which may incorporate renewable energy resources, namely wind and hydropower energies." Further, it noted that this method avoids high power converters for fast charging. However, battery swapping may require large robotic equipment to perform the exchange process and extra battery packs onshore. [77]

Fuel Cells

Fuel cells are another electrification option that provides power independent of the grid unlike battery technologies that require EGUs for recharging. A fuel cell is a device that converts an oxidizing fuel (hydrogen, methane, etc.) into electricity and water through an electrochemical reaction. Fuel cells can use a variety of fuels including natural gas, hydrogen, ammonia, renewable methane, and methanol. Fuel cells can be used to power marine vessels as well as onshore port systems. Fuel cell technology in the marine and offshore industries can provide improved energy efficiency and reduced air pollutant emissions. Proton exchange membrane, molten carbonate and solid oxide fuel cells appear to be the most promising options for maritime applications.[78]

Several fuel-cell powered ships are currently being designed or built. Samsung Heavy Industries (SHI) has designed an LNG-fueled fuel cell-powered WTIV SHI's "ECO WTIV" that will use solid oxide fuel cells (SOFC) to split methane into hydrogen and carbon, and convert the hydrogen to electrical power while the carbon is oxidized to CO_2. Although methane fuel-cells result in GHG emissions, they convert chemical energy in the fuel directly into electricity without burning it, thereby enabling efficient generation of electricity and a relative reduction of CO_2 compared to fuel combustion. SHI's technology partner for fuel cell development is Bloom Energy, an established manufacturer of natural gas-powered SOFC units. Its first commercial devices shipped in 2008, and it has supplied its SOFC "energy servers" to 500 land-based sites

[77] Siamak Karimi, Mehdi Zadeh, Jon Are Suul; IEEE Electrification Magazine, Shore charging for plug-in battery-powered ships: power system architecture, infrastructure and control, Volume: 8, Issue: 3, September 2020; https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/2736779/IEEE_EM_Shore_to_ship_charging_Submission.pdf?sequence=2

[78] Hui Xing, Charles Stuart, Stephen Spence, and Hua Chen, Fuel Cell Power Systems for Maritime Applications: Progress and Perspectives

over the intervening years. Specific cost information about the fuel cells used in marine vessels was not found.[79]

In San Francisco, Sea Change, a 70-foot, 75-passenger zero-emissions, hydrogen fuel cell-powered, electric-drive ferry is set to operate as a test pilot project in August 2023 on the San Francisco Bay. The vessel is equipped with a hydrogen fuel cell comprised of 360 kW of Cummins fuel cells and hydrogen storage tanks. This system is integrated with a 100 kWh of a lithium-ion battery and a 300 KW electric propulsion system. The hydrogen fuel cell powertrain has similar operational flexibility as diesel but with zero emissions and less maintenance. The project received municipal support including a $3 million grant from the California Air Resources Board (CARB) and a loan guarantee to secure a $5 million construction and term loan.[80]

Cost Considerations

One report indicated that the cost of a complete maritime fuel cell system was approximately 2,132 Euro/kW (approx. $2,205/kW) in 2020 but prices are expected to fall with increased production. Given the current focus on heavy duty road vehicles, fuel cell systems for maritime applications should benefit from developments in the on-road sector which may lead to cost reductions.[81] Ballard reports a current fuel cell system cost of $1,200/kW and lifetime of 25 thousand hours for buses which represents a predicted 60% decline in cost by 2030 and a lifetime of 30 thousand hours in 2026.[82] Additionally, there would be costs related to auxiliary systems.[83]

Extended Use of Nonroad Marine Diesel Fuel (< 15 ppm S)

Another possibility to protect local air quality would be to require the use of nonroad marine fuels (< 15 ppm S) in place of ECA compliant fuels (< 1000 ppm S). Obviously switching to nonroad marine fuels would reduce sulfur and PM emissions by 98.5 percent. The smaller Jones Act Category 1 and 2 vessels already use these fuels, which include a large number of offshore wind power support vessels such as supply boats, crew boats, dive boats and tugs. Larger Category 3 vessels are allowed to use less expensive and high sulfur content ECA compliant fuels. Research estimates fuel costs to account for approximately one to two percent of total

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79 The Maritime Executive, SHI unveils LNG Fuel Cell-Powered Wind Turbine Installation Vessel; PUBLISHED APR 8, 2021 4:09 PM. https://www.maritime-executive.com/article/shi-unveils-lng-fuel-cell-powered-wind-turbine-installation-vessel

80 AAM + Switch Maritime Announce the Launch of Sea Change, The World's First Commercial Vessel Powered 100% by Hydrogen Fuel Cells. https://www.allamericanmarine.com/hydrogen-vessel-launch/

81 Aarskog, Fredrik G.A; Danebergs, Janisa; Strømgren, Trondb ; Ulleberg, Øysteina; Institute for Energy Technology, Kjeller, Norway; Ocean Hyway Cluster, Florø, Norway;Energy and cost analysis of a hydrogen driven high speed passenger ferry; Maritime Hydrogen; DOI: 10.3233/ISP-190273; International Shipbuilding Progress, vol. 67, no. 1, pp. 97-123, 2020; 8 July 2020. https://content.iospress.com/articles/international-shipbuilding-progress/isp190273

82 Deloitte, Ballard, Fueling the future of mobility – Hydrogen and fuel cell solutions for transportation [Online report]. China: Deloitte; 2020 [cited 2020 Apr 20]. https://info.ballard.com/deloitte-vol-1-fueling-the-future-of-mobility.

83 Aarskog, Fredrik G.a; Danebergs, Janisa; Strømgren, Trondb ; Ulleberg, Øysteina; Institute for Energy Technology, Kjeller, Norway; Ocean Hyway Cluster, Florø, Energy and cost analysis of a hydrogen driven high speed passenger ferry; Maritime Hydrogen; Norway; DOI: 10.3233/ISP-190273; International Shipbuilding Progress, vol. 67, no. 1, pp. 97-123, 2020; 8 July 2020. https://content.iospress.com/articles/international-shipbuilding-progress/isp190273

offshore installation and O&M costs, respectively, of an offshore windfarm.[84] Thus, given the total cost of an offshore wind project and the long-term potential profits, the requirement of nonroad marine fuels is not the most significant cost consideration.

Current Capacity and Uses

Due to its required use as an on-road (highway) transportation fuel (< 0.0015 % S) in the U.S., the equivalent nonroad marine fuel (also < 0.0015 % S) used in Category 1 and 2 engines, is widely available in the Northeast (see maps 18 to 20 in Appendix B) and throughout most of the European Union. Use of nonroad marine fuel requires little or no changes to marine engines and meets the international standards for sulfur. However, nonroad marine fuel may not be readily available in the volumes needed. Therefore, to use nonroad marine fuel off the coast of the U.S., additional landside shore storage facilities maybe needed to insure sufficient supply.

Cost and Pollutant Considerations

Cost Considerations

Table 7 presents marine fuel costs in terms of U.S. dollars (USD) per metric ton of fuel were obtained from the Ship and Bunker website (8/28/2023).[85]

Table 7. Marine Fuel Price Comparison

Port	Price (USD$ per metric tonne)		
	VLSFO	MGO (ECA compliant fuel)	IFO380
New York	638.5	**965.5**	566.50
LA/Long Beach	705.0	**1,076.5**	577.0

Compared with the approximate price of regulated nonroad fuels: $1,571/metric tonne[86] based on fuel price data obtained from the DOE's U.S. Energy Information Administration.[87]

As noted earlier, the cheaper VLSFOs and IFO fuels can be used by Category 3 vessels within the NA ECA if the vessel is equipped with a scrubber that reduces SO_x emissions to the level expected if an ECA-compliant fuel were to be used. Installing a scrubber can cost from $500,000 to $5 million.[88] Scrubbers may be economically appealing if the price differential between IFO and ECA compliant fuels is large. For large tankers the payback period associated with scrubbers can be very shore, approximately a year.[89]

84 https://ore.catapult.org.uk/wp-content/uploads/2020/09/AI_Impact-of-oil-price-in-offshore-wind-final-01.00.pdf

85 Ship and Bunker. Americas Bunker Prices. Accessed September 22, 2023. https://shipandbunker.com/prices/am

86 For the purpose of this analysis, it is assumed that the price of nonroad marine fuel is assumed to be similar to highway fuels with the same sulfur content.

87 U.S. Department of Energy, Energy Information Administration, Petroleum & Other Liquids, Weekly Retail Gasoline and Diesel Prices, US Annual values 2017-2022. (accessed 8/28/2023) https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm

88 INAMEQ, Cost of Scrubbers on Ship, https://inameq.com/auxiliary/costs-scrubbers-ship/

89 S&P Global Scrubbers Bet Pays Off for Ship Owners as Marine Fuel Spread Remains Wide, 3 March 2020. https://www.spglobal.com/commodityinsights/en/market-insights/blogs/shipping/030320-scrubbers-bet-pays-off-for-shipowners-as-marine-fuels-spread-remains-wide

Scrubbers also incur operation and maintenance costs, requiring a power source, and if a closed loop system is needed to protect water quality, liquid sodium hydroxide is required at a cost of USD $350 per tonne which could equate to USD $360,000 per year per vessel. To accurately estimate the payback period, it is necessary to quantify the duration spent in ECA waters when the scrubber is required.[90]

Pollutant Considerations

In addition to reducing SO_x by approximately 98.5% compared to ECA compliant fuels, use of nonroad marine fuel can also reduce vessel emissions of PM, as well as NO_x, given the lower amount of fuel-bound nitrogen in distillate fuel relative to traditional marine fuel oils.

Bunkering Capacity

Nonroad Marine fuel storage and distribution facilities are widely available in coastal areas. No change would be needed to the existing storage and refueling equipment.

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[90] Klara Andersson, Byongug Jeong and Hayoung Jang, Life Cycle and Cost Assessment of a Marine Scrubber Installation, 2 November 2020. https://www.tandfonline.com/doi/full/10.1080/25725084.2020.1861823

Appendix A: Results of Interviews with Port Personnel Regarding Bunkering and Refueling for Alternative Fuels for OCS Vessels

Key Points:

- It is challenging for port experts to consider costs of alternative fuels/electrification in context of offshore wind because there are very few wind turbine installation vessels (WTIVs) available, and those that are available do not currently use alternative fuels. The vessels that are in use are foreign and could not come into port anyway. Additionally, none of the WTIVs currently have specifications for how they would use alternative fuels or electrification.
- Ports are not the sole driver for many of these decisions. They can decide how to manage their spaces (e.g., set up for electrification or bunker LNG fuel) but private companies decide which ports they will use for offshore wind (OSW) or what types of ships they want to commission.

LNG

- Feasibility: Feasibility of LNG is affected by many factors including public opinion, location and permitting regulations. While LNG is not always feasible for every port, some shipping industries, especially those based in Europe, believe it is the future for fuel for their carriers for the next 20 years.
- There is a new mobile LNG skid-mounted system that could get around the permitting and space issues, though it is dependent on location of existing LNG infrastructure. This system could likely fill bunker vessels that go out to foreign flag vessels or at minimum it could refuel vessels directly calling into a port. This system is currently being considered by the Port of Providence.
- Cost: None of the stakeholders have estimates.

Electrification

- Feasibility: Space will be an issue for infrastructure in ports that are more developed and have less space. Planning for sea level rise added another layer of planning and complexity for Providence Port, who will prioritize adaptation measures before investing in electrification.
- Several ports considered electrification for cold ironing or other shoreline uses (e.g., electrified cranes). Some ports have researched these uses and found that the costs outweigh the benefits, due to the size and vessel types that currently come to their ports.
- Some ports are considering setting up infrastructure for future use of electrified barges that could ferry components between the port and foreign WTIVs.
- Upgrading or designing a port for this can be complex, time-consuming, and costly. Private-public partnerships appear to be key to helping finance shoreline electrification.
- There is a lot of ambiguity about what US-flag WTIVs electrification needs would be and ports do not feel that there is enough transparency from all involved. Much of the technology is not where it needs to be to plan for electrification beyond shore power.

- Costs: Costs are hard to conceive because of uncertainty on voltage needed for larger vessels. There is some concern about needing to upgrade distribution significantly (and possibly transmission lines).

Possible Next Steps:

- Initiate conversations with marine construction and shipping companies who are currently working with ports to set up alternative fuels or electrification could provide more insight on to the costs and requirements to adopt alternative fuels.

Summary of Outreach to Ports November to December 2022

Objectives of discussions: To learn more about costs and feasibility of LNG and electrification at ports and what considerations or efforts ports have made to support offshore wind installations.

Interview conversations included:

- Port of New York/New Jersey
- Port of Salem, MA
- Port of Davisville, RI
- Port of Providence, RI

Email conversations included:

- New Bedford Port Authority
- Port of Albany

Basic Text of Email Request for Interviews:
Port contacts were initially contacted by email using the template below.

> Subject: Request for conversation on alternative fuel feasibility at your port
>
> My name is Charles Goodhue, and I'm working with EPA to better understand the feasibility and estimated costs of using alternative fuels at ports to support offshore wind turbine installation vessels. This information will help EPA approach permitting of offshore wind in a consistent and informed fashion.
>
> If you have about 20 to 30 minutes between now and December 16, we would love to talk to folks at your port to discuss feasibility, logistics, and costs of installing liquified natural gas [LNG] storage and fueling equipment and/or electric storage and charging equipment sufficient to support larger (e.g., wind turbine "jack-up") vessels.
>
> If your port **has not considered** electrification/charging or LNG infrastructure to support larger vessels, please just send me a quick email so I do not need to follow up.
>
> If your port **has considered** *either* electrification/charging or LNG infrastructure to support larger vessels, please send 3 to 4, 30-minute windows (between now and December 16) that might work for a quick discussion. We're hoping to talk to someone at your port who could talk about the feasibility issues and estimated costs of either alternative fuel.
>
> Thank you!

Interview questions

Below is a list of potential interview questions that were used to guide the conversation. Each interviewed started with introductions and participants provided an overview of their port operations, questions were modified in the interview based on each port's context and progress with alternative fuels.

1. What types of offshore wind economic activity could your port support?
2. Would a jack-up vessel be able to come close enough to your port to pick up components to bring to the installation site? Would docking be possible?
3. What fuel technology have you considered for vessels that use your port over the next 10, 20, 30-year horizon (Ultra Low Sulfur Diesel (ULSD), bunker fuel, LNG, electrification, biofuel as a drop in fuel or as a separate fuel)?

LNG

1. Have you ever considered installing an LNG facility, for purposes like refueling your ships or other? Have you performed a feasibility/cost study for that? Would it be possible to get a copy? If you did not, what influenced your decision to use or not use?
2. Have you considered the possibility of using existing equipment from another location (e.g., if it were available)?
    a. **If yes, (keep if the port is in MA)** What steps would it take to move LNG existing infrastructure from existing storage facilities (e.g., the Constellation facility in Everett, MA) to your port to allow for LNG fueling of jack up vessels (for example, existing pipelines, storage tanks, cryogenic equipment, etc.)?
3. What equipment are needed and estimated costs (with approximate ranges) of setting up LNG fueling of jack up vessels/large containerships at your port using <u>existing infrastructure</u>? Can you break down these costs at all by type of cost?
4. What equipment are needed and estimated costs (with approximate ranges) of setting up LNG fueling of jack up vessels/large containerships at your port using <u>new infrastructure</u>? Can you break down these costs at all by type of cost?
    a. Interviewer**-** can ask about pipelines, storage tanks, cryogenic equipment, etc.
5. What is the estimated timeline for setting up LNG fueling of jack up vessels/large containerships at your port? How might this be different for using existing infrastructure compared to installing new infrastructure?
6. Are there any permitting safety, challenges, or other considerations associated with installing LNG fueling for offshore wind activities- specifically jack up vessels/large containerships?
    a. Would there be more appetite for an LNG facility if it was supporting OSW as opposed to another activity, like container shipping?
7. What mechanisms for funding do you consider could be leveraged for financing the installation and maintenance of this fueling system? (Note to interviewer- can suggest the following to spark discussion: PPP, long-term contract, federal, state, developer?
8. Short response: How long does it take to fuel a ship using LNG and how does fueling happen? In a scenario where LNG is used to fuel jack-up vessels or a similar ship (crane barge or large container vessel) how long would it take? Would climate conditions

impact the ability to refuel (temperature, rain, stormy conditions, extreme heat)? Do you need specially trained personnel to operate an LNG facility that fuels ships?

Electricity

1. Have you considered electricity charging stations as a source of energy for ships that call at your port or off-road equipment?
    a. If not, what are the factors that are influencing your decisions, cost, feasibility, utilization, etc.?
2. What steps and equipment would it take to install electric infrastructure to charge jack up vessels?
3. Does your port currently have adequate electric charging serving the port for electric charging of vessels and off-road equipment? Would it be sufficient for charging large jack up vessels (e.g., 150 - 400 MWh/year)?
4. What are the estimated costs (with approximate ranges) of setting up electric charging of jack up vessels at your port? Can you break down these costs at all by type of cost?
5. Are there any other feasibility (e.g., permitting, safety considerations, etc.) issues with setting up electric infrastructure to charge jack up vessels?
6. What mechanisms for funding do you consider could be leveraged for financing the installation and maintenance of this fueling system? (note to interviewer- can suggest the following to spark discussion: PPP, long-term contract, federal, state, developer?
7. Short response: Thinking about operations for OSW, are there any factors that would enable or inhibit charging activities, such as pricing, physical constraints, climatological conditions? Does your port have a special electricity rate with the [insert regional electricity provide]?

Interview Notes

Interview with Port of New York/New Jersey, December 2, 2022, 3pm ET

What has the port authority considered for offshore wind (OSW)?

The Port Authority supports stakeholders, including tenants, but all work done by private entities at the port. We can nudge them in the direction to fit them in alignment with the port authority's (PA) goals. My department doesn't make business decisions (i.e., is this a type of material or preparation of land to invite people to come?) – we structure properties, review proposals of businesses on why they need a maritime facility. It's a weird spot to be in – the port can accommodate OSW companies, but the port isn't in the driver's seat to make these decisions. They are a landlord org – they just decide how to manage their spaces.

The PA knows the lay of the land but doesn't own or have any direct relationship with any fuel bunkering or refineries. The Port doesn't have any bunkering operations within footprint. My department has done the research to understand the lay of the land and there have been previous Requests For Proposals. We have had properties that we've offered tours from OSW folks but they decided to look elsewhere. We also had LNG industry folks come to evaluate properties to see if it fits their needs.

LNG

Have you ever considered installing an LNG facility, for purposes like refueling your ships or other? Have you performed a feasibility/cost study for that? Would it be possible to get a copy? If you did not, what influenced your decision to use or not use?

The port knows about LNG facilities from past experience, and it seems like it's probably not possible to have them in NYC or densely populated areas in NJ. The political resistance from host communities to LNG (either bunkering or generation) is too strong.

We didn't make it to the feasibility step for considering LNG. There isn't a market right now so any estimates would all be postulated. Especially after knowing the political atmosphere in the PA's area, it doesn't make sense to do that. Since decision makers say it's not possible, we didn't do any more analysis or cost study for LNG.

Electricity

Have you considered electricity charging stations as a source of energy for ships that call at your port or off-road equipment? Do ports have the capacity to install large charging stations for ships at port?

We have equipment at the port for vehicles coming to and from the ports. Electrification equipment needs vary depending on the types of uses. The general consensus of ports and ocean-going companies ("carriers") is that it is not possible to have all vehicles equipped with batteries for their entire voyage. Propulsion will likely be from low carbon or net zero fuels (ICE) and eventually switch to be combined into a fuel cell. Battery storage isn't feasible. It would become a vessel of batteries.

For ports and marine vessels, the process and design is much more complicated that plug-in electric vehicles. Everything going into the future will be a hybrid of multiple fuels.

What information or data do you have on costs to electrify ports?

There isn't enough information to say how much the costs of components would be – each port is too customized and there are not enough sample sizes. Here are a few examples:

- There are some 1MW chargers installed, the cost was about $4 million (no transmission or supply required). Increasing port capacity to be able to manage 100MW could be about $400 million.
- Brooklyn installed shore power and it cost $21 million because they didn't have structural loading on wharf and needed to reinforce pilings. It's not really a one-to-one replacement in a port– ports will need more infrastructure and space to make these upgrades.
- One OEM estimate was $500,000 to install a 600KW charging tower.
- Shore power isn't really charging – it's supplying continuous electricity. It costs $10-20 million per wharf per system. And it costs about $1 million per vessel to upgrade receive electricity from receiving sources.

What are the carrier considerations that would factor into the decision to electrify for cold ironing?

You would need very stable service lines, and both ends have shore power systems, that would make it more sustainable to do that upgrade. It varies also for type of vessel:

- For vessels that carry low margin cargo – they don't consume a lot of energy when not moving.
- Cruise vessels, especially when docked, use a lot of energy. They're the best candidates for shore power systems, though they also causes issues; they still receives the most benefit given amount of investment.

Energy needs of various vessel types at ports also differ. MW needs of cruise ship depend on if they hold port or passing through, for example. For example:

- NY is usually the first stop. The cruise comes in the morning, take off in the afternoon (8-12 hours in port total). Load is 8-12MW/hr.
- Container ships – stay at port for 10 to 60 hours or longer (depends on cargo).
- Vessels holding fuels and low profit – stay longer, upwards of 120 hours in port.

Biofuel or ultra-low sulfur diesel

What do you know about the state of biofuels or ultra-low diesel fuels for marine vessels?

The Port doesn't have operations using biofuels or ultra-low diesel fuels but has done some research. Biofuel is complicated both in terms of carbon emissions from production and temperature considerations. Biodiesel and renewable diesel are applied on road and their main challenge is cost and the amount of supply. That's why cost competitive ship owners are looking into ammonia and methanol instead. Very low probability that renewable diesel can scale up to reach demand. Biofuel isn't meeting the mark for either supply or cost.

Since 2016, the requirement is to burn 0.01 sulfur content fuel. People aren't that worried about low sulfur now. People are more worried about greenhouse gas emissions or local air quality. Sulfur has a low enough content to not be a huge issue for local air quality. It's possible that existing engines might not be able to use ultra-low sulfur fuels. States or US Fed gov't don't have a good way of mandating vessels since they're international as well so there's very little appetite to go from 0.1 to 0.05 percent.

Interview with Port of Salem, December 7, 2022

Port of Salem Overview

The Port of Salem primarily facilities ferry operation (seasonal) and is entirely owned by the city through the port authority (PA). They have a flexible berthing space for larger recreation and smaller cruise ships. Through that space they also have private deep-water berth that PA has been operating through an agreement, which currently sees a handful of cruise ships a year. The Port used to rely on a coal fired plant, which has been replaced by a smaller gas fired power plant which opened up more land.

OSW status: They currently have a partnership with Crowley wind services to develop a port project in a public-private partnership (PPP) where the city will own the berth and 5 acres of upland area and it will be operated by Crowley. Crowley is leading the design and construction of the port project itself. It will mainly be a construction staging facility - heavy lift vessels come from manufacturing ports bringing primary turbine parts, offloading, and strategic positioning components into 1 or more full assemblies to be loaded on a barge to go out to sea for installation.

The port views this as a long-term port use in Salem. As of December 2022, they have a 60 percent design with Crowley and are working on permit and funding now. Currently dealing with inflation, design, and supply chain issues – cost is over $100 million.

For the deep-water berth – the goal is to follow the California (CA) cold iron requirements. The community and PA is excited about electrification.

LNG

Have you considered installing LNG infrastructure? If so, what challenges have you faced?

The port's property is downtown so it is tough to have LNG in this location and it would be a challenge to store on land. There is a LNG storage facility about a mile and half away. But it wouldn't be viable to do a transfer from there because of loss going through cool down. The best option would be bunkering on barge.

The biggest obstacle to LNG is space allocation and public safety concerns. Japan is the best example of how they stationed storage tanks in densely populated area. We just don't have that space here (they did underground).

Electricity

Have you considered electrification for cold ironing?

Crowley is committed to including underground infrastructure necessary for forward-looking options for electrifying larger vessels down the line. The port itself is situated with a power station linked to a national grid on adjacent power.

We know the west coast has been doing this for quite a while with many different types of ships. Crowley is mostly familiar with electrification for smaller vessels. Currently Crowley is only committed to cold iron electrification for tugs and barges. They argue that because WITVs with US flag don’t exist they can’t set up all the infrastructure to cold iron those vessels yet.

Crowley says they are uncertain in the service required and the upfront cost and are not comfortable taking that risk without understanding needs.

Question from Salem– what’s the voltage requirements for different vessels? It seems like it wouldn’t vary that much across some of the larger vessels so it could be possible to set up Salem for these larger vessels now.

Where we stand right now – it is unlikely to have WTIVs at the berth in the first period. We are planning for cold iron for tugs and barges, but not a WTIV in the future. The port will have a conduit to the berth so that it could be done later. The electrical build out will be there for tugs and barges since we will likely be using foreign flag installation vessels that will be fed components through a barge for the first planning period - currently in the design phase. We have a solid commitment from Crowley that the conduits will be there for larger vessels but not for immediate need/use.

There’s been some community push back to that plan – the community wants electrification. The City of Salem wants to do this intentionally at each step. Salem has some issues with the current approach of electrification for tug and barge only and how it doesn’t accommodate heavy lift vessels.

Crowley argues that it is hard to set up for more when those higher-level vessels aren’t built yet but putting conduit for later. We do know that heavy lift vessels have similar requirements – quite certain that technology exists on the west coast that accommodates many different types of ships. On the west coast, cold ironing is already being done for larger cargo vessels- it’s becoming mainstream. In the future when there is a US flag WTIV it could come into port (no physical issues with the design).

How are you funding your current expansion?

We secured a fair amount of public funding through large buckets – $34 million from the Maritime Association and the state. Now they want to look at smaller buckets of funding to do the most possible to set up for electrification.

We’ve been successful to date in finding funding for electrification. It is an easy area to separate out and to find smaller buckets of funding to support.

What data do you have on costs for installing alternative fuel infrastructure? Have you done any feasibility studies for LNG?

LNG likely isn't feasible but it is feasible to provide heavy electric. The cost of the technology is the question. We do not have itemized costs of the 60 percent design. It's information we could get out of them (Crowley) in the future. The public-private partnership disclosure is a bit difficult to navigate funding costs.

If WTIVs have some electric component in the future, are there ships that could also go to the same berth to use that infrastructure?

We think it's possible but need more information on the technology. Whether it's a tanker, cruise ship or heavy lift – can't image they don't have a way to transform that voltage to be useful, there may be some issues of design. It's more of a voltage issue than getting ships to different berths.

Interview with Port of Davisville, Rhode Island, Friday, December 9th, 11 am ET

Background and context of Davisville Port

The Port is part of quasi-business corporation. It is a quasi-public-private entity created with the objective of reusing closed naval bases. The Port is part of a larger business park that uses the old base.

Davisville Stats:

- 3,200-acre business park, of which about 150 acres belongs to the port.
- 13,000 employees
- Over 200 businesses – featuring electric boat and manufacture of submarines (2M sq ft)
    - Japanese company that makes film for snack bags.
    - Ocean State Job Lot warehouse.
    - Start up making an airboat also there (classified as a boat)- will run on electric batteries to provide local/regional transportation.
    - Some of part is dedicated to business park operated by Kingstown.
    - Some small public beaches.

Port infrastructure

- 3 piers – 2 of which are used, 1 is being rebuilt.
- An additional pier is used by the SE shipyard.
- Water and sewage system that is owned and operated and maintained by port.
    - They sell water and water treatment to tenants.
- Quasi-state airport. Also used by the national guard – owned by different state entity (RI air corporation)

Description of Port Operations

We are a “roll on, roll off” Port. We are the 6th largest port for car carriers in the country. Volkswagen is the biggest client, followed by Subaru. The VW route is from Germany to Mexico and back.

VW is aggressive in terms of having the entire berth, supply and logistics chain decarbonized. More so in Europe than in the US. I believe VW just made an investment to electrify a dock in a California port. They built 2 LNG ships that call out here. They’ve ordered 2 more. Two or three other shipping lines have all ordered LNG ships. The industry thinks this is the next fuel for 20 years while alternative fuels come into market. These ships are very large – they never come full (for fuel efficiency and speed).

LNG

We are having conversations with SIEM. They've asked RI if they are interested in supplying LNG – they want more options. We are looking at providing LNG through a barge and some kind of system with tanks. I'm not sure how or when will happen or who will finance. There seems to be a disconnect between alternative fuels being ready for larger engines.

> **Update** In February, the Davisville RI port director provided this info: *SIEM is the primary shipping company that serves NORAD, and have approached Quonset, saying that they are moving to LNG RORO ships. They'd like to be able to fuel with LNG at Quonset, as a source of LNG fuel that's better and cheaper than what they can get in Germany. They already have a fueling source in Jacksonville, but want an alternative. Their ships come from Germany, sometimes directly to Quonset, sometimes via Mexico/south, or Nova Scotia. Other shipping companies have approached Quonset about hydrogen fueling. Have plenty of power to support either fuel type.*

Any infrastructure set up from LNG use for other purposes?

We would be starting from scratch. We have a few civil engineers on site that have done the space planning and we think we know how this would work to bring LNG to the site on a permanent basis instead of a barge or tank outside of the dock. We think we have space for a large LNG storage tank.

There's no information on cost or timeline yet – that will be the next step we take with SIEM. When we had conversations with other shipping lines- they didn't have an idea of when these ships will be put into use. – there is a lack of good data out there.

There would likely be partnerships with VW to help with costs – they're a major driver of this interest.

There are some other finished vehicle logistics to consider. Electric Subarus just started coming in and it brings ups some other safety issues (i.e. lithium battery fires, offload of damaged cars from storms). Unfortunately, the port isn't a driver of that. We don't even know how much power that the port or auto trusts should provide to the manufacture to charge its cars. There's no sharing of information on that.

Electricity

We have done back of the envelope calculations on electrifying the pier for cold ironing and passed. The thinking was the ships aren't here that long (4-8 hours) rarely more than a day. There might be a large conduit underneath pier 2 built in anticipation of electrifying at some point.

Hydrogen Fuel

At the North Atlantic Ports Assoc. meeting there was a presentation by Charlie Meyers (Hydrogen expert) – a big advocate for mobile containers for hydrogen fuel cells attachments. This concept is new – Charlie wants to come down and speak to engineers of cargo ships to get a better understanding of the power needs of a ship while it is at dock. For example, while a ship's propulsion is shut down – the ventilation system is still going (which is a high electricity use).

He could pick a newer ship for that but not LNG or an older ship. Seeing some older ships call here – the assumption is the older ship, the more emissions produced. Car carriers don't need as much energy when dockside as some of the other types of larger ships. I believe National Grid has some money available for consultants to do some analysis.

Are there other electrification opportunities at the port?

We have a fleet of vehicles of small cargo vans, passenger vans, a lot of trucks (we maintain the roads) and some very large dump trucks and plows. We didn't find many alternatives for the trucks that we use here, which was disappointing. There is a possibility of electrifying some of the SUVs – they are public safety vehicles, and we are open 24-7 so some uncertainty about the charge last and unplanned needs.

I am disappointed in the 3 stevedores operating here – 2 have a fleet of 8 or 9 passenger vans (workers that drive cars to first destination). The auto processer also has a fleet of the same 8-10 passenger vans. That are driven hard. There doesn't seem to be a comparable electric van product for this. I think each of the companies would consider electric vans if there were options.

There's also electrification of the Pier 2 conduit. We don't have calculations on electrification for shore power. A mobile hydrogen tank is an interesting alternative – thinks it's fairly ready to go. There were some other ports interested in pursuing it too. I always think there will be some kind of retrofit – all of these ships are different. Even supplying water to ships – everyone has to bring their own hose and adapter. Assuming its similar for electrical. An example of that is LNG ships from SIEM can take fuel on both sides.

Have you considered the port for staging and installation of OSW?

We did that for the Block Island wind farm – we staged the blades and tower sections here. They sailed out of another port. Those are like Legos. We are active in OSW – we are positioned for fuel transfers, equipment, supplies crews, specialty workers, and we have 3 berths available. Will have 4 in another year and 5 in about 2 yrs.

All of these wind farms are staged in a good amount of land. It cost $40 mill to reconfigure space to get blades and foundations. The power sections are still going to come from Europe.

Marshaling tower sections somewhere else because there won't be bridge obstructions – as you go down the coast, you'll see larger parts of property be developed to be part of the staging. For example, former oil tank farm in NJ. Bridge obstructions will be an issue, particularly in RI. I know Albany is manufacturing foundations and Virgina has 600 acres available.

Davisville would be able to plan and site for future WITVs. We had a shipment stored for South Fork off of Long Island two weeks ago. We're going to do that for a couple of months and also for a lot of other suppliers and manufacturers. We have cable companies looking for spool storage (they're huge and can't be stacked).

Seems like there's a lot of talk about electric vessels but no consensus. Not sure how electric vessels would be able to charge – questions include what's the effect of bad weather that makes you burn more energy? Most of the routes go through Right Whale migratory path so they have to go slowly. There are lots of variables and not a lot of transparency – it's frustrating for private developers.

Anything to relay to EPA?

Clarity, timeliness. The private sector seems to do their own thing and move forward. We understand the need for alternative fuels, but the majority of our business is car carriers and no one there sees anything but LNG for 20 years.

Interview with Port of Providence, December 12, 2022, 8am ET

Overview of operations:

We are the terminal operator for "Prov Port" and run stevedore operations in Davisville and New Bedford, MA. We're a family company, started in 2000. At New Bedford, we were part of operations for OSW. Generally focused on bulk shipping.

History of Prov Port

From 1994-2000, a public-private partnership ran from a legacy stevedore in Prov Port, this company formed to take in that gap of the port. Waterson merged to form stevedore and terminal manager at Prov Port. The primary commodity was importing bulk coal until about 2010.

Offshore wind experience

We were involved in early discussions of Cape Wind and were a staging facility for RI deep water wind in 2015-2016. We are regional experts in RI – the only stevedore company that handled OSW in the United States.

Currently working with Ørsted with foundation components and cable installation and are running out of space to do more than that for OSW.

In New Bedford, we are working with developers and installation contractors for GE turbines for Vineyard Winds. This involves unloading vessels from Europe with components to get into the preassembly area. We step aside at that point for building to do the preassembly work. We get involved when those components get back onto a barge to get sent to the WTIV because of the Jones Act.

We also are providing personnel in Quonset, RI – all the CTV and SOS types of vessels coming into port to service the turbines long term will be coming there.

LNG

We are starting to see a small handful of vessels with LNG. Volkswagen SIEM car carrier has LNG powered vessels. We had some conversations with companies that would potentially set up LNG bunkering in Providence or Davisville. The logistics of that are unknown – it's more complicated for marine diesel than for trucking. There's a lot of talk of vessels that could go to the foreign flag vessels to help fuel those.

Is there potentially a partnership with Volkswagen for LNG infrastructure?

We haven't had direct conversations with them, more with other service providers who have the capacity to support this (driven by the supply side more than the demand side).

What challenges have you come across in planning for LNG?

We are concerned with LNG safety and opposition from the community around the port - pushback on the safety side and the fossil fuel side. For any storage required – permitting could be a challenge because city ordinances have limits on storage (that's why portable systems are attractive).

We're close to RI energy supply and wouldn't need any permanent structure. It might not be a cost – it would be a third-party service provider that would sell to these vessels coming in. We haven't talked to RI Energy yet.

Another (non-marine) facility on the coast just completed LNG storage tank. There's still a stigma towards LNG and the community fought against that project. We'd need to work hard to communicate the benefits.

Possible LNG solutions: There is a skid mounted system for LNG that you could truck in and run through skid mounting to get to a vessel – it doesn't involve hard infrastructure. This mobile system could fill bunker vessels that go out to foreign flag vessels. At minimum we could do vessels directly calling prov port.

Are there other types of ships interested in shifting over to LNG?

OSW heavy installation type vessels – there's definitely a lot of desire to convert vessels to reduce fossil fuel use for building OSW. We don't have an idea on the time frame. LNG is more realistic and desirable than other alternative fuels.

Some of the crew transfer vessels that come into port more frequently – like some of those vessels built for the Ørsted project will be built to be hybrid ready for propulsion. These come into and out of port daily and are currently being built in RI.

Have you looked at infrastructure to support electrification?

We looked at shore power years ago – around 2011 or 2012 part of tiger grant application. We needed new cranes at the port. Tech for mobile harbor cranes had the ability to electrify. We bought the cranes but there was no funding to support electrification.

On the quayside – Prov port is 100-year structure, we don't want to put into electrification infrastructure before elevating the dock for sea level rise (SLR). Next year we will start master planning with Providence to look at it more realistically to see what needs to be done to adapt to SLR and then add electrification.

Do you know the voltage capabilities?

We were more focused on powering the cranes and having power to connect them on the quayside – do not anticipate it would be as difficult to connect to a large vessel.

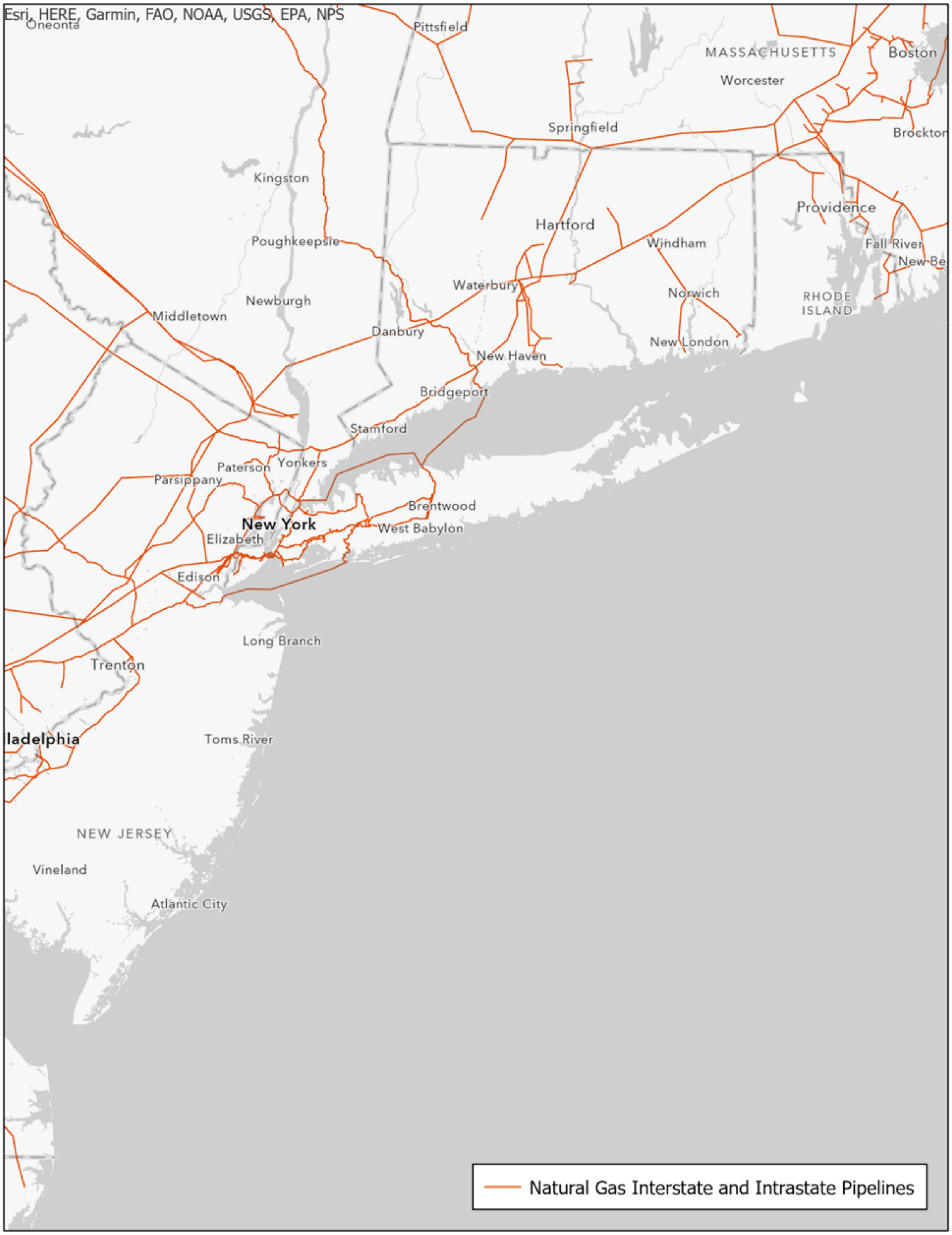
We got $10.5 million for the cranes. The total project is in the $40-50 million range. Half of that was for the electrification of the cranes. We have 3,500 linear feet of dock with 6 or 7 connection points.

Appendix B: Infrastructure Mapping

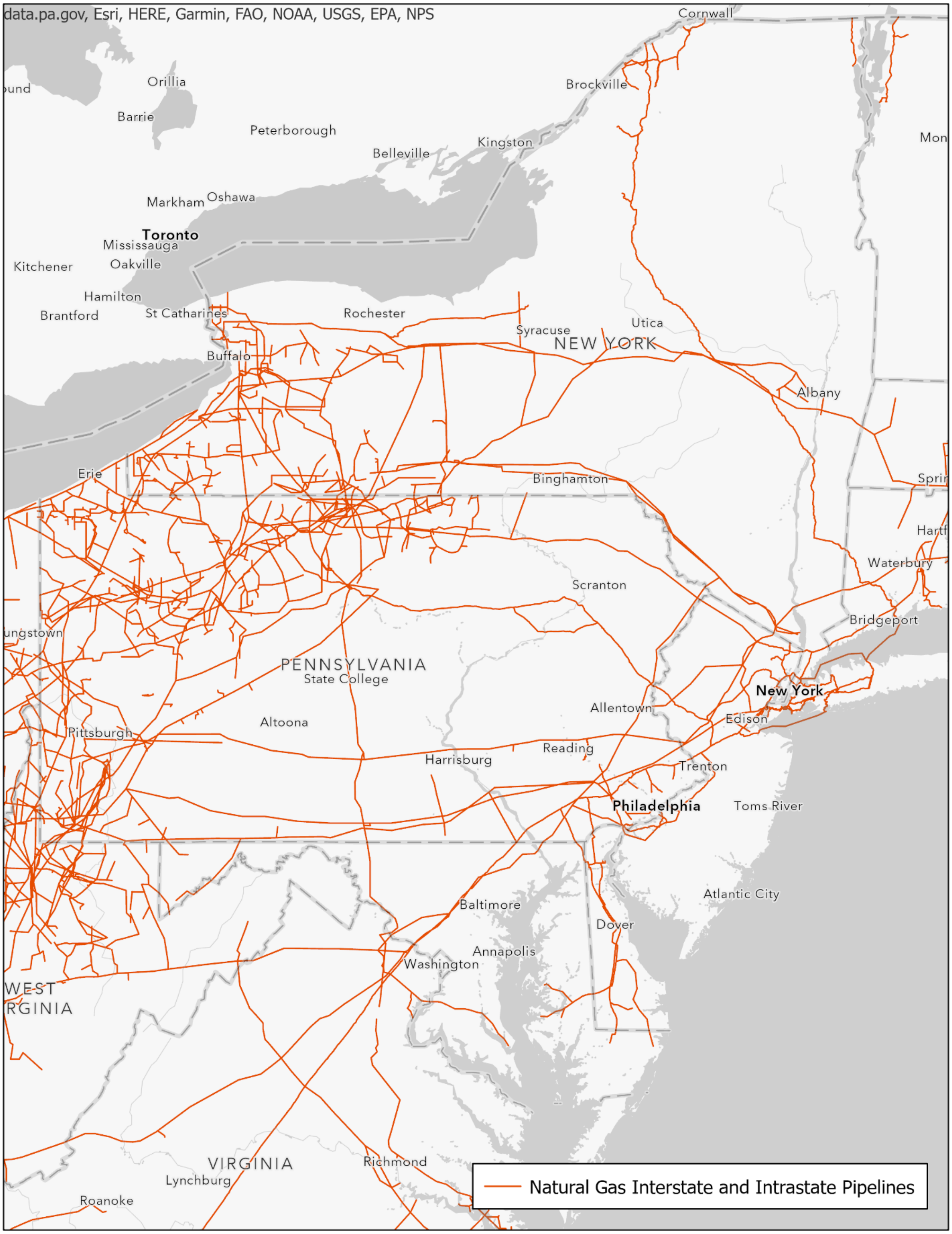
The following maps contain GIS layers obtained from the U.S. Energy Information Administration (EIA) at: https://www.eia.gov/maps/layer_info-m.php

Map 1. Natural Gas Pipelines Northern New England

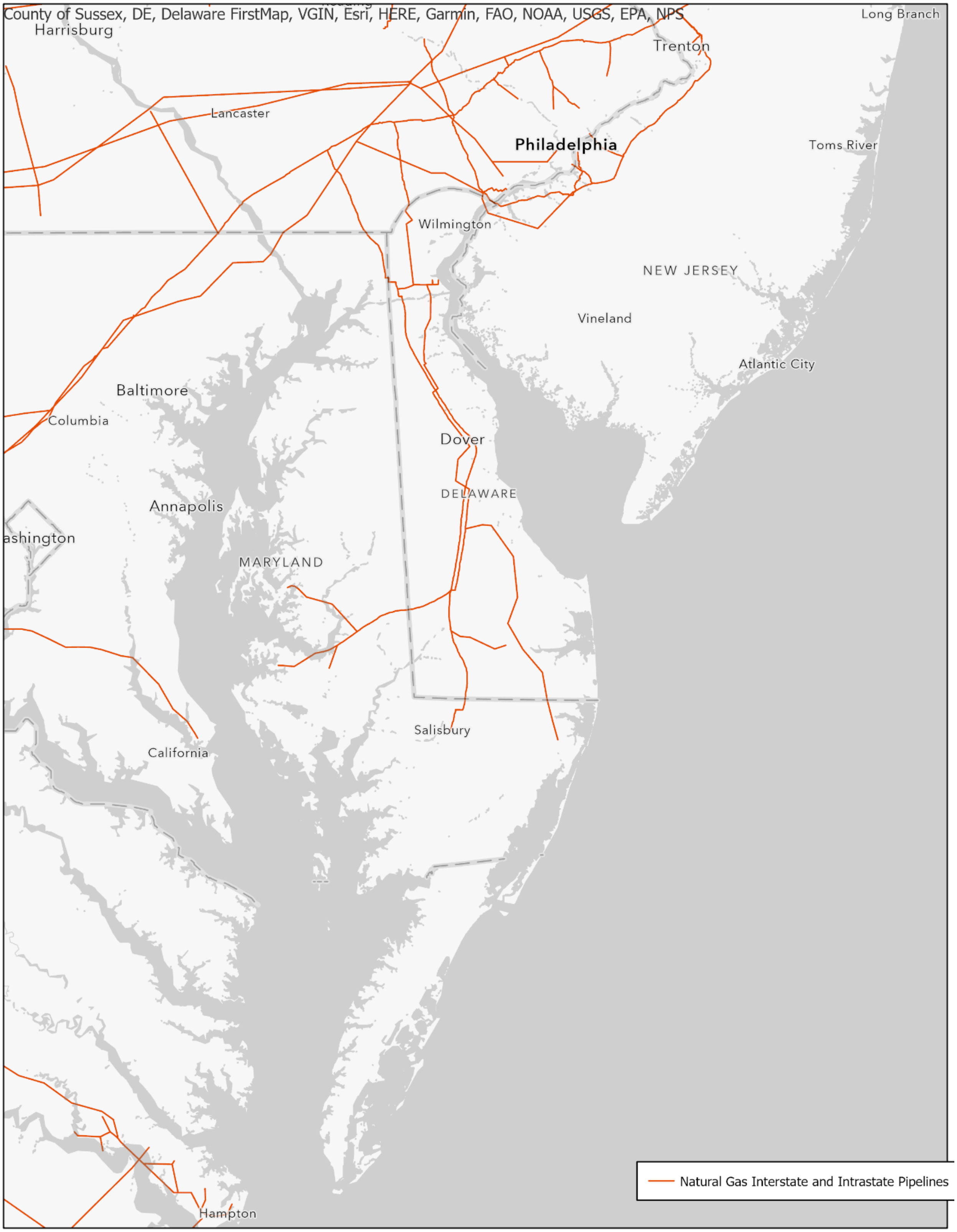
Map 2. Natural Gas Pipelines Southern New England



Map 3. Natural Gas Pipelines Mid Atlantic

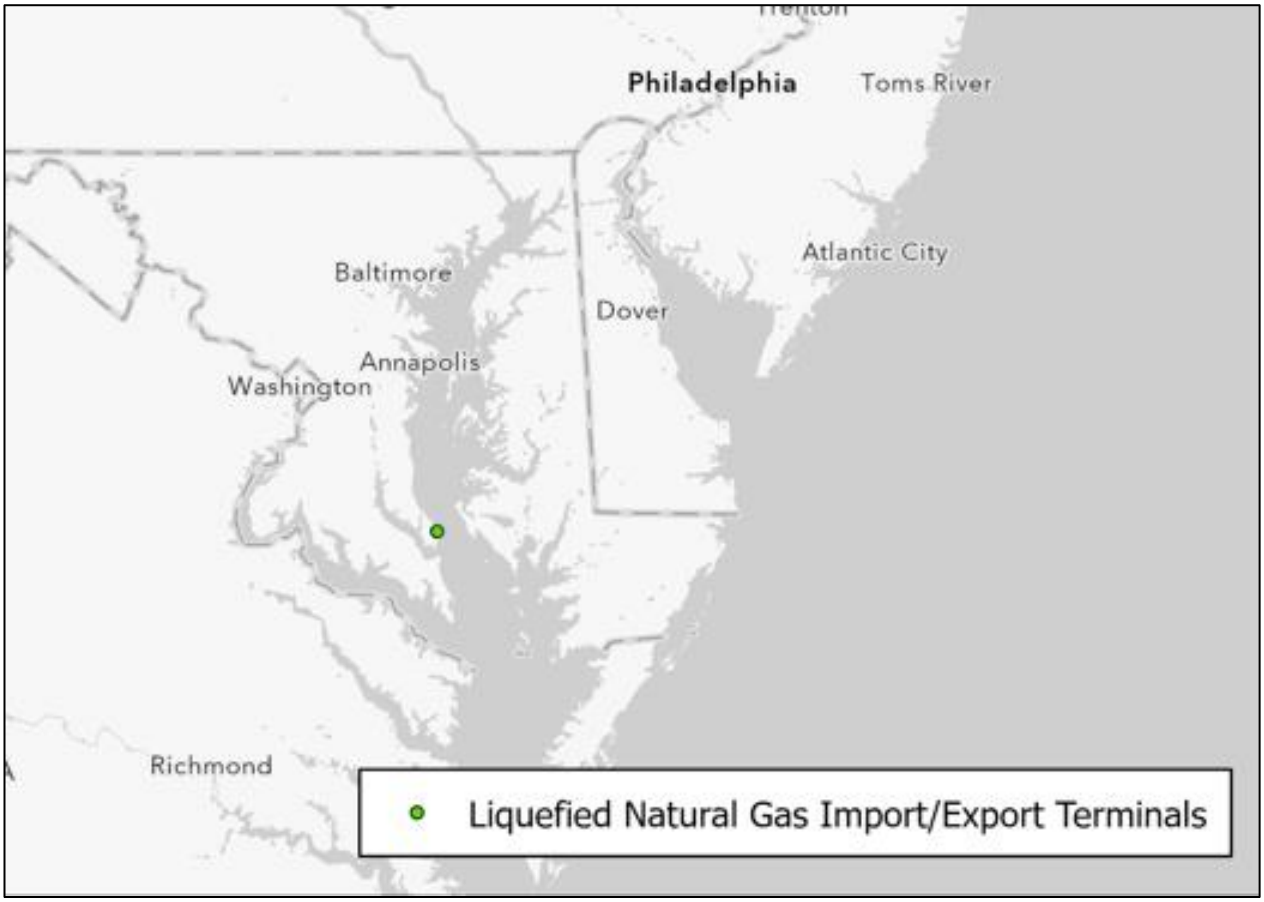


Map 4. Natural Gas Pipelines Mid Atlantic Enlarged



Map 5. LNG Terminals Northern New England

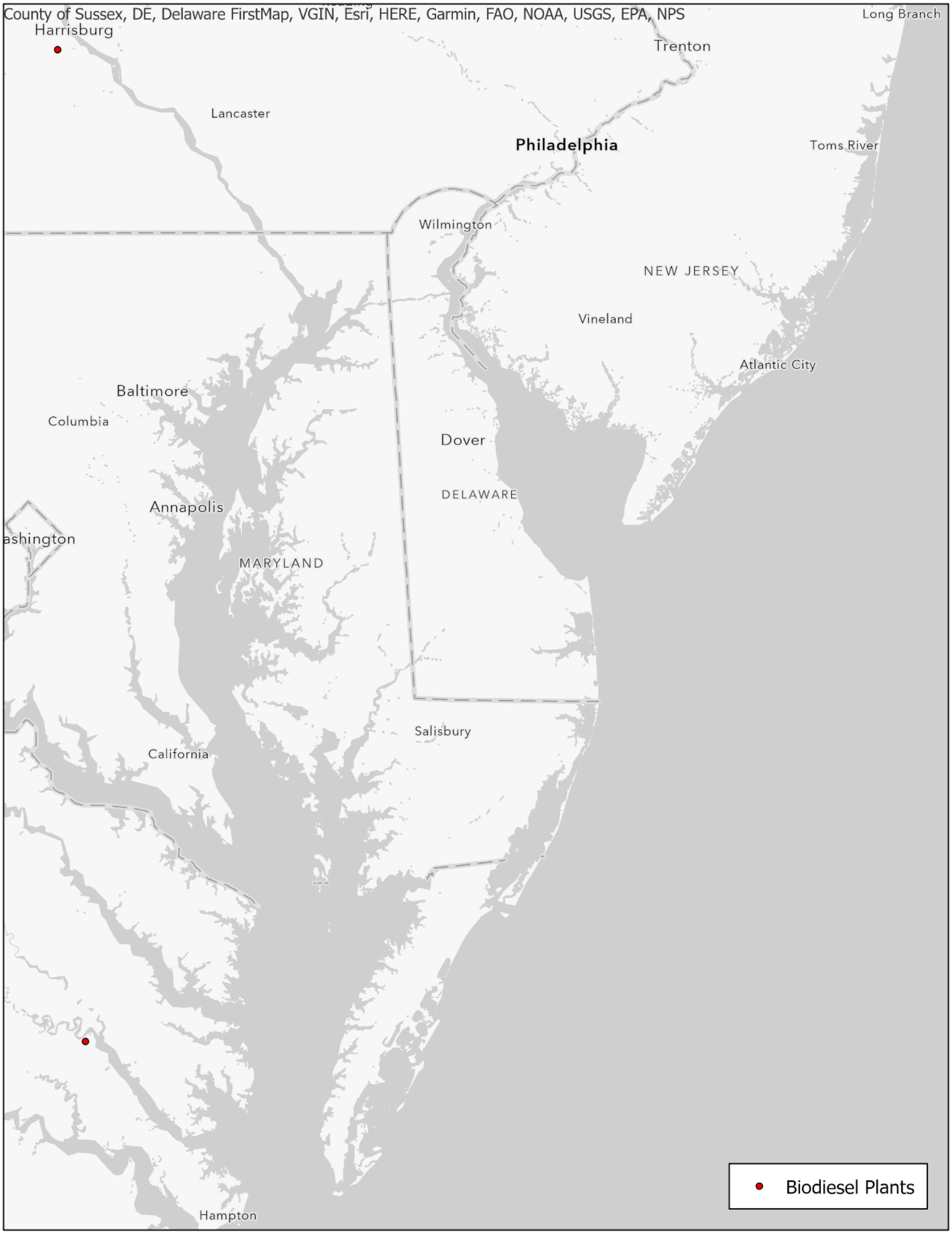
Map 6. LNG Terminals Mid Altantic



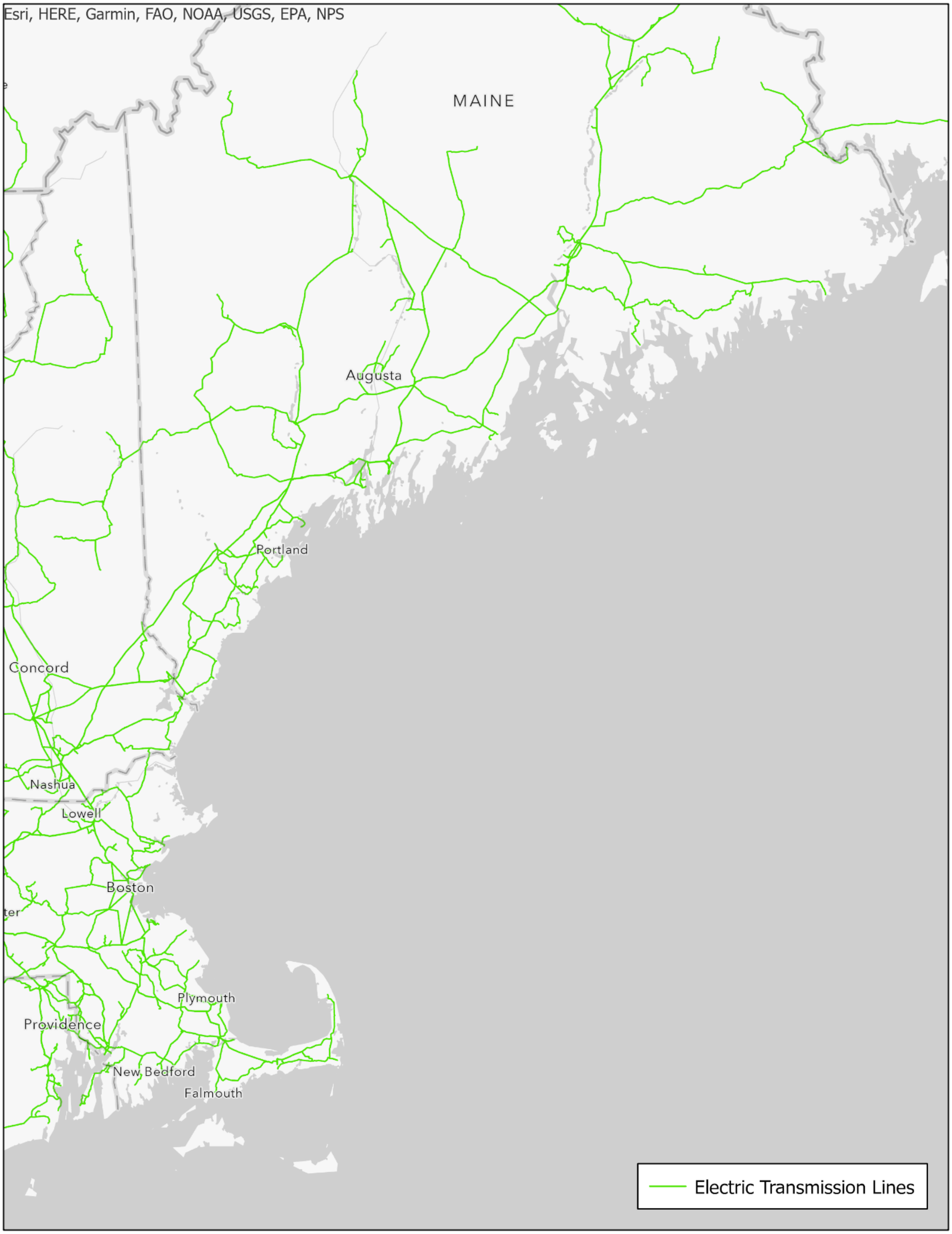
Map 7. Biodiesel refineries Northern New England

Map 8. Biodiesel refineries Southern New England

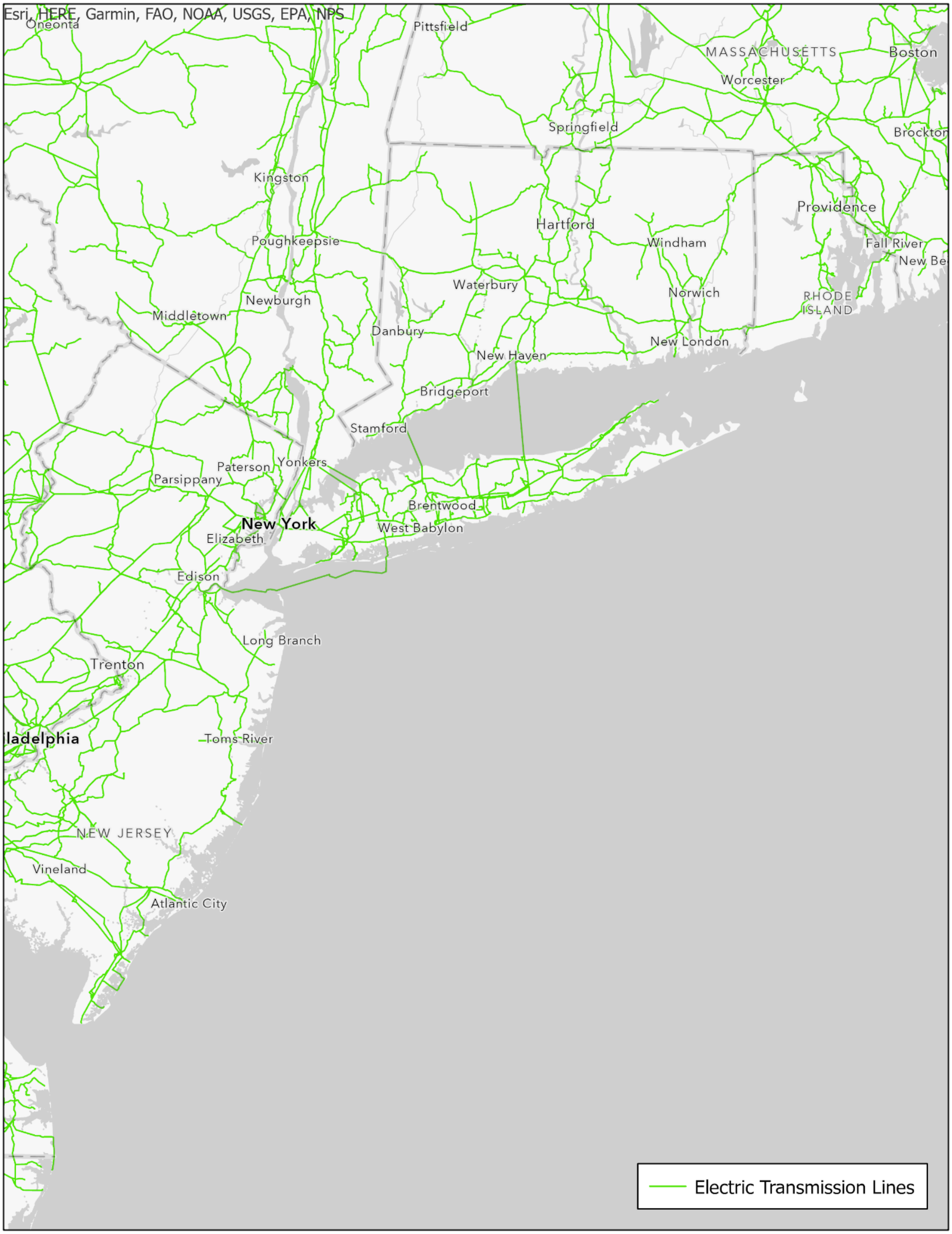
Map 9. Biodiesel refineries Mid-Atlantic



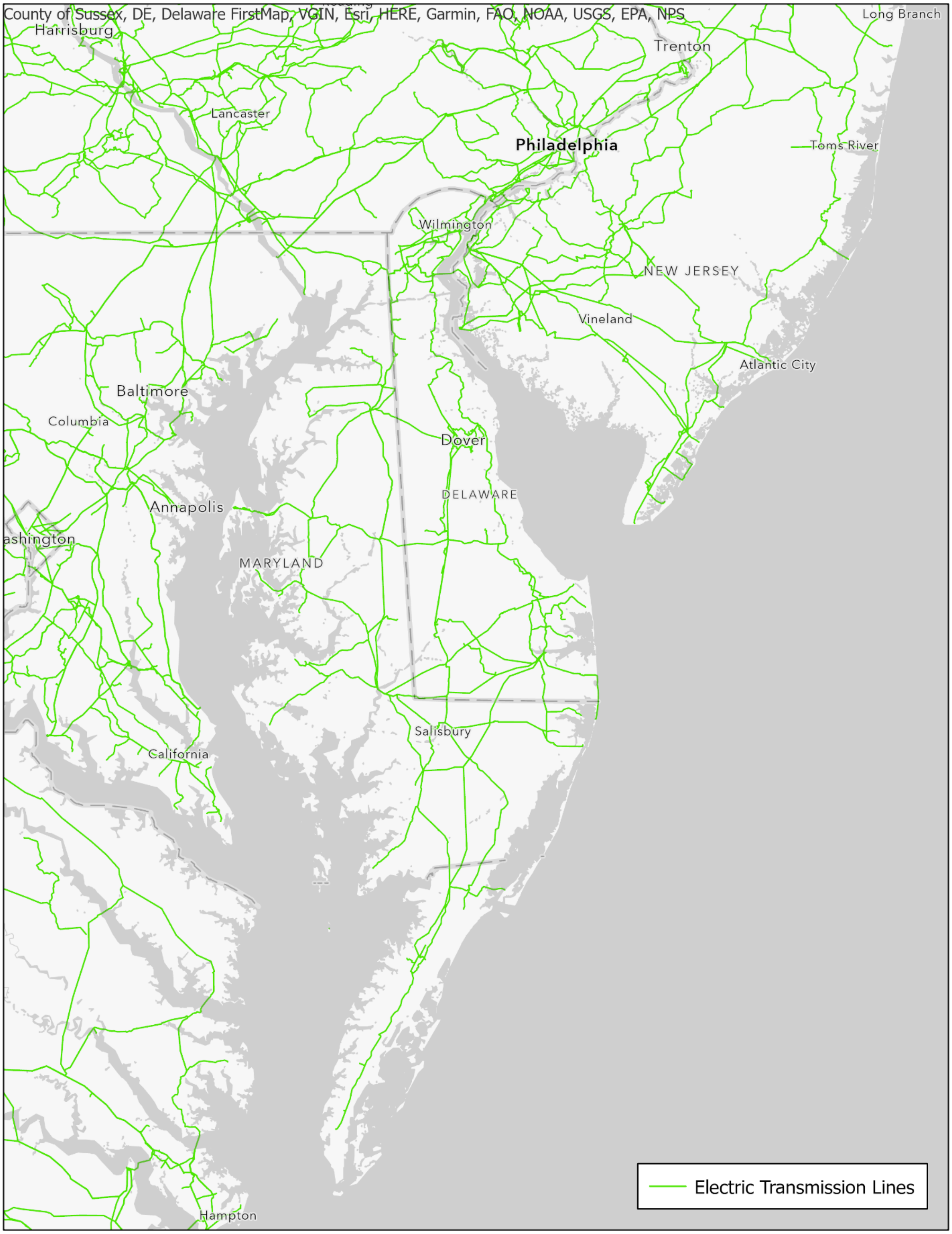
Map 10. Electric Grid Northern New England



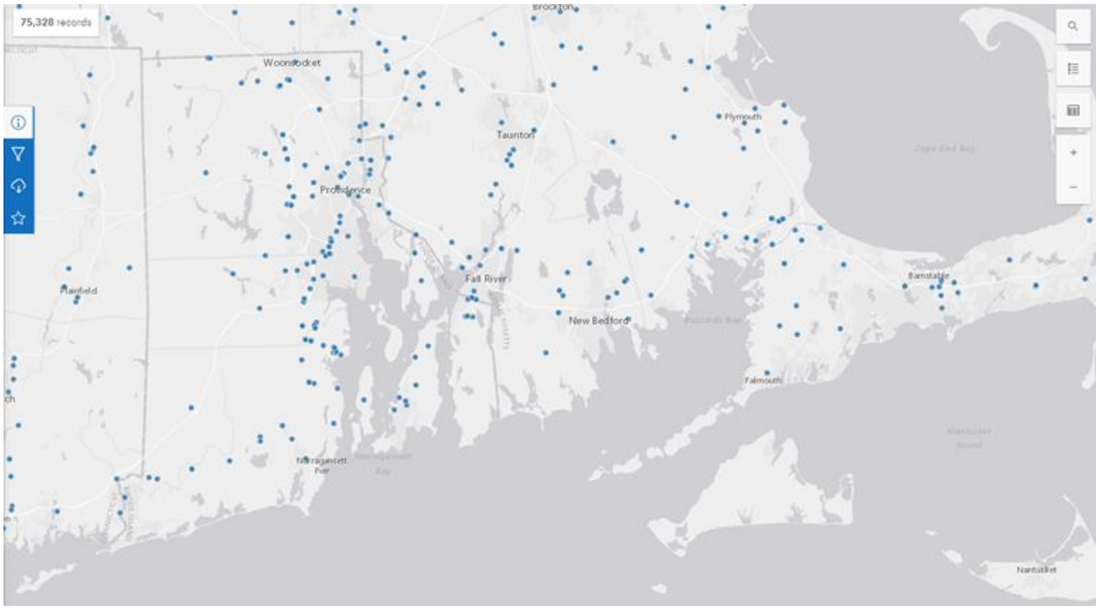
Map 11. Electric Grid Southern New England



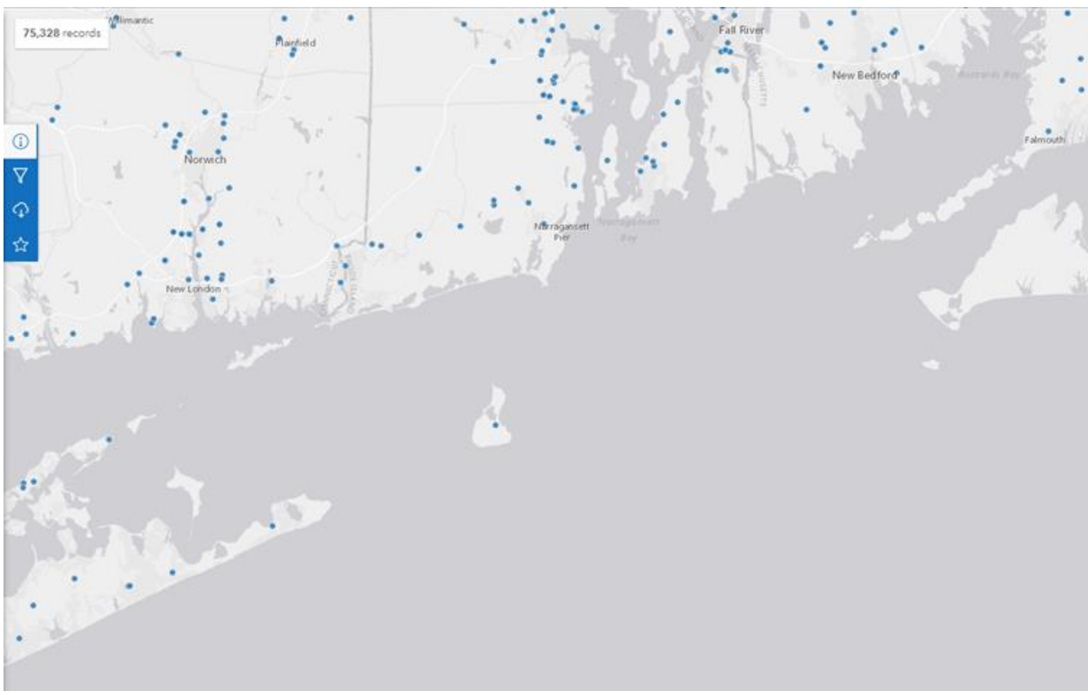
Map 12. Electric Grid Mid Atlantic



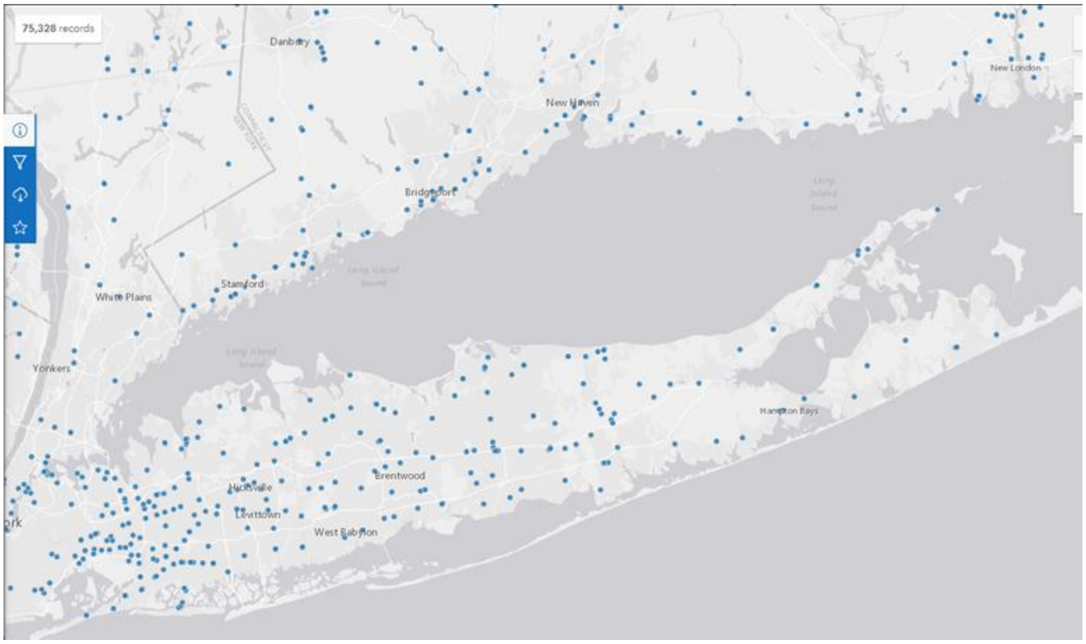
Map 13. Electric Substations New England



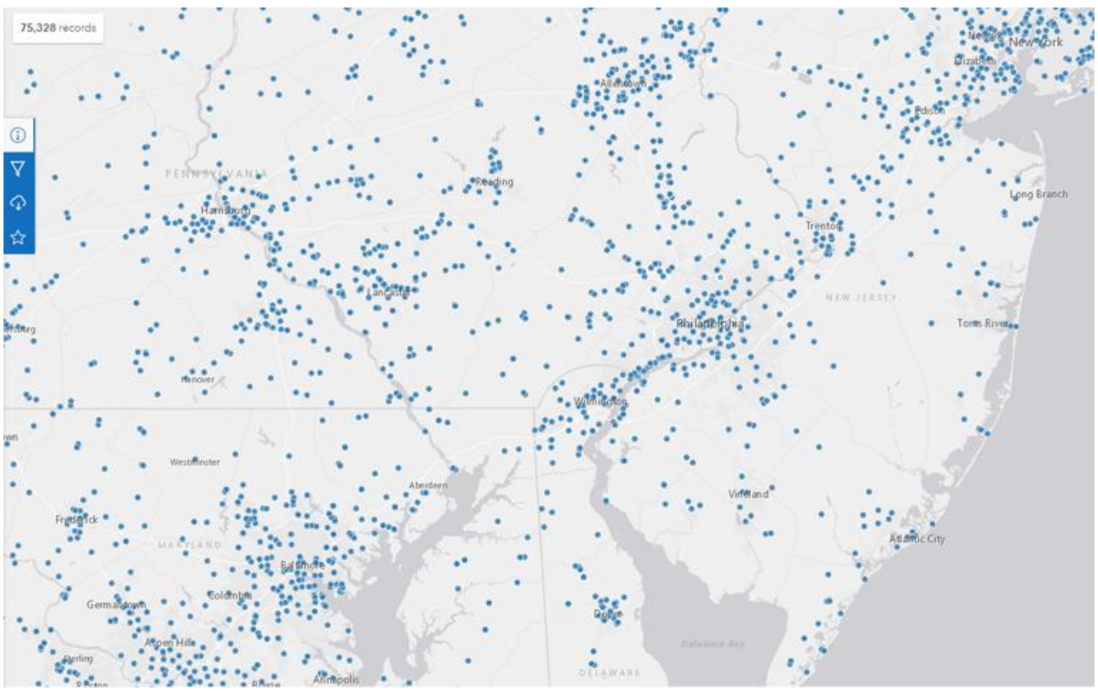
Map 14. Electric Substations New England Enlarged



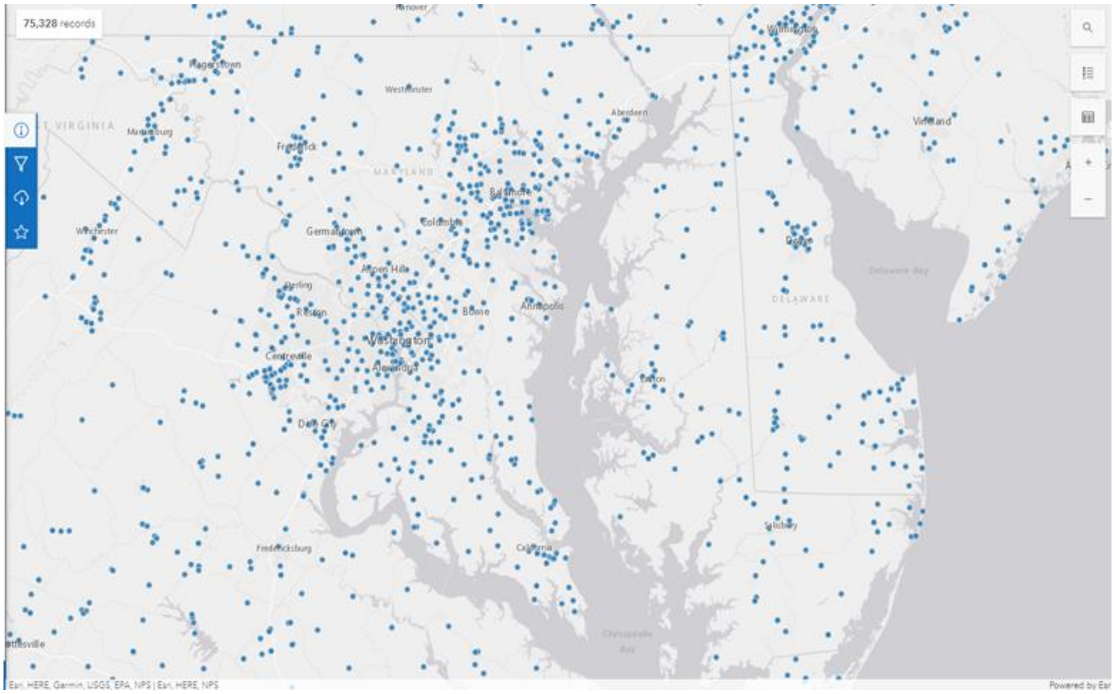
Map 15. Electric Substations New York Area



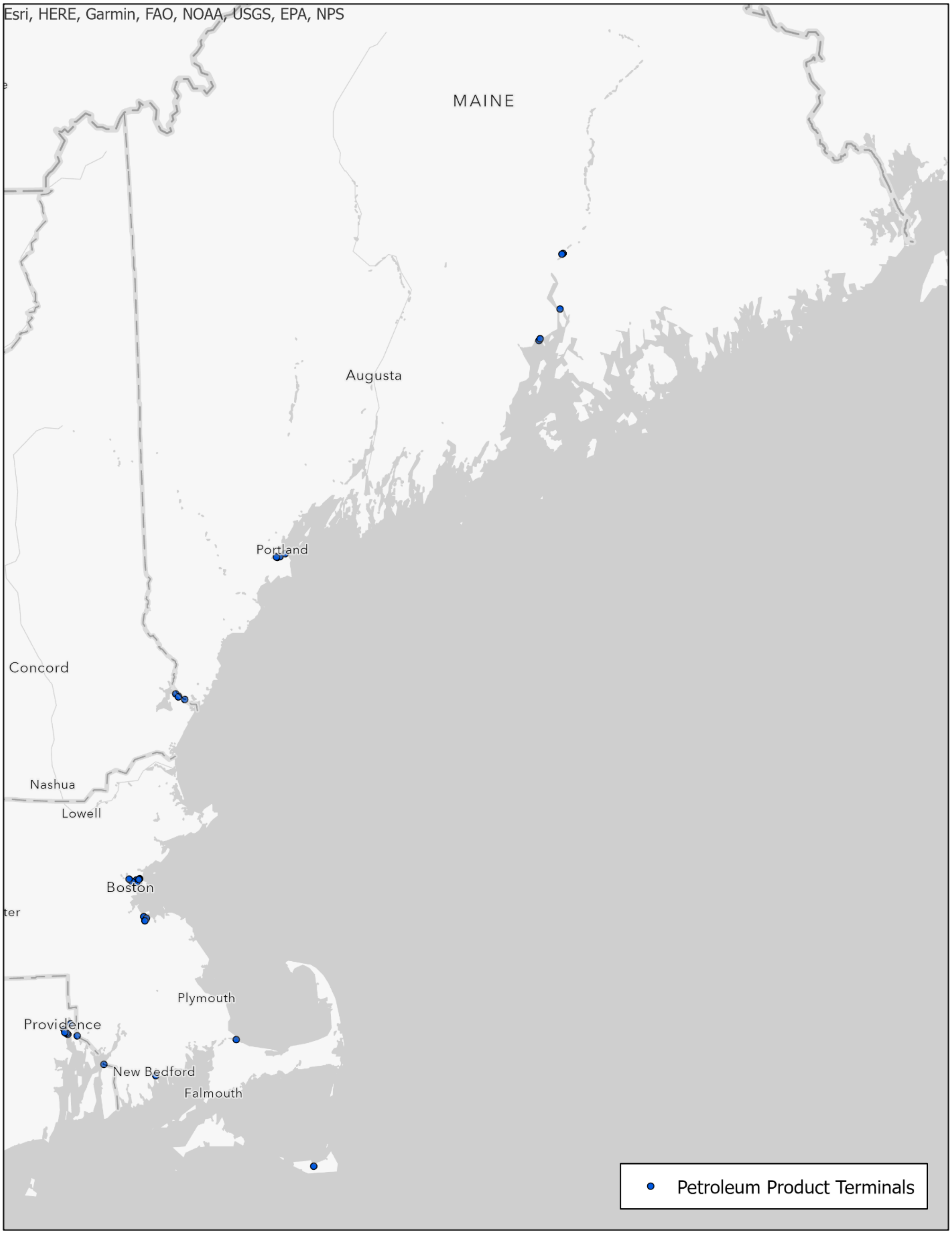
Map 16. Electric Substations Mid Atlantic Enlarged



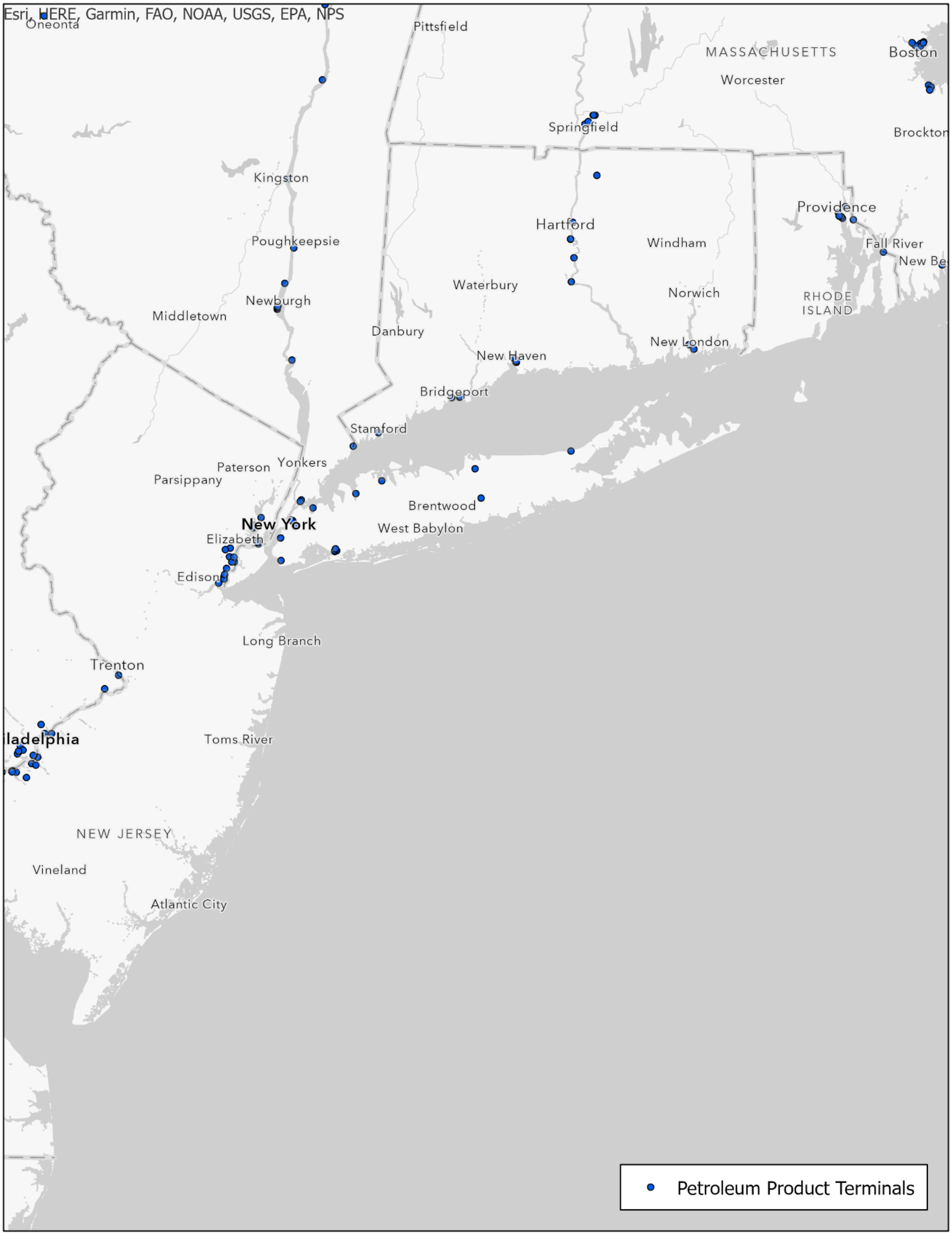
Map 17. Electric Substations Mid Atlantic



Map 18. Petroleum Terminals Northern New England



Map 19. Petroleum Terminals Southern New England



Map 20. Petroleum Terminals Mid Atlantic