# Port Decarbonization Survey: Trends and Lessons Learned

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# A. INTRODUCTION

## A.I Importance of Port Decarbonization

Maritime transportation is the backbone of the global economy. More than 80% of the world's trade volume is carried by sea, and the sector is expecting more than 2% annual growth for the next five years [1]. Despite the industry's indispensable position, climate change has brought new challenges to bear. Maritime transportation is often labeled a "hard to abate" industry, and the International Maritime Organization (IMO) estimates that greenhouse gas (GHG) emissions could grow to as high as 130% of 2008 levels by 2050 unless alternative action is taken [2]. By one estimation, ports emit around 2% of global carbon dioxide ($CO_2$) emissions [3].

While the maritime industry has focused squarely on emissions from ocean-going vessels (OGVs), relatively less attention has been given to port emissions. These emissions are difficult to measure, in part because ports' emissions come from sources outside of direct control of the port, including vessels, rail and trucks.

With these pressing environmental developments, due to their strategic location at the interface between land and sea, ports play a crucial role in the integration of global supply chains by ensuring seamless connection to international markets. More than ever before, ports are expanding their attention beyond logistics and into mitigation strategies.

## A.II Goals and Objectives of the Publication

This report aims to provide a concise but insightful update on the port decarbonization landscape. It contains information on trends and lessons learned that will help ports, terminal operators, vessel operators, community stakeholders, policymakers and others work together toward maritime decarbonization targets.

The unique collaboration between the American Association of Port Authorities (AAPA) and the American Bureau of Shipping (ABS) provides an opportunity to join perspectives from both port authorities and vessel operations experts. An advisory group of 15, including AAPA members, ABS personnel, and industry, was formed to support the project in reviewing the survey questions, draft and final report.

As part of the project, a survey with 25 questions was prepared and shared with all the AAPA port authority members for feedback. The survey results and observations are covered in section B of the report. Further, follow-up personal interviews were conducted with 12 port authorities to discuss their responses and experiences in detail. The observed trends, brief review of relevant technologies and recommendations are covered in sections C (Trends in Technologies and Best Practices) and E (Policy Recommendations) of the report. The regulatory landscape and grant funding opportunities are covered in section D. Finally, policy recommendations and conclusions are included in sections E and F respectively. Section G provides a list of resources and references.

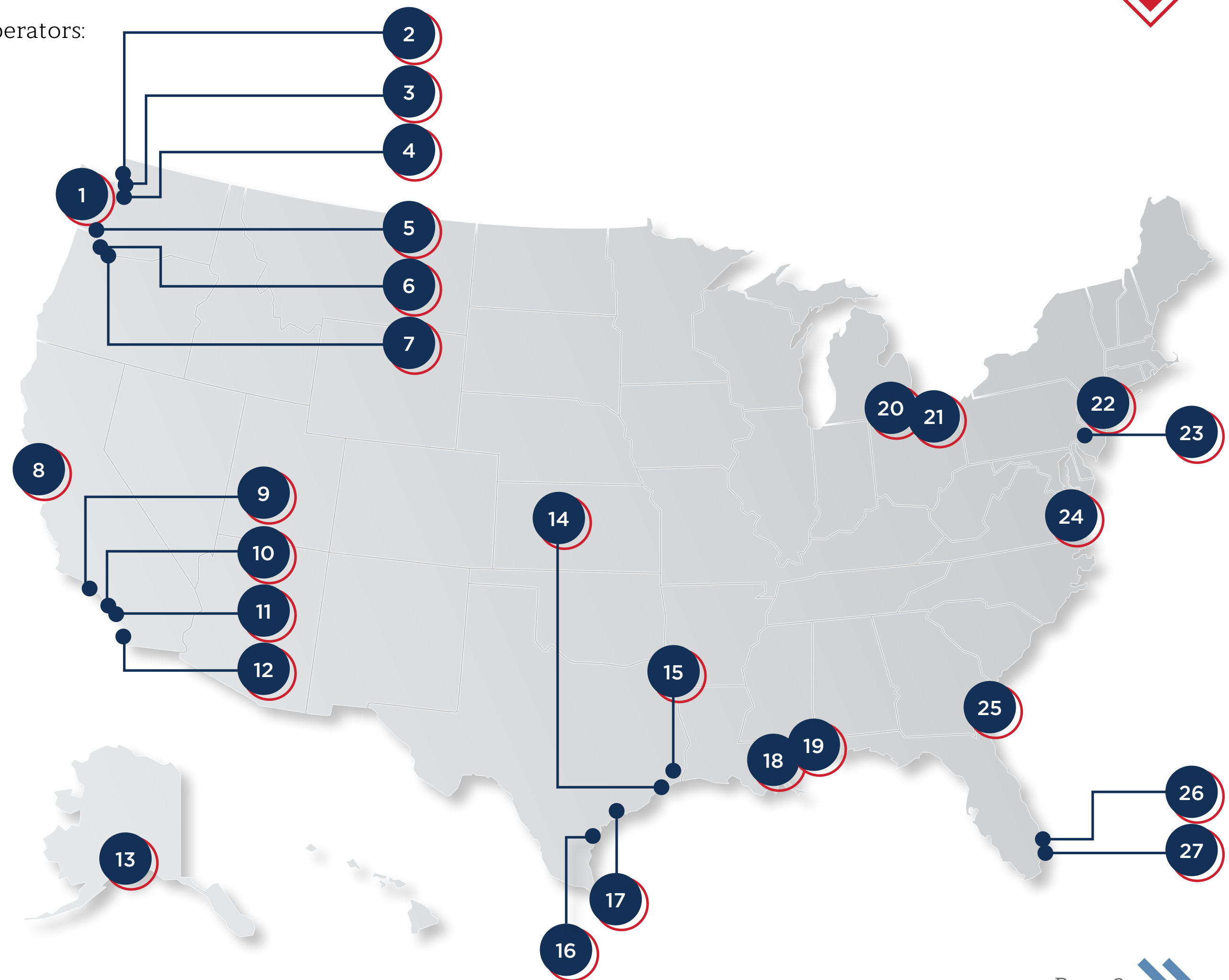
A central goal of this report is to provide a snapshot of current trends and near-term goals. While much work has been and needs to be done on long-term plans and strategies for port decarbonization, this report is focused on the here and now. What is working, what is not and what can the maritime industry learn from projects and planning efforts currently underway at America's ports?

# B. SURVEY RESULTS AND INTERPRETATIONS

A survey with 25 questions was shared with all AAPA members and we received responses from 27 unique ports and two terminal operators. Questions 1 and 25 were personal details (with identifying information) and therefore not included in the report.

Responses were recorded from the following ports and terminal operators:

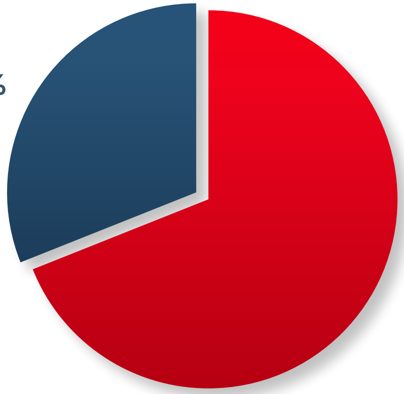
1. Port of Grays Harbor
2. Port of Everett
3. Port of Seattle
4. Northwest Seaport Alliance
5. Port of Longview
6. Port of Vancouver USA
7. Port of Portland, OR
8. Port of Oakland
9. Port of Hueneme
10. Port of Long Beach
11. Port of Los Angeles
12. Port of San Diego
13. Don Young Port of Alaska
14. Port of Galveston
15. Port of Beaumont
16. Port of Corpus Christi
17. Calhoun Port Authority
18. Port of New Orleans
19. Port of Pascagoula
20. Toledo-Lucas County Port Authority
21. Port of Cleveland
22. The Port Authority of New York and New Jersey
23. South Jersey Port Corporation
24. The Port of Virginia
25. Georgia Ports Authority
26. Port Everglades
27. Port Miami
28. Crowley *(Terminal Operator)*
29. The Pasha Group *(Terminal Operator)*



The results and interpretations of the survey are as follows:

## QUESTION 2

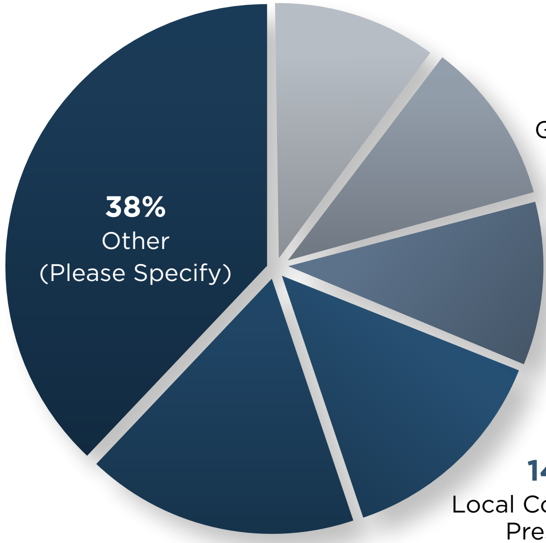
Have you set any internal or external decarbonization goals, including reduction of greenhouse gases or criteria pollutants?




Results show a majority of ports have set formal goals for decarbonization. There is some risk of selection bias since ports with ambitious decarbonization plans could be more likely to respond to the survey. However, it is important to note that ports with no decarbonization goals do not necessarily lack awareness. The survey and interviews conducted have demonstrated that small ports with limited budgets may not be able to afford expensive decarbonization initiatives. Of respondents with a decarbonization goal, eight have net-zero or carbon-neutral goals, including five with goals addressing both emissions in and out of the ports' direct control. Seven others have set other decarbonization goals. While often complementary, plans and technologies to mitigate GHG and criteria pollutants are distinct. A future study could measure differences in ports' plans related to different categories of emissions.

## QUESTION 3

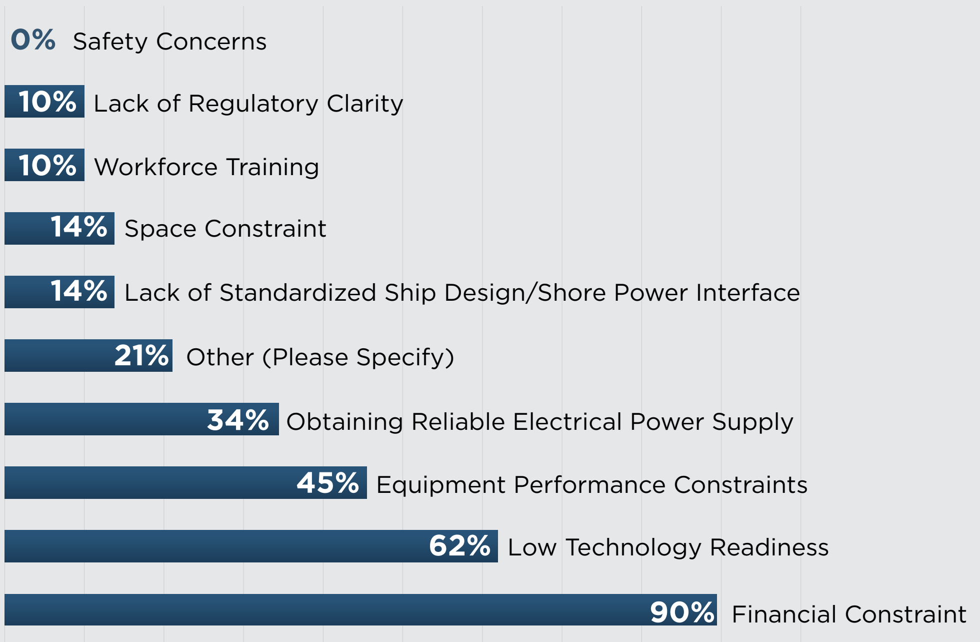
What has been the biggest driver for your decarbonization efforts?




Question three highlights the broad variety of factors that motivate port decarbonization. When presented with five options, 38% of respondents chose "other." Among these respondents, seven ports cited internal commitments as the leading motivator of decarbonization, which stands out as the most common answer. Three ports indicated that all options were motivators. The fact that no one motivator leads above the rest shows that there are multiple compulsive reasons for ports to decarbonize. Pressure from community stakeholders and government are powerful motivators, but corporate commitments and customer demand also make decarbonization good for business.

## QUESTION 4

What are the biggest hurdles to date, if any, faced in decarbonizing? Please select three.

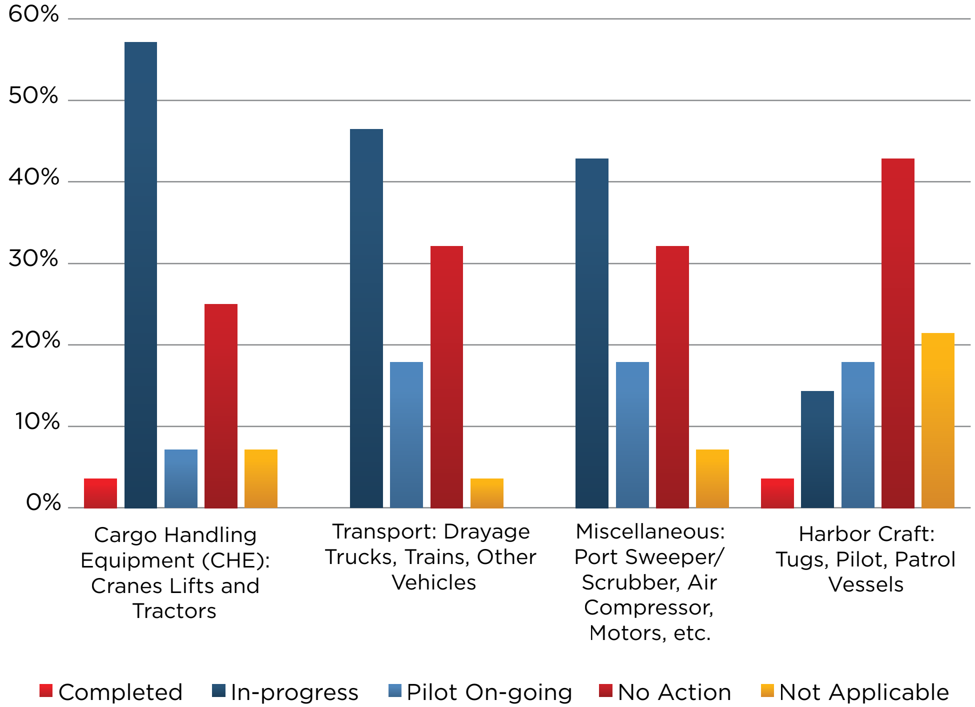



There are more than enough challenges to go around in port decarbonization, so the survey asked respondents to choose the three biggest hurdles. Unsurprisingly, financial constraints stood out as the most common response (90%). Low technology readiness and equipment performance constraints are the second (62%) and third (45%) most common responses, while obtaining a reliable electrical power supply comes in fourth (34%). The implication is clear: compared to traditional equipment, decarbonized alternatives require significant investments to pilot, demonstrate proof of concept and certify operational viability. These are challenges that will need to be overcome not just by ports, but by a broad range of supply chain partners, if ports are to achieve decarbonization goals. Among "other" respondents, a few ports mentioned the uncertainty in the future alternative fuel trends and business constraints to minimize risk on capital investment, while others are still building knowledge and just getting started.

## QUESTION 5

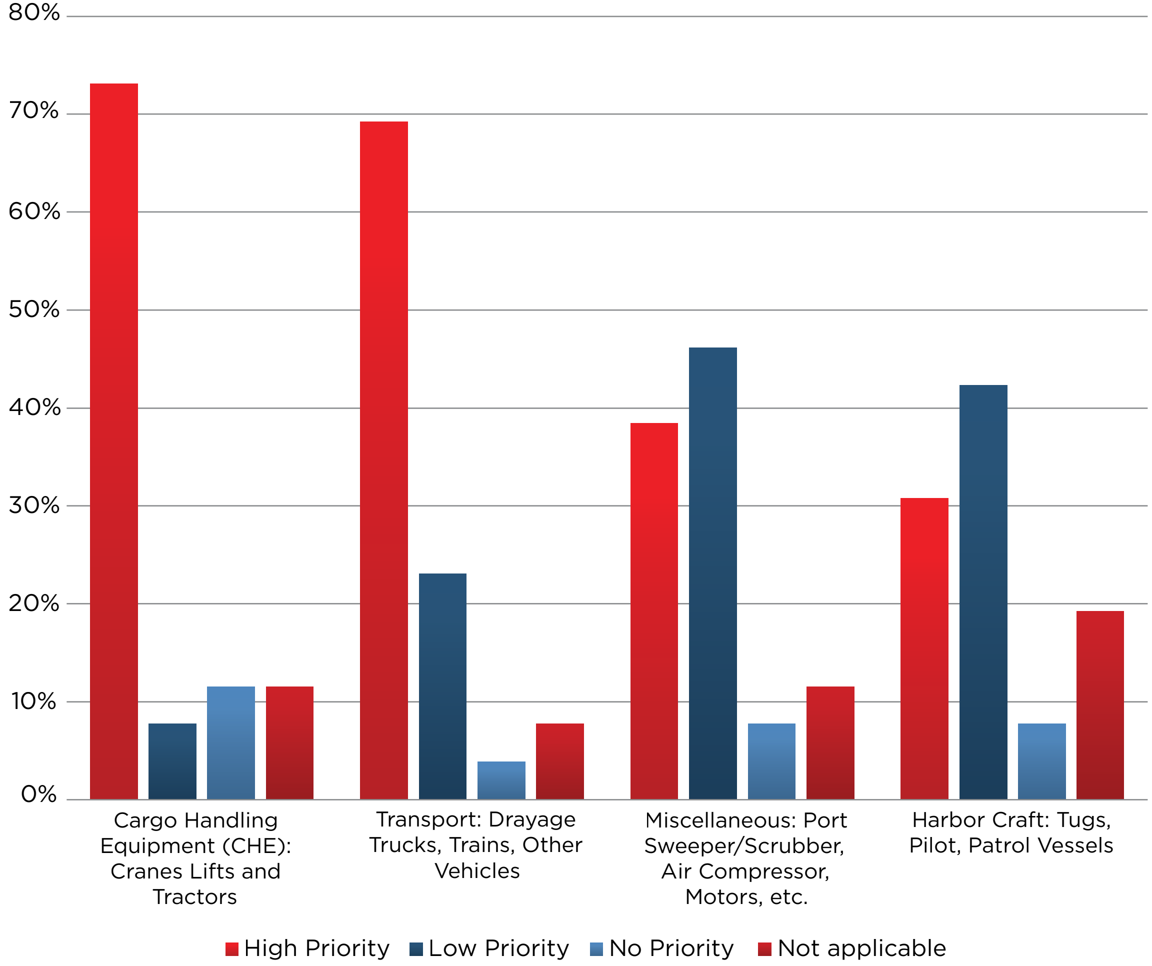
Categorize the current status for decarbonization of equipment based on your goals.

Harbor crafts present the larger share of "no action," followed by miscellaneous equipment. Cargo handling equipment (CHE) presents the highest share of "in progress" decarbonization projects, with fewer ports in progress on transport, miscellaneous and harbor craft. These results are consistent with literature reviews, which suggest that most port decarbonization appears to focus on CHE electrification. The survey, interviews and other research indicate there is less of a focus on decarbonizing harbor crafts. While port authorities typically work closely with private terminal operators to procure CHE, they have a smaller stake in trucks and trains, with harbor crafts usually outside of ports' direction and control. As will be discussed further below, harbor craft decarbonization technology is also less developed than other types of port equipment.



## QUESTION 6

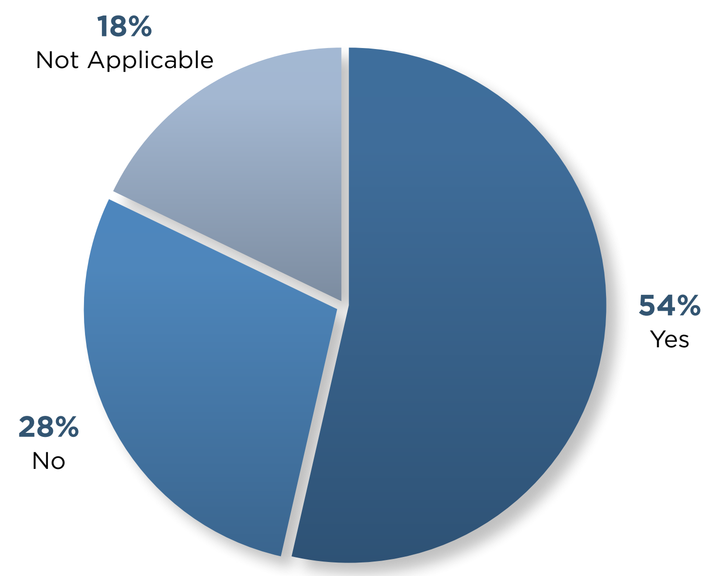
Categorize the future priority for decarbonization of equipment based on your goals.



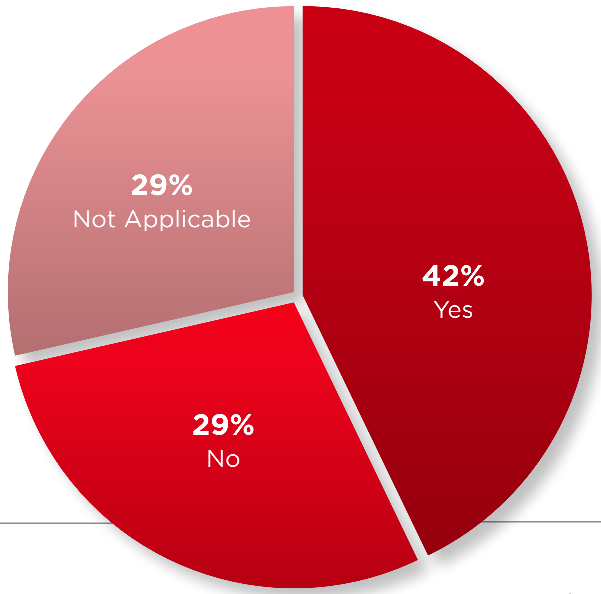

Expressions of ports' future priority for equipment decarbonization follows a similar trend as question five. Decarbonization of CHE and transportation equipment is of the highest priority, while miscellaneous equipment and harbor craft are a relatively lower priority for decarbonization.

## QUESTION 7

Have you faced space constraints when installing new charging stations and fueling systems for shoreside equipment?




Space constraints appear to be a major issue in the installation of new charging stations and fueling systems for shoreside equipment. Interviews indicate that terminal reconfiguration to allow for additional space can be costly and tends not to be in the cards for most ports. Equipment manufacturers and infrastructure planners will need to find creative solutions to charge equipment with minimal physical space. However, with 29% of respondents not facing space constraints, some ports have at least one advantage in their favor: ample space to work with for the installation of charging and fueling infrastructure.




## QUESTION 8

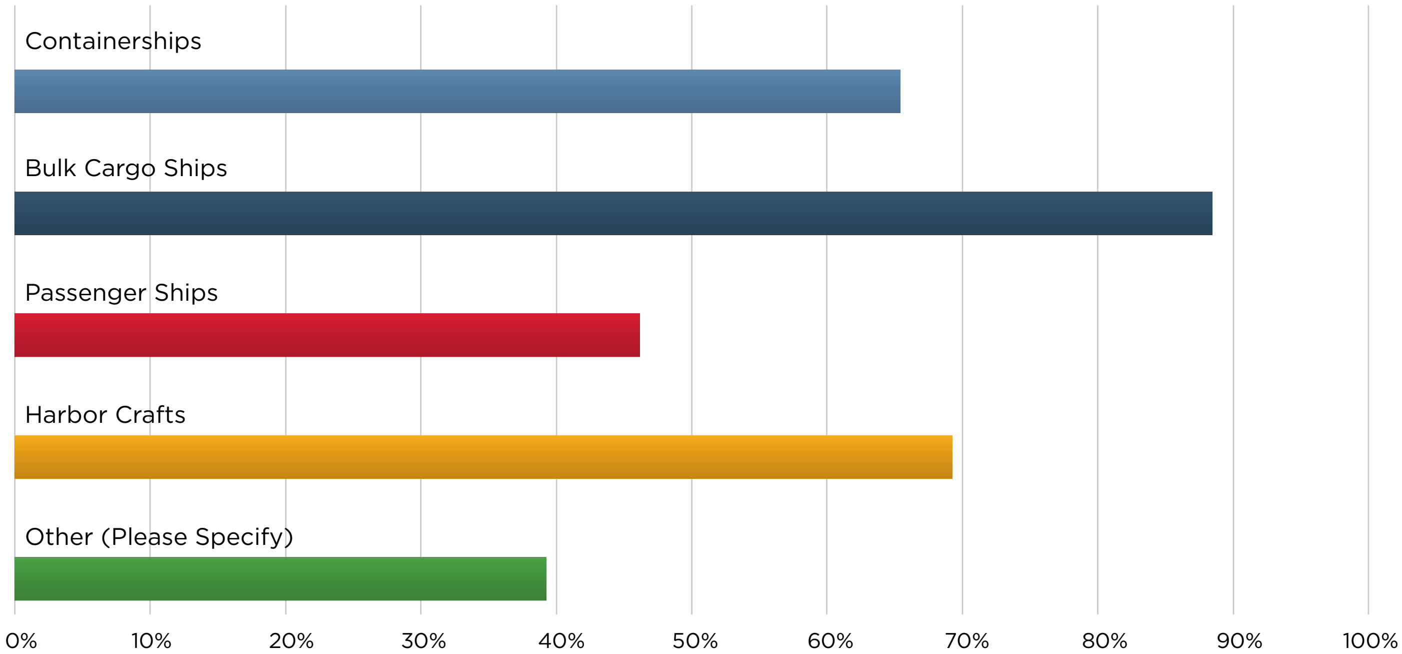
Was the cost for installation of new charging stations and transmission/distribution infrastructure supported by a local utility company or any other partner?

The port-utility relationship is key to the success of port decarbonization. Responses to question eight and interviews highlight that ports enjoy different levels of relationships and collaboration with their utility companies. With 42% of responding ports having received some financial support in the installation of charging infrastructure, many ports appear to have a good partner in utilities. However, levels of support can become complicated when you break up costs between charging stations and transmission infrastructure. In interviews, many ports related that while utilities support costs on the utility side of the meter, costs are mostly borne by ports on the customer side. We will expand upon finer points of the port-utility relationship throughout this report.

## QUESTION 9

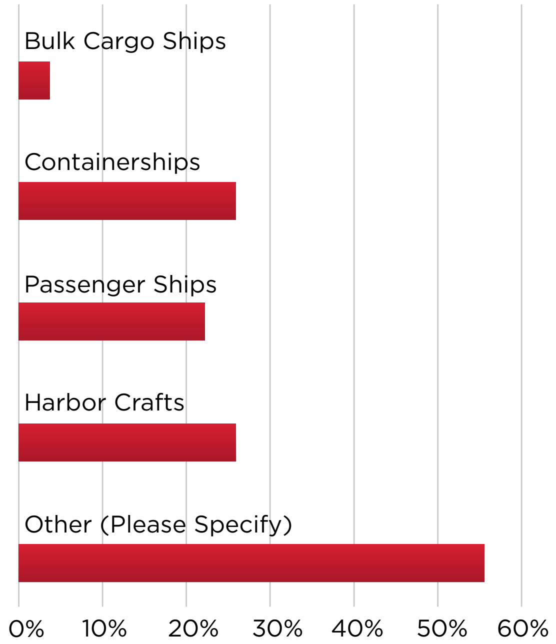
What types of vessels are currently coming into your port/terminal? Select all that apply.

Responses to question nine show that the types of vessels and terminals are well represented in the various ports in this study, thereby increasing reliability of the general results. As most ports accommodate different types of vessels at different terminals, future studies on specific terminals are recommended as they may reveal different operational level trends. "Other" responses include several ports serving roll on-roll off (ro/ro) vessels. Two ports also serve military vessels, and two serve commercial fishing vessels, which each present unique decarbonization challenges.



## QUESTION 10

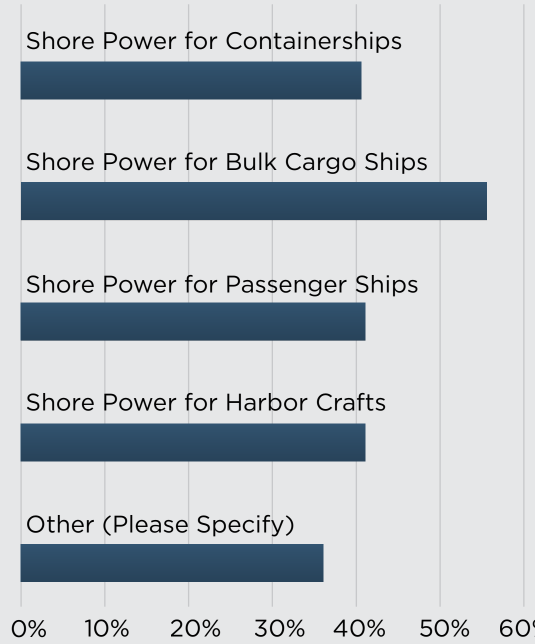
What is the current availability of shore power supply at berth? Select all that apply.




Question 10 suggests that shore power for bulk vessels is not yet commonplace. Shore power for containerships, passenger ships, and harbor crafts are about equally commonplace. Among "other" respondents, two indicated shore power for military berths, one at a lay berth, and six provide shore power for smaller vessels, like yachts, fishing vessels or paddle wheel riverboats.

## QUESTION 11

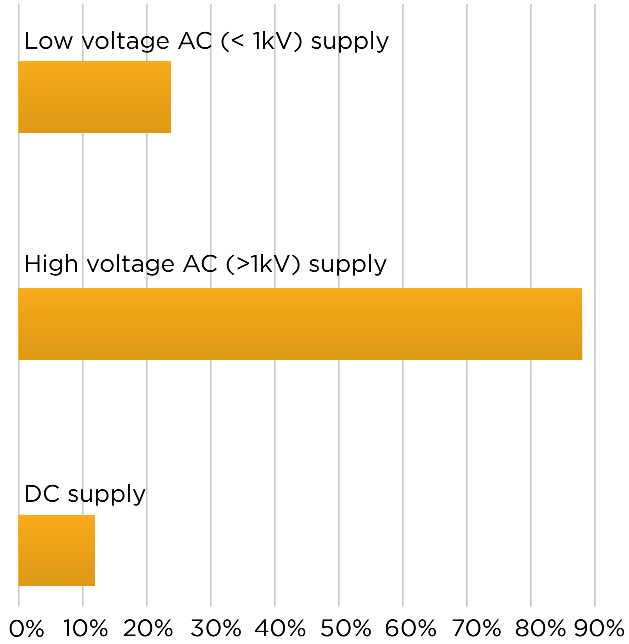
What type of shore power connections do you plan to have in the future? Select all that apply.




While 41% of respondents plan to install containerships, passenger ships and harbor craft shore power access, 54% of ports plan to install shore power for bulk vessels. This represents progress compared to the status quo, with only one port in question 10 indicating the availability of shore power for bulk vessels. Work must be done by port authorities, terminal operators, ocean carriers, shipbuilders and others to standardize technology for bulk vessel shore power systems, as has been done for other types of vessels covered in Table 1. Among "others," five ports plan to install shore power for ro/ro vessels.

## QUESTION 12

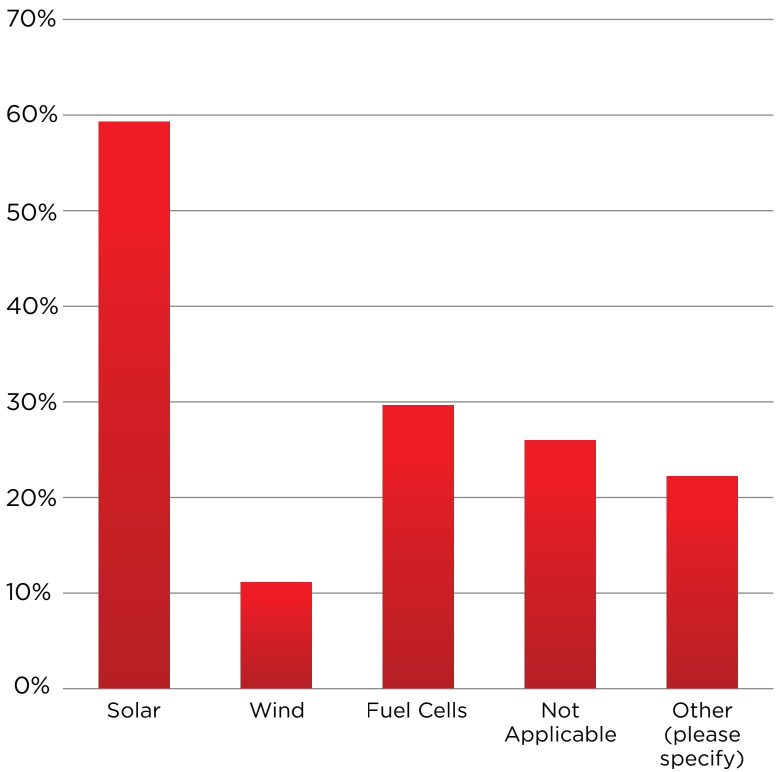
What type of shore power connections do you plan to support in the future? Select all that apply.



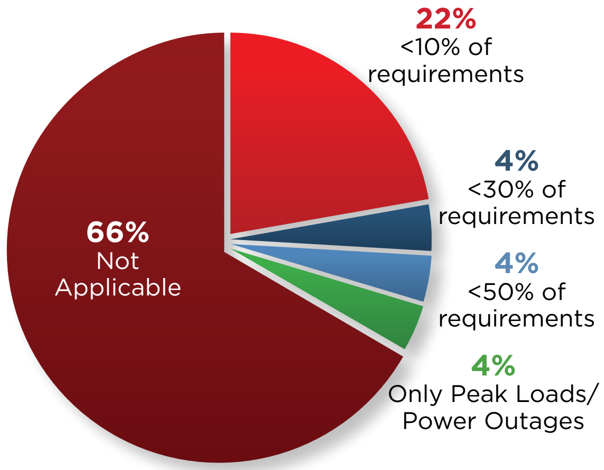

Currently, the number of ports providing low voltage (LV) shore power capability is much higher than the ports supporting high voltage shore power. Results of question 12 suggest that ports intend to build HV shore power supply systems targeting bulk carriers, container ships, and passenger ships. A quarter of ports also plan to build LV shore power connections generally used by smaller cargo vessels and harbor crafts. We note that 10% of ports plan to install DC shore connection/DC charging stations that can support fully electric vessels, generally yachts and ferries, operating on DC power systems.

## QUESTION 13

If you have plans to generate power locally, please select the power source.




Solar power generation presents a particularly attractive option for ports. Solar panels can be installed on the roofs of warehouses, offices and other structures. Co-locating local power generation with equipment in need of charging can ease ports' demand on the electric grid. While many ports are involved in the supply chain for offshore wind farms, comparatively few ports plan to install wind turbines on or nearby port terminals for renewable energy options. Among "other" respondents, a few mentioned ammonia, hydrogen and liquefied natural gas (LNG) as fuel sources for local power while others are still investigating.

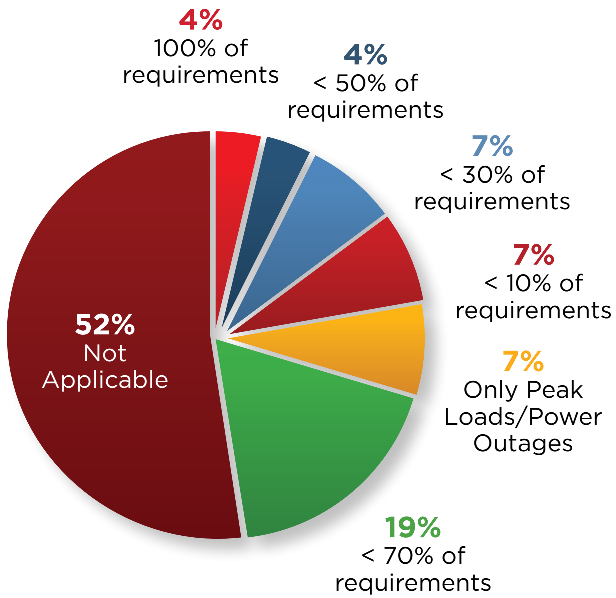



Percent of total port's power requirements

## QUESTION 14

What is your current status for local power generation?

The results from question 14 are clear: few ports are currently employing local power generation, and those that are, are not doing so on a large scale. A small number of ports are generating a significant amount of power, suggesting that there may be opportunities for ports to expand local generation in the right circumstances.




Percent of total port's power requirements

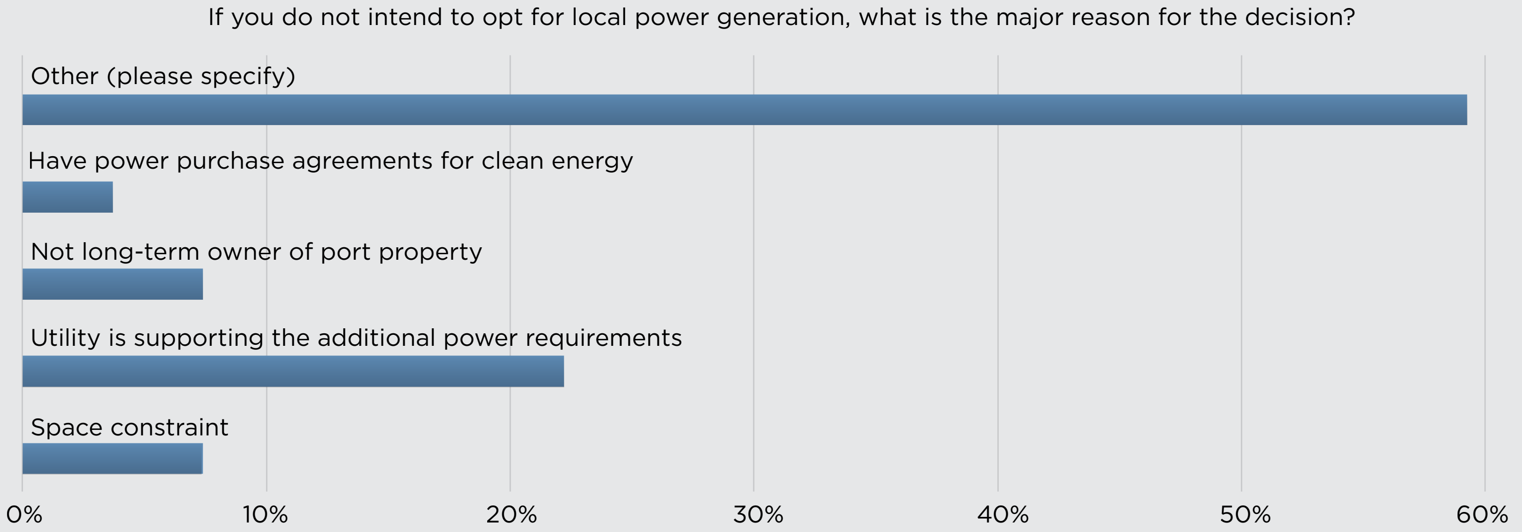
## QUESTION 15

What are your approximate goals for future local power generation?

While very few ports are currently employing local power generation on a large scale, question 15 shows that, while not a majority, many ports do have ambitious plans to generate most of their power needs locally. As demand for power increases with electrified assets, the prospect of supplying a majority of power from local sources is appealing. Nevertheless, most respondents selected "not applicable," indicating that local generation is not in their plans. While local generation may be a strong substitute for utility connections in some ports, it should not be viewed as a panacea for the industry.

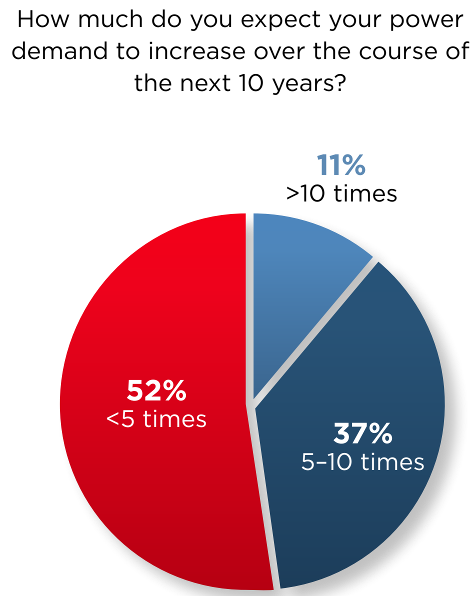
## QUESTION 16

Among "other" respondents, several are still investigating whether to invest in local power generation. Of those who have decided not to invest in local power generation at this time, reasons cited include cost and a combination of the other available question 16 options. Two "other" respondents indicated that their utility provides them with sufficient low- or zero-emission electricity.



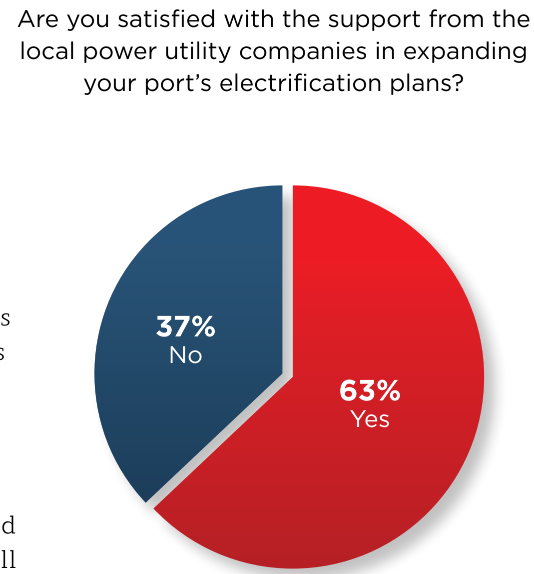

## QUESTION 17

While 52% of respondents expect power demand to increase by less than five times over the next 10 years, 48% expect demand to increase by over five times. There are three chief conclusions to draw. First, about half of ports expect power demand to grow by over five times is a formidable trend, indicating that power needs at ports are projected to skyrocket. Second, further research will be needed to measure this trend more precisely to forecast the incremental demand increases and trends. Finally, 11% of respondents expecting power demand to increase by more than 10 times suggests that significant changes may be needed in transmission planning in some regions.



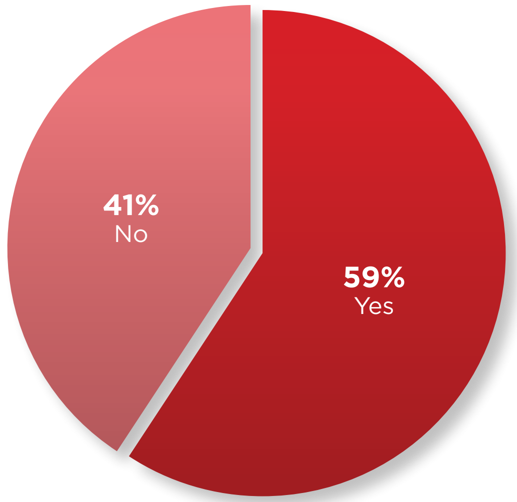

## QUESTION 18

The relationship between utilities and ports is crucial to port decarbonization. Feedback heard from ports in the verbal interviews will be described in the policy recommendations section that follows, but question 18 summarizes the relationships as a mixed bag. Most port authorities report having a satisfactory level of support (speed, responsiveness, infrastructure readiness) from utilities. However, 37% report an unsatisfactory level of support, and those with satisfactory support still seek improvement.



## QUESTION 19

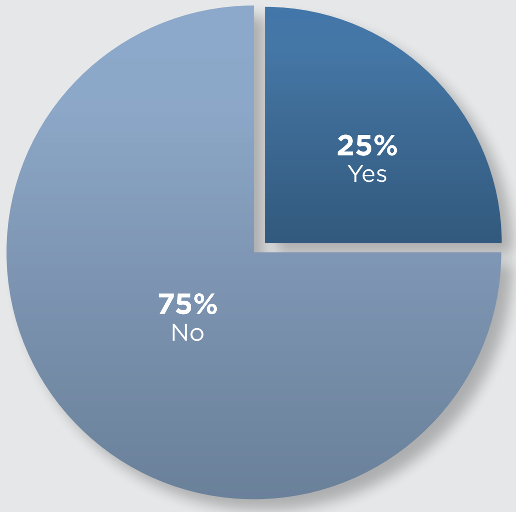
Is there a need for regulatory updates to support the ease of port electrification? If yes, please specify.




Question 19 highlights the divided motivations and pace of decarbonization across ports. Only 41% of ports do not feel there is a need for regulatory updates. Among respondents who feel there is a need for regulatory updates, three indicated that they would prefer decarbonization mandates to incentivize terminal operators or original equipment manufacturers (OEMs) to speed up production or adoption. Two respondents indicated Build America, Buy America rules should be eased, and two cited the need for permitting reform. The leading response was the need for greater cooperation between utilities and terminal operators, with six respondents.

## QUESTION 20

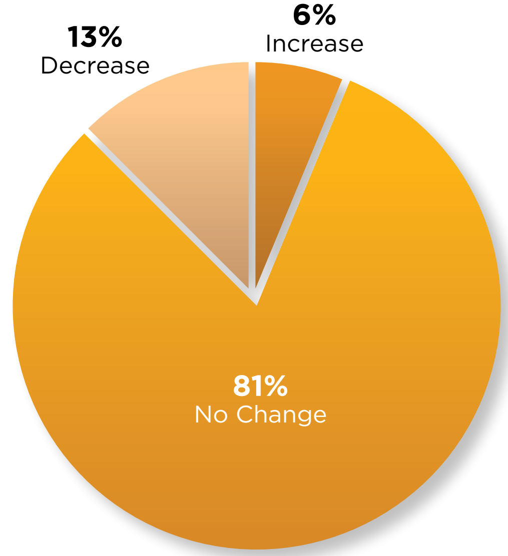
Have you faced shortages of electricity due to brownouts/blackouts after the introduction of electrified equipment?




The results of question 20 appear positive on their face; however, the issue of power shortages should be viewed as a critical challenge in port decarbonization. With 25% of respondents experiencing brown or blackouts, as forecasted demand increases as expected, port operations will be more dependent on the electric grid. This is a theme that came up frequently in interviews. Some interviewees cited that ship-to-shore cranes take at least an hour to repower after power has been cut off, effectively shutting down port operations.

## QUESTION 21

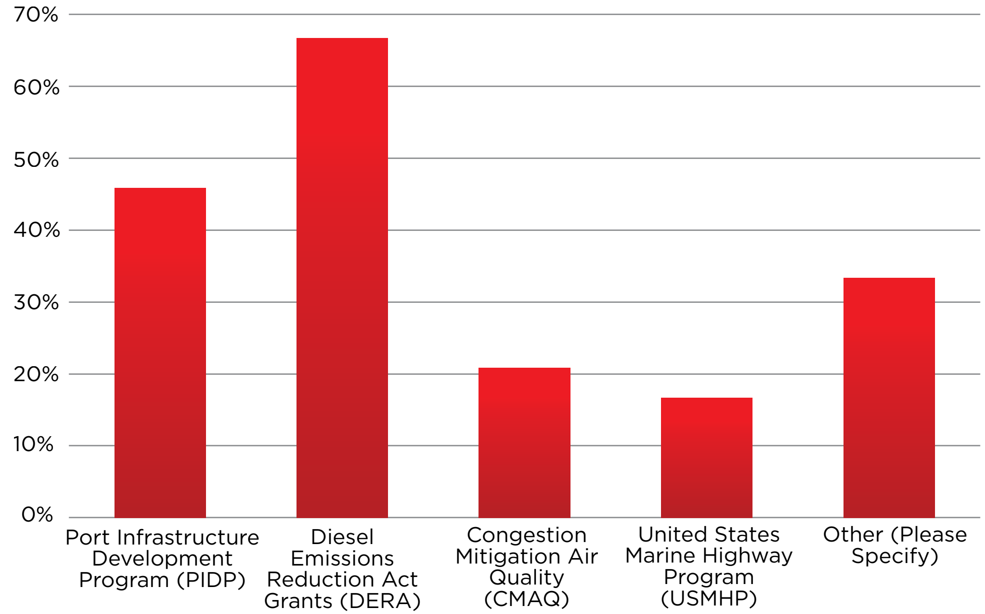
How has the cost of energy changed after the installation of local power generation/storage?




Question 21 aimed to elucidate whether the installation of local power generation and storage was proving to be an economic benefit for ports. While the installation of this technology is expensive, having power generated and stored on site should allow ports and their tenants to optimize utility rates and purchase power at the best prices. However, based on earlier questions, it seems that few ports have already installed this technology. More implementation and studies will be necessary to determine if ports can use local generation and storage to save a significant amount of money and energy in practice.

## QUESTION 22

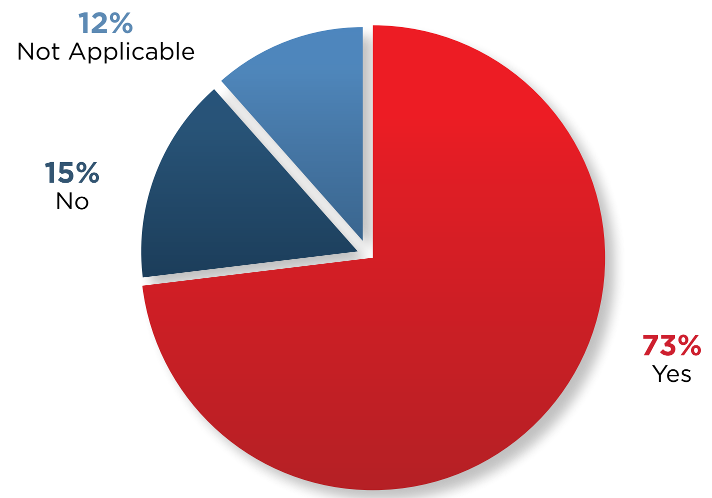
Select any federal funding programs you have used to fund port decarbonization projects. Select all that apply.




As discovered in question four, financial constraints are the biggest obstacle to port decarbonization. Grant funding is crucial, and thanks to the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA), there is more federal funding available than ever before. The Diesel Emissions Reduction Act (DERA) program is a leader, with over half of respondents receiving grant funds. The Port Infrastructure Development Program (PIDP), a mainstay of the port industry, was the second most popular federal program for port decarbonization. Congestion Mitigation Air Quality (CMAQ) and the U.S. Marine Highways Program (USMHP) also received significant responses. Not included in the survey is the Clean Ports Program, a new $3 billion Environmental Protection Agency (EPA) program funded by the Inflation Reduction Act (IRA). At the time of publication, two Notice of Funding Opportunities (NOFOs) for "Zero-Emission Technology Deployment Competition" and "Climate and Air Quality Planning Competition" were announced under the EPA Clean Ports Program. These NOFOs will soon become a leading source of federal funds for ports.

## QUESTION 23

Have you used any state, local or outside funding programs for decarbonization projects? If yes, please specify.




While much attention has been paid to the BIL and IRA, question 23 indicates that the vast majority of ports utilize non-federal sources of funding for decarbonization projects. The vast majority of "yes" responses reported specific state government funding programs, suggesting that ports should continue to advocate that their state governments provide port infrastructure funding.

## QUESTION 24

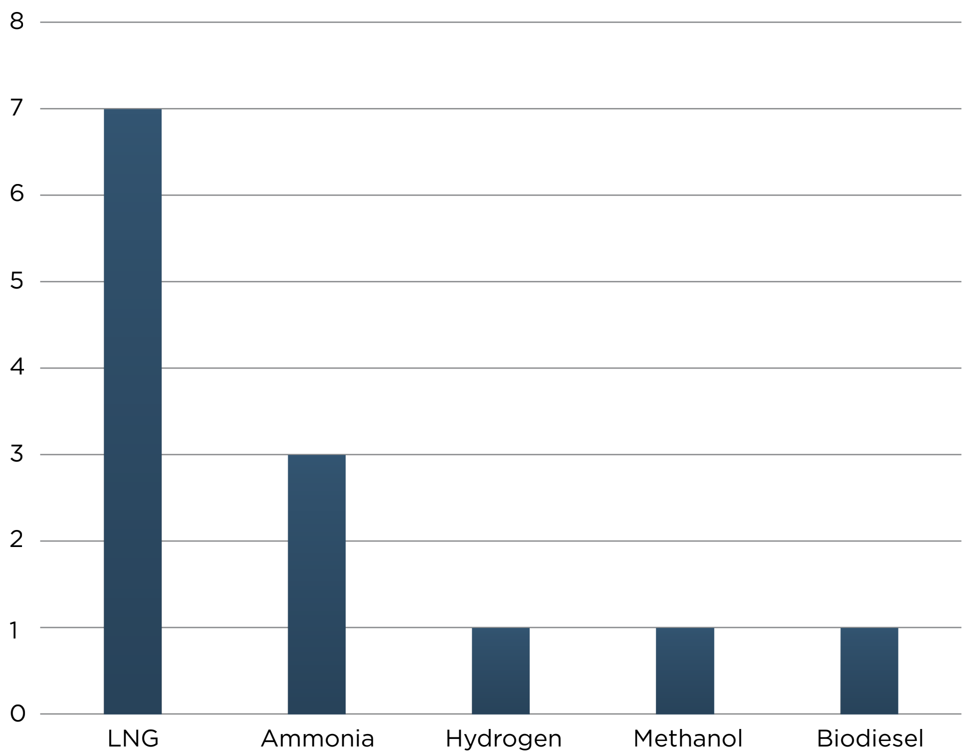
What additional support, if any, would be beneficial for your port to decarbonize?

Question 24 provided an opportunity for respondents to highlight any needs not captured throughout the survey. As expected, the most common response was the need for financial support for decarbonization, with 12 respondents. Four respondents indicated a need for electric grid upgrades, three indicated a need for funding specifically for pilot projects and three highlighted a need for regulatory coordination to spur technological development. Other responses included faster grant administration, matchmaking with OEMs, permitting reform, Buy American flexibility and workforce training.

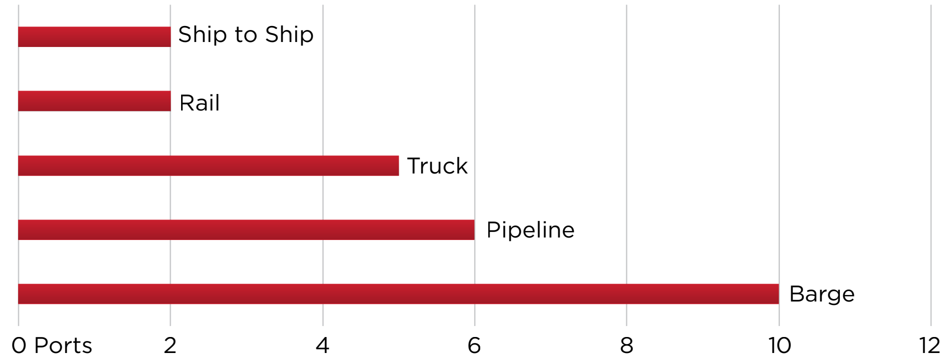
## AAPA Alternative Fuels Bunkering Survey

In this report, AAPA and ABS also sought to understand current offerings and plans to adopt alternative fuels in addition to electrified technologies. While electrification is a good option for some land-side equipment, other types of fuels will be necessary for the decarbonization of certain vessels. AAPA conducted a survey of its members in 2023 to measure their progress in using and planning for alternative fuels. Rather than repeat these questions in this report, which had mostly the same respondents, the results from 2023 are republished here. Thirty-six U.S. port authorities, marine terminal operators (MTO), and two international port authorities responded to this survey. Further information can be found through the citation in the references section. [4]

Do you plan to offer alternative fuel bunkering?

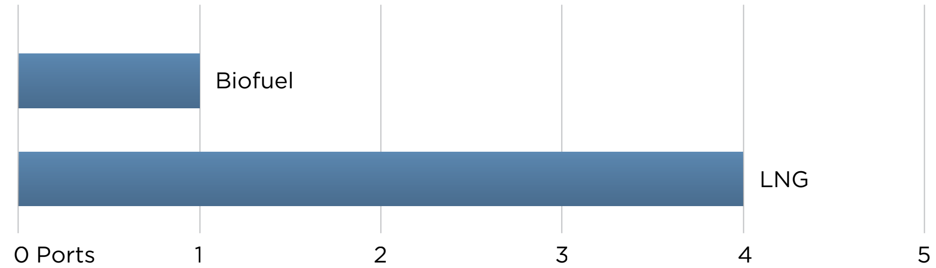



By what method are you delivering or plan to deliver the fuel?

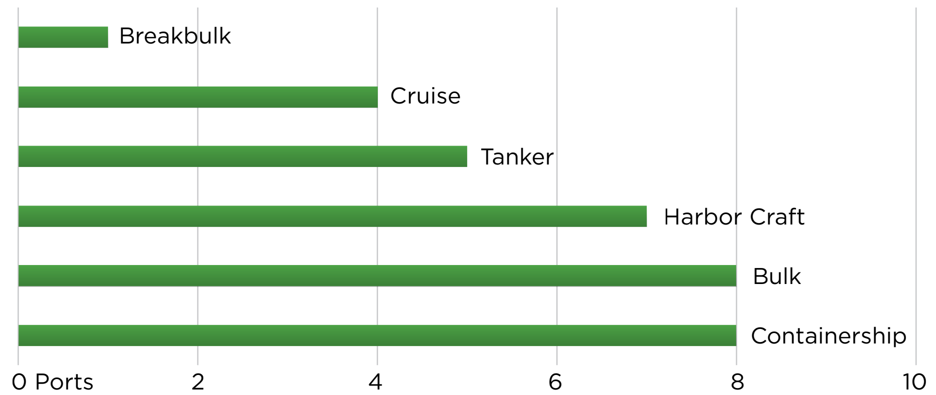



## Vessel Bunkering

Do you currently offer alternative fuel bunkering for marine vessels?

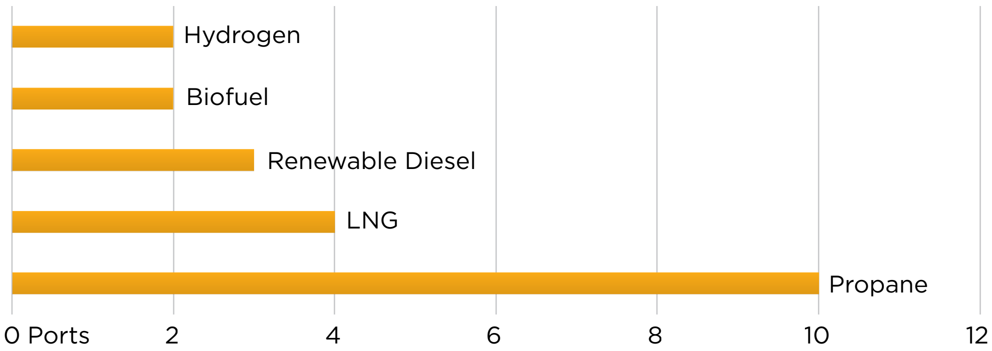



What type of vessel are you bunkering or planning to?

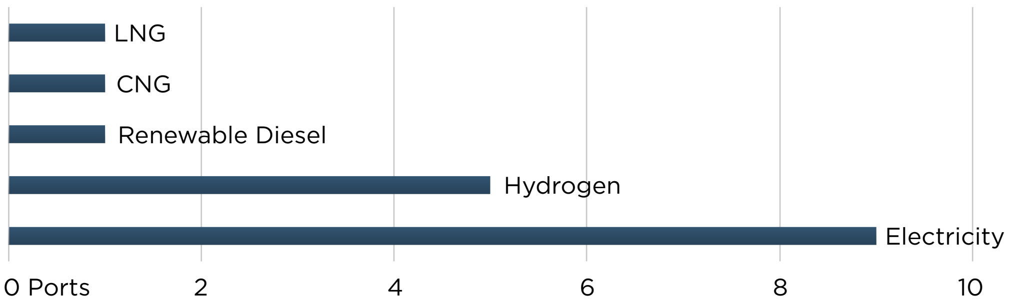


## Land-Side Fuels

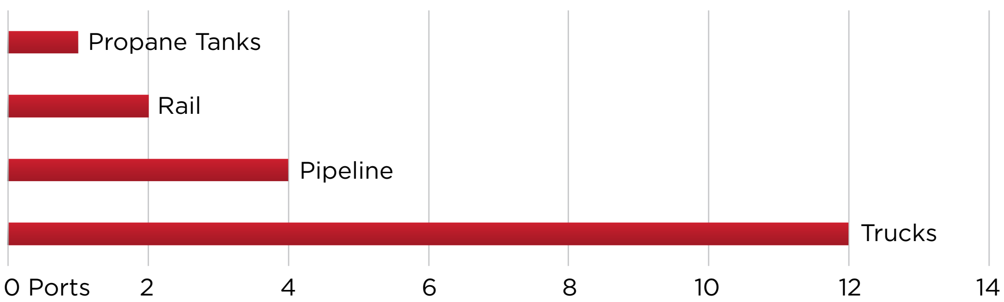
Do you currently offer alternative fuels for land-side equipment?




Do you plan to provide alternative fuels for land-side equipment?




How will you deliver fuel to land-side vehicles?




Note: Some respondents included current or planned offerings of more than one fuel.

# C. TRENDS IN TECHNOLOGIES AND BEST PRACTICES

## C.I Emissions Inventories

Ports can mitigate emissions without conducting a comprehensive emissions inventory, but to best track progress internally and evaluate the efficacy of technologies, it is important for ports to conduct inventories. Inventories can measure both GHG and criteria pollutants. Inventories can include at least the following categories of emissions:

1. Ocean-going vessels
2. Harbor craft
3. Cargo handling equipment
4. On-road vehicles
5. Rail
6. Facilities

Port emission inventories can be developed by following detailed methodologies covered in [5], [6]. According to the EPA [7], only 13 major ports in U.S. have published their emission inventories. However, from our survey (Questions 2,3) and interviews we note that most of the participant ports have established decarbonization targets. The "Climate and Air Quality Planning Competition" funding opportunity under the Clean Ports Program provides incentives and requirements for grant recipients to conduct and publish emissions inventories.

From our interviews we have noted that many ports have volunteered to participate in the Green Marine Certification program as part of their commitment to decarbonization efforts. "The Green Marine environmental certification program offers a comprehensive framework for maritime companies to benchmark and reduce their environmental footprint" [8].

As ports continue to work with a broad range of stakeholders to decarbonize, including foreign-flagged ocean carriers, the truck and rail industries, community groups and government, there is clearly demand for a comprehensive system of emissions inventories. Such a framework would allow stakeholders to compare emissions across ports. This will be discussed further in the policy recommendation section.

## C.II Marine Elements

### Ships and Harbor Crafts

There are several ways to mitigate emissions from OGVs and harbor crafts. Electrification is a relevant option for smaller vessels. The most common form of vessel electrification is the installation of hybrid power systems. These systems have a combination of traditional energy sources like internal combustion engine-driven generators with other low-emission/zero-emission sources like fuel cells, lithium batteries, etc. In interviews, ports noted that they do not own or operate harbor crafts, including pilot boats, ferries, or tug and tow boats. Further, we were informed that emissions from the harbor crafts constitute a very small percentage of a port's overall emission profile. Therefore, the decarbonization of harbor crafts is not highly prioritized by ports compared to CHE or trucks.

A cost-effective measure to reduce emissions from old harbor crafts is to upgrade older propulsion engines (uncontrolled, EPA Tier 1 or EPA Tier 2) with new EPA

Tier 3 or EPA Tier 4 engines. Further, reducing vessel speed can also decrease emissions by reducing energy consumption. However, speed restrictions on harbor craft can have a wide range of negative effects on efficiency and pose life and safety risks in inclement weather [9].

All-electric vessels have been gaining a lot of industry attention lately due to the promise of zero emissions. Maid of Mist tour boats in Niagara Falls and the E-Wolf tug, deployed at the Port of San Diego, are examples of fully electric vessels in the U.S. In interviews, several ports remarked that all-electric tug and tow boat technology was still nascent, and that for near-term harbor craft decarbonization, hybrid technologies were closer to deployment.

The diversity of available electric power sources in hybrid and all-electric vessels helps improve operational flexibility and reliability by allowing for a minimum number of generators to be run where previously multiple generators were operated with less-than-ideal loading. Using the appropriate energy storage system can decrease generator use, with the energy storage providing ride-through power to prevent a blackout until the time it takes for the standby generator to come online. Since harbor craft are typically owned and operated by private companies not under the control of port authorities or terminal operators, ports must collaborate with partners to coordinate harbor craft emission mitigation.

## Energy Storage Technologies [10]

Lithium-ion (Li-ion) batteries and supercapacitors are promising energy storage systems and are reviewed in this section. These systems have a limited range compared to traditional engines. Therefore, in ocean-going vessels, they are generally used to supplement peak loads, and in smaller, short-range vessels such as ferries or tugs, they can be used as the main source of power. Battery-powered electric vessels are ideal for performing short-range operations but may not be able to support long voyages at this time.

Li-ion batteries are the most popular energy storage devices due to their high energy density and low maintenance requirements. One of the most critical challenges associated with Li-ion batteries is thermal runaway. Thermal runaway is an uncontrolled self-sustaining and accelerating chemical reaction that occurs at the cell level and results in the cell's destructive failure. Damage and destruction may not be confined to a single cell but may propagate to adjacent cells, the complete module and the ambient environment. Several events could lead to thermal runaway such as an external short circuit, internal short circuit, overcharging, high ambient operating temperatures, overheating from external sources, mechanical damage and battery management system (BMS) failure. Therefore, special safeguards must be incorporated to protect against thermal runaway and the possibility of resulting fires, and ports should continue to work with their safety and security teams to prepare for Li-ion fires. Other battery technologies in the research and development stages include metal-air batteries, redox flow batteries, ammonia batteries and solid-state batteries.

The commercial use of supercapacitors for energy storage is a relatively new concept made possible by the development of Electric Double Layer Capacitor (EDLC) technology. The EDLC is an electrochemical capacitor, commonly referred to as a super or ultra-capacitor. Another type of capacitor often associated with the supercapacitor is the lithium-ion capacitor (LIC). They are considered safe as they do not have risk of thermal runaway and can operate in a wide range of temperatures, -40° C to 65° C for EDLC and –20° C to 70° C for LIC, which makes them an attractive option for harsh weather conditions.

Challenges associated with supercapacitors include lower energy density and high self-discharge rate compared to Li-ion batteries. Supercapacitors and LICs are suitable for applications where energy needs to be delivered to a load quickly. Although the technology associated with supercapacitors and LICs is still maturing, they are presently considered a viable energy storage solution that may be confidently deployed in the right application.

## Energy Generating Systems [11]

Clean energy generating systems observed in our survey/interviews include fuel cells and renewable sources such as solar and wind power. This section reviews these technologies.

A fuel cell is an electrochemical device that continuously converts chemical energy from a fuel (hydrogen, methane, etc.) into electricity and water through an electrochemical reaction with oxygen. Some of the key types of fuel cells available today include proton exchange membrane, alkaline, phosphoric acid, molten carbonate and solid oxide fuel cells. The maximum power output of fuel cells is normally only several megawatts (MW), which limits the use of fuel cells in auxiliary power units (APUs), as well as propulsion power plants for inland and short-sea shipping. Advantages of fuel cells include high efficiency, low emissions, reliability and low maintenance. The byproduct of fuel cell reaction is water and heat and therefore does not produce any tailpipe emissions. As fuel cells have fewer moving parts, they operate quietly around 60db.

Safety of fuel cell systems primarily depends on a fuel's density, flashpoint, auto-ignition temperature, flammability limits and toxicity. Fuel cells require complex support and control systems. Support systems include vaporizers, reformers, fuel purifiers, pumps, heat exchangers and power conversion equipment.

Unfamiliarity with nontraditional fuels combined with concerns about safety, volatility and hazardous area zones increase the complexity. Adding additional complexity, fuel cells have a relatively slow dynamic response. This may require energy storage integration to provide for large dynamic load changes. Fuel cells can be sensitive to operating conditions such as temperature and humidity, and their durability can be affected by exposure to saltwater and other marine environments.

Hydrogen fuel cells have been successfully deployed for naval submarine service. Several commercial fuel cell technology projects are underway to demonstrate the feasibility and viability of the technology. However, widespread deployment of fuel cell technology will require further development, testing and validation.

The maritime industry has been mainly focused on deploying solar technology on smaller vessels and car carriers, but the use of photovoltaic (PV) solar technology in larger ships is slowly gaining acceptance and is seen as one of the viable pathways to reducing GHG from shipping [12]. Some of the most recent solar PV panels developed and available in the market are those made using mono-crystalline cells, with polymers of high strength. These PV solar panels are specified to withstand harsh conditions at sea.

One of the biggest challenges with solar power is maximum power point tracking (MPPT). Currently, there are many control methodologies available for tracking maximum power from PV panels. The application of these methodologies in ship PV systems becomes complex as the marine environment frequently varies. The performance of typical MPPT methods decreases especially when a large-scale PV system is installed in marine vessels [13]. Therefore, more reliable and robust MPPT control methodologies for large oceangoing ships need to be developed. Challenges with wind generator installations include space constraints, obstruction during transit (in the form of bridges) and safety concerns during loading and unloading operations.

### Power System Design Optimization

With a higher variety of energy types, automation and energy efficiency technologies can allow for more dynamic power management systems. Modeling and simulation tools can aid in the optimization of system performance. A simulation model assists in regulating carbon emissions deriving from seaport operations and shipping inside terminals. From the simulation-based experiment results published in [14] it is noted that reducing ship speed in waterway channels from 24 to 8 knots can reduce the carbon emissions of these ships by up to 48.4% and by about 32.9% for the whole container terminal.

Some of the use cases for simulation include:

- Digital modeling of a complex system such as a marine vessel can be developed and used for performance and reliability studies.
- Studies on fuel consumption and GHG reduction by integrating various green energy technologies in a virtual environment.
- Optimal sea route selection by considering vessel performance under weather and sea conditions, fuel consumption, voyage time, etc.
- Comparison and benchmarking of various design concepts in different operational scenarios in a cost-effective manner.
- Develop, evaluate, and test controller algorithms using model-in-the-Loop (MIL), software-in-the-loop (SIL) and hardware-in-the-loop (HIL) in a safe and cost-effective manner.

### Alternative Fuels Availability [15], [16]

The term "alternative fuels" refers to non-conventional fuels not currently in full production for marine applications, including LNG, liquefied petroleum gas (LPG), methanol, ammonia, hydrogen, biofuels and synthetic fuels. Any alternative fuel must be available at scale in major ports. Most alternative fuels have applications in land-side CHE in addition to their use in marine vessels. This section reviews the different popular alternative fuel options.

#### Liquefied natural gas (LNG)

LNG is the cleanest-burning fossil fuel currently available at scale. Its use as a marine fuel is supported by advanced engine technologies that have been proven in practice. As a fuel, it reduces nitrogen oxide ($NO_x$) emissions, eliminates most sulfur oxides ($SO_x$) and particulate matter, and contributes to $CO_2$ reduction (a maximum potential of 21% as compared with heavy fuel oil [HFO]). It will not meet the IMO GHG targets for 2030 or 2050 alone, but combined with other technologies, it has the potential to play an important role.

#### Liquefied petroleum gas (LPG)

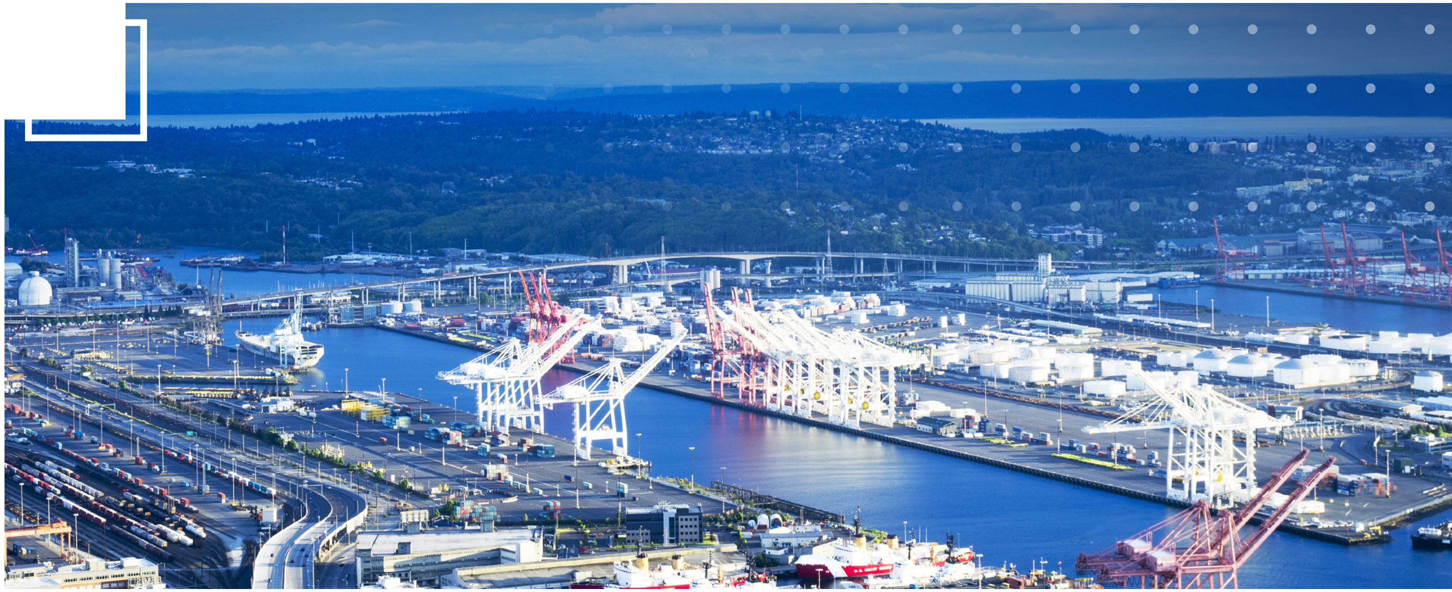
The use of LPG as fuel is relatively new in the commercial shipping industry but is expected to be limited to LPG carriers. Typically, an LPG tank needs three times more volume than a tank for HFO. LPG fuels tanks are mainly non-refrigerated or semi-refrigerated C-Type tanks (up to 5,000 $m^3$). They do

not have the cryogenic complexity associated with LNG storage and are not required to withstand cryogenic temperatures. Although LPG offers more environmental benefits than HFO or diesel, its $CO_2$ and $NO_x$ emissions are higher than for LNG. Providing LPG bunkering infrastructure, including shipboard equipment, would be less costly than the operating systems and equipment required for LNG. LPG is heavier than air, so any leaks tend to accumulate in the lower sections of a space. Special attention needs to be given to the ventilation and the placement of detection equipment of double barrier concepts (such as tanks) and machinery spaces.

### Ammonia

Ammonia is carbon free from tank to wake and when synthesized from renewable power sources, it is also carbon free from well-to-wake. Like hydrogen, it can be produced from renewable energy or fossil fuels, with or without carbon capture and storage. In a liquid state, ammonia is not considered flammable and cannot ignite. However, it vaporizes rapidly, and the vapor is flammable when the percentage in air is between 15% and 34%. Ammonia is toxic to humans and poses risks to crews in the event of a leak. As ammonia is commonly shipped today as a commodity, safety measures are known and can be implemented to mitigate risk.

Interest is growing in the use of ammonia as a feeder to hydrogen-fed fuel cells. Once cracked, the hydrogen from ammonia can be abundant for cells that generate electric power. Certain fuel cell types can internally reform the fuel to run on ammonia directly, eliminating the need to separate the hydrogen and nitrogen elements before input. When used for internal combustion engines, ammonia



produces water, nitrogen, unburned ammonia and $NO_x$. Its combustion may be carbon free, but managing its byproducts will be a key environmental challenge.

### Hydrogen

Hydrogen is a highly volatile gas at most temperatures and pressures. Its flammability range in air is approximately 4% to 75% compared to methane's 5% to 15%, and its ignition energy is a small fraction of that of other common fuels. These characteristics make any onboard leaks or venting of hydrogen dangerous. Therefore, any hydrogen storage system should aim to guarantee that there will be no venting in normal operational scenarios.

In its current limited application as a marine fuel, hydrogen is either used to generate power by combustion in piston engines or gas turbines, or it is used directly as a fuel for fuel cells with much higher efficiency compared to use in internal combustion (IC) engines. A greater volume of hydrogen would be required to offer energy content similar to other fuels – typically more than four times the volume for liquid hydrogen and approximately eight times for compressed gaseous hydrogen. This means that compressed or liquefied storage of pure hydrogen may only be practical for small ships. The deep-sea fleet will likely need a different fuel as a hydrogen carrier, such as ammonia, to limit the significant loss of cargo space.

### Biofuels

Biofuels tend to oxidize and degrade (over a few months) during storage. They degrade faster in water, a fact that has positive effects for spills, but negative ones for long-term storage. The degradation of biodiesel can produce highly corrosive hydrogen sulfide, which corrodes metals, including steel storage tanks.

Some types of biofuels support GHG reduction but, ultimately, they may not be cleaner fuels in terms of $NO_x$, $SO_x$, and particulate matter. A recent report by the International Transport Forum (ITF) found that standard methods of producing biodiesel, for example, can reduce GHG by 70% to 80%, compared to conventional fuels due to the amount of carbon absorbed in growing the feedstock. However, they produce slightly more $NO_x$ emissions due to the higher oxygen content.

### Methanol

Methanol is available worldwide and has been used in a variety of applications, most commonly produced on a commercial scale from natural gas. It can also be produced from renewable sources such as biomass, which could considerably reduce the $CO_2$ footprint of its use as fuel. The hazards associated with storing, transporting and combusting methanol include low-temperature service, pressurized storage tanks and flammable gas; it is also corrosive and toxic and can cause asphyxiation. Methanol vapor is heavier than air, indicating that any leaks would have the tendency to accumulate in the bilges or lower sections of a space. Therefore, special attention needs to be given to the placement of ventilation and detection arrangements in double barrier concepts and machinery spaces.

## C.III Port Logistics Elements

Port authorities and terminal operators have invested in electrified port cranes, CHE, and drayage trucks. Some hydrogen equipment has also been deployed in limited cases. Small-scale local power generation and storage is also growing in popularity, with the dual goals of lowering ports' carbon footprint and improving the reliability and resiliency of power supply. When it comes to land transportation, some ports have banned older trucks or incentivized the use of newer, more energy-efficient trucks. The expansion of cargo movement by rail and barge, even without alternative fuels, can also drastically reduce emissions by leveraging these more efficient means of transportation.

### Electrification and Use of Alternative Fuels for Port Equipment and Vehicles

#### Trucks

Drayage and other heavy-duty trucks are often the biggest source of emissions among on-road vehicles. Trucks are often out of ports' and MTOs' direct control, so decarbonization efforts may require incentives from not just ports, but local and state governments.

Adoption of electric and hydrogen trucks has been slow, mainly due to the need for large infrastructure upgrades, including charging stations and power distribution systems from utilities. Ports with space constraints and old infrastructure are often unable to support the needed upgrades to support electric trucks. Further, trucks traveling long distances (over 350 miles) or carrying heavy loads (over 80,000 pounds) every day are not suitable candidates for operation based on batteries [17].

The Ports of Los Angeles and Long Beach levy Clean Truck Fund (CTF) fees for all the drayage trucks entering the port as part of the Clean Trucks Program (CTP) in an effort to reduce emissions. Trucks using batteries, zero-emission fuels, or low $NO_x$ fuels (until December 31, 2027) are exempted from the CTF fees. The fees collected are allocated to funding zero-emission drayage trucks in the region through the California Hybrid and Zero-Emission Truck and Bus Incentive Project (HVIP) [18]. Since the commencement of the CTP, port truck emissions have been reduced by more than 90% [19]. The federal Diesel Emissions Reduction Act (DERA) funding program has also successfully helped many ports replace or retrofit hundreds of old diesel drayage engines with newer, cleaner engines.

Some of the ports within the U.S. Department of Energy (DOE) designated hydrogen hubs are actively exploring the use of hydrogen fuel cell-powered trucks. The Port of Los Angeles and Port of Hueneme have recently completed a pilot under the "Shore to Store" project in collaboration with Toyota, Kenworth and other partners to demonstrate the feasibility of fuel cell electric trucks, zero emission yard tractors usage in port operations [20].

### Rail

There are typically two types of locomotives that support ports' cargo operations. First, switcher locomotives are smaller capacity engines that are used inside the boundary of the port. Second, line-haul locomotives travel long distances, which will fall outside the boundary of the port. Yard engines or switcher locomotives could be electrified considering the lower hauling capacity required in comparison to the long-distance line-haul locomotives. Even without any new technology, using locomotives in place of diesel drayage trucks can significantly reduce emissions and congestion on roads. The port of Savannah's massive rail capacity improvement project, "Mason Mega Rail," is estimated to double the current rail capacity to 1 million containers per year while also greatly reducing the congestion in the community by moving rail activities onto the port and removing six at grade rail crossings [21].

### Cargo-Handling Equipment (CHE)

Terminal tractors, top handlers, ship to shore cranes, rubber-tired gantry cranes (RTGs), rail mounted gantry cranes and container handlers are some of the most common types of CHE. Electric versions of most CHE are available; although, scale, buy American compliance and cost are concerns for most ports.

In many ports, diesel RTGs are being replaced by or retrofit to a hybrid or fully electric RTG model. Especially for these large CHE models, hybrid equipment may allow for faster emission mitigation than zero-emission systems. Electric RTGs are estimated to achieve 86.6% energy savings and 67.7% reductions in $CO_2$ emission compared to conventional RTGs [22]. A variety of electric RTG models are available in the market such as busbars, cable reels, and overhead cables. In interviews, several ports recommended conducting a pilot program before full adoption to ensure that the selected configuration and equipment is best suited for operating conditions and required duty cycles. Electric RTGs require additional space for infrastructure and may require layout changes.

Most ship to shore (STS) cranes being used in the American ports are already fully electric. STS cranes with a regenerative braking feature may be able to generate around 18 minutes of electricity for every hour of operation, which makes them a favorable choice [21]. Forklifts powered by electricity or propane are increasingly popular, and this smaller category of CHE can be a "low hanging fruit" machine for ports to decarbonize. Fuel cell-powered forklifts are also available in the market. Electrification of cargo handling equipment is especially challenging for older ports. In addition to charging infrastructure upgrades, structural rehabilitation is needed to support the heavy weight of electric CHE.

Hydrogen may be a better fit than battery-electric for heavier CHE working multiple shifts, as the fuel can generally support higher hours of operation compared to electric equipment. Hydrogen equipment can also refuel in a fraction of the time it takes electric equipment to recharge.

Gladstein, Neandross & Associates' Feasibility Assessment for Cargo-Handling Equipment [23] is a good resource to understand the near-term technology readiness of the zero emission and non-zero emission cargo handling equipment. This feasibility study was conducted based on operations at the San Pedro Bay Ports.

## C.IV Port Energy Systems

The Port Planning and Investment Tool Kit released by U.S. Department of Transportation (DOT), Maritime Administration (MARAD), and AAPA is a great resource for ports to develop a framework for planning, accessing funding and executing intermodal projects [24].

### Shore Power [25]

Cold Ironing, also known as Alternative Maritime Power (AMP), or more commonly shore power, consists of connecting vessels to shoreside power sources, thereby allowing electricity to flow from the port into ships [26]. Many ports are seeing a greater demand from vessel operators to support shore power connections. Considering the strong drive towards decarbonization and the rise in fuel costs, this technology has been proved to bring financial and environmental benefits [26]. The shore power emissions calculator developed by EPA is a good source to estimate the emissions mitigation potential of shore power systems [27].

Shore power connections found in U.S. ports generally fall under types: high voltage system (over 1kV, AC) and low voltage systems (<1kV, AC). High voltage shore power systems support large vessels with high power demand such as cruise, containers, refrigerated vessels, etc. with 6.6kV or 11kV power systems. Low voltage shore power supports vessels with low voltage distribution system between 220 and 480V and lower power demand like fishing vessels, tugs, and offshore supply service and working ships [25]. Standardization of shore power requirements for many types of vessels with LV and HV systems is still in progress and a challenge brought up in our survey question four. The need for standardization of DC shore power connection systems to support all-electric vessels is also rising steadily.

The following table provides a summary of available standards for HV and LV shore connections.

| Type of Shore Power Connection | Power Requirement | Nominal Voltage | Type of Vessel Covered in the Standard | IEC/IEEE Applicable Standard |
|---|---|---|---|---|
| **High Voltage Shore Connection** | >1MVA | 6.6kV/11 KV | • Ro/ro cargo and passenger ships<br>• Cruise ships<br>• Containerships<br>• LNG carriers<br>• Tankers | IEC/IEEE 80005-1 |
| **Low Voltage Shore Connection** | <1MVA | 440V/480V/690V | • Offshore supply, service and working ships<br>• Containerships<br>• Tankers | IEC/PAS 80005-3 will be replaced by IEC/IEEE DIS 80005-3.2 (under development) |

*Table 1: Summary of available standards for HV and LV shore connections.*

Shore power installations are very expensive and require upgrades to the port and grid infrastructure. Public private partnerships and government grants play a crucial role. According to ports in our interviews, shore power systems can cost $25 million per berth and $1 million per vessel to be shore power-compatible. For ports with small budgets, infrequent calls from shore power-compatible ships, or frequent calls from bulk vessels, shore power systems may not be a cost-effective investment.

It is crucial that ports involve the utility companies from the initial planning stage to ensure that shore power systems can be supplied without interruptions and the infrastructure is designed to consider future power demand. Design should also consider the use of mobile cable positioning devices to ease connection. In practice, it is difficult for vessels to berth in the window of several feet that a stationary connection provides. Mobile positioning devices like a cable reel allow for connection along a wide range or the entire length of the berth.

## Local Power Generation and Storage

Our survey results (questions 13, 14, 15) show that, while there is mixed interest, ports are investigating the installation of local power generation. Per the survey results, generally, local renewable power sources generally support less than 10% of the total power needs of the port. Solar PV leads the list of ports' preferred local energy source. Building roof tops and canopies over parking spaces can provide space for solar power generation.

While ports play a pivotal role in the construction of offshore wind projects and the movement of onshore wind components, few seaports envision installation of wind power on port property. However, studies have indicated that that wind energy can be efficiently applied to meet the power demands of ports [28].

Fuel cells are also being investigated by many ports to support local power generation. By incorporating low/zero-emission energy sources and battery storage systems, ports are building micro grids that can support charging of electrical cargo handling equipment, vehicles and improve energy resilience.

# D. POLICY LANDSCAPE IN THE STATUS QUO

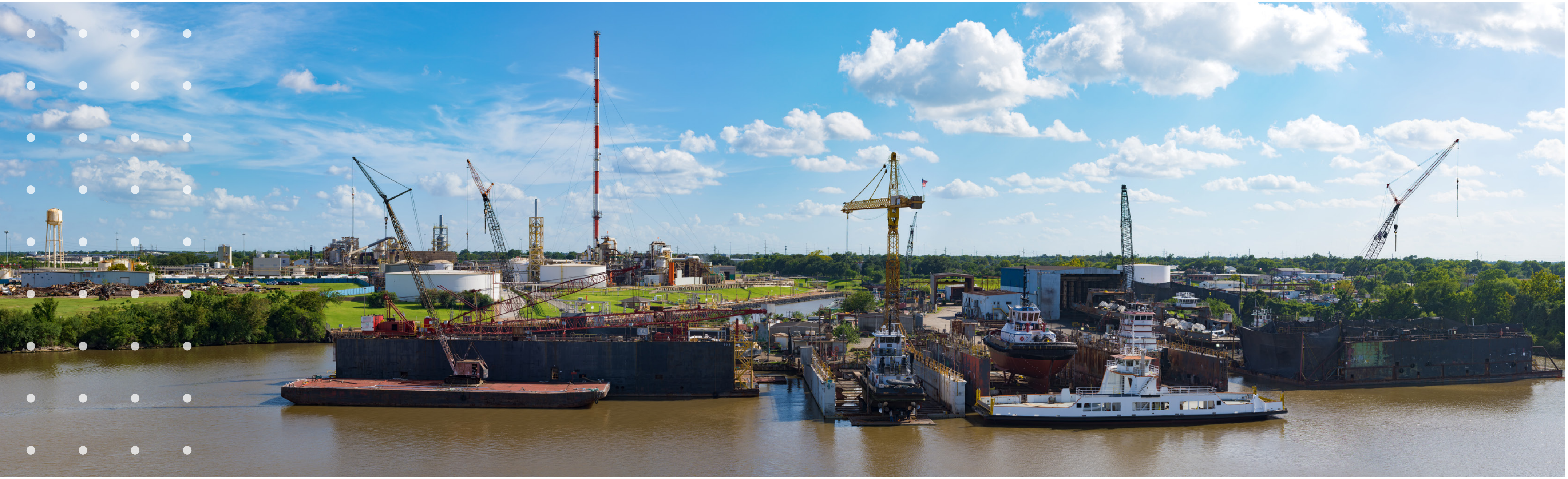
## D.I Current and Emerging Regulatory Issues

There are currently no federal government regulations specifically requiring port decarbonization. As a result, the landscape across the port industry is uneven, with decarbonization progress at specific ports largely driven by state and local regulation, customer demand and community pressure (see question 3). Action is often taken at the local level, with local governments with jurisdiction over port authorities setting decarbonization goals. Perhaps the most prominent example is the South Coast Air Quality Management District (SCAQMD), which has jurisdiction over air emissions in several Southern California counties. SCAQMD has proposed an indirect source rule (ISR), which would require the Ports of Los Angeles and Long Beach to mitigate criteria pollutants significantly. The California Air Resources Board (CARB) has also set several emissions standards to require vessels connect to shore power at berth, require harbor craft to mitigate emissions, and require the trucking industry to shift towards zero-emissions. While technologies and programs to mitigate criteria pollutants and GHG differ, the result is often the same: implementation of zero-emission equipment. However, hybrid equipment can in many cases reach decarbonization and criteria pollutant mitigation goals in far shorter timelines than zero-emission equipment.

While the federal government has not established regulations mandating port decarbonization, there are bills introduced that would mandate or fund these goals. The Clean Shipping Act (H.R.4024) [29] would require all vessels calling at U.S. ports to be powered by zero-emission fuels by 2040 and for all vessels to connect to shore power by 2030. These timelines are largely regarded as infeasible within the port and maritime industry. The International Maritime Pollution Accountability (IMPA) Act (S.1920) [30] would establish a tax on emission for vessels calling at U.S. ports. While the bill would not require vessels to connect to shore power or run on zero-emission fuels, an escalating tax on emissions would eventually make fossil-fueled shipping cost-prohibitive. IMPA would redistribute the fees collected to zero- and low-emission shipbuilding capacity, port infrastructure, workforce training, and other programs.

## D.II Voluntary Port Initiatives

Individual port authorities, whether driven by regulation or other motivations, are increasingly working with their tenants to decarbonize. As found in question three, most ports with decarbonization goals are not facing mandatory regulations but are decarbonizing due to a variety of pressures. Most port authorities operate on a landlord model, whereby they lease their property to private MTOs, who own much of the equipment used to move cargo and operate terminals on a day-to-day basis. The contracts governing these leases are long-term, often in effect for decades. Port authorities can negotiate with MTOs to include requirements or incentives that MTOs mitigate emissions, either when contracts are up for renewal or mid-contract through renegotiation. Port authorities can also set up incentive funds to subsidize the purchase of low- or zero-emission equipment. Funds can be used to either subsidize individual pieces of equipment or



install infrastructure that will enable decarbonized equipment, such as chargers, microgrids or shore power systems.

## D.III Grant Funding Opportunities

There is more federal funding available for port authorities than at any point in the nation's history. Thanks primarily to the BIL and IRA, there are new and expanded grant programs for port authorities that can fund decarbonization projects. Most relevant is the $3 billion Clean Ports Program, funded by the IRA, which the EPA made available on February 28, 2024. This program is available for zero-emission port equipment. While other programs are also available to port authorities, the most relevant ones include:

- Port Infrastructure Development Program (PIDP)
- Clean Ports Program
- Reduction of Truck Emissions at Port Facilities (RTEPF)
- Diesel Emissions Reduction Act (DERA) Program
- Multimodal Project Discretionary Program (Mega)
- Infrastructure for Rebuilding America (INFRA)
- U.S. Marine Highways Program (USMHP)
- Hydrogen Hubs Program
- Rebuilding America with Sustainability and Equity (RAISE)
- Consolidated Rail Infrastructure and Safety Improvements (CRISI)

State governments are also providing significant funds for port decarbonization. While AAPA does not track state funding comprehensively, prominent examples include California's state government providing $1.5 billion in 2023 for port decarbonization [31]. The survey uncovered other examples of ports taking advantage of state funding, including most significantly in Washington and Texas.

Local governments and legal settlements are other prominent sources of funds. The Los Angeles Department of Water and Power (LAWPD) through the "ChargeUp L.A" program is offering rebates to residents and businesses for installing EV charging stations [32]. The Volkswagen Environmental Mitigation Trust has allocated $60 million in funds for "Combustion Freight and Marine Projects" category which can be used by ports in replacing older and high polluting engines [33].

# E. AAPA POLICY RECOMMENDATIONS

While port authorities and terminal operators can make operational and environmental improvements on their own, there is only so much they can do without policy changes. Changes are needed at various levels of government. The policy recommendations here are the product of the above survey, interviews conducted for this report, and the experience of AAPA staff and members. These recommendations should be viewed as a starting point for policymakers and stakeholders to consider. All regulatory and business models will not work for all ports, but these recommendations reflect a trend observed across at least a majority of respondents.

## E.I Utilities

Much space has been devoted in this report to utilities, because the relationship between utility and port is absolutely critical to building out new electrification projects.

1. **Utilities and ports should form formal relationships.** Several respondents remarked that they have memoranda of understanding (MOUs), committees, or boards established by local or state law. These bodies provide for streamlined communication between utility and customer. They also allow utilities and ports to make long-term plans about the future of transmission projects. One port, which is a state agency, has staff represented in a state government body which also has representatives of the state environmental and energy agencies. Ports without formal relationships can still have professional, staff-to-staff relationships and communicate through official channels, but turnover, misunderstandings, and low communication can hamper development efforts.
2. **Utilities should draft official policies to govern net-metering at ports, and these policies should incentivize local power generation.** A majority of survey respondents indicated they are not planning local power generation, but utilities could reverse this trend by reducing barriers to these projects. Power generated locally will not always be used 100% locally. Excess power needs to either be stored locally or sold back to the broader electric grid. Some ports indicate that their utilities do not have policies in place for ports to sell power back to the grid (net-metering). Other ports indicate that utilities require ports to pay for some, if not all, of the infrastructure needed on the utility side of the electric meter.
3. **Plan future transmission projects early to reduce wait times.** A common refrain heard from ports is that their utility will not begin transmission construction, or even planning, until the port reports their exact anticipated power requirement for a specific project. If the nation's ports order new power projects, one or two MW at a time, port decarbonization will be excruciatingly

slow, and costs will balloon. Many ports have already developed, or are developing, long-term electrification plans. These plans include assessments of power demand years or even decades into the future. Utilities should be party to the planning process, and they should build ports' plans into their own long-term development plans. Ports have unique advantages in this regard, compared to other industries. Whether operators or landlords, port terminals are long-lived assets, with leases or capital construction plans lasting decades. When a port tells a utility how much power it will need in 2040, the utility can be confident that the assessment is accurate. While it can be risky for utilities to build out transmission infrastructure on assessments alone, they should explore options to build transmission projects ahead of actual electric equipment acquisition. Ports are electrifying, there is no use in waiting until electric cranes are delivered to build transmission lines.

## E.II Holistic Electrification Planning

Building out electric charging infrastructure efficiently and at low cost requires meticulous planning by engineers, but policymakers and planners at every level must understand efficiencies if they are to fund and regulate projects well. While grant funders may be tempted to fund only specific pieces of electric equipment and their requisite chargers, there is much more that goes into building an electrified port.

1. **Upgrade supporting infrastructure.** Older ports' infrastructure tends to bear less weight than newer terminals. Electric equipment weighs more than diesel-fueled equipment, and so docks and other infrastructure must be capable of bearing more weight. Electrification grants and plans should include allowances for these types of improvements.
2. **Fund projects to improve efficiency and reduce congestion.** Building out more rail and barge capacity can drastically reduce emissions, even without any new energy technologies. Moving more cargo by rail or barge can ease the load on new electrified trucks.
3. **Both physical and operational improvements can reduce truck idling.** These projects can take multiple forms, including expanding gate access and pickup space or digital platforms to streamline appointments for truck drivers. While reducing diesel truck idling can directly reduce emissions, electric truck idling wastes the limited range a single charge can convey. A minute spent wasted in line is a minute longer spent waiting at a charger.
4. **Think of future projects during construction.** The telecom industry has increasingly adopted "dig once" policies, incentivizing internet service providers (ISPs) to install broadband lines, or at least conduits for future cables, whenever construction is undertaken on co-located infrastructure. Ports can find similar efficiencies. Terminals are crowded places, with decades-old electrical, stormwater, fueling, lighting, communications, and other infrastructure crisscrossing above and below ground. Whenever construction is done on any one of these systems, planners should conduct long-term planning exercises and endeavor to construct multiple system improvements at once. One port indicated that they are installing electrical conduit at their berths during stormwater infrastructure

construction in anticipation of future shore power systems. When the port does eventually build shore power, it will be much cheaper since conduit is already laid.

## E.III Standardization

1. **Standardize charging infrastructure.** Charging infrastructure, for trucks, CHE and vessels is expensive. The cost can be brought down considerably by standardizing charging equipment. Shore power systems for HV containerships and cruise vessels have already been standardized in large part. Shore power standards are not yet widespread for bulk vessels, LV and DC power-based vessels. Electric trucks and CHE are still developing technologies, but more standardization will increase economies of scale for OEMs. Federal regulations are not always the best solution, but with most electric equipment manufacturing happening outside the United States, there may be a role to play for the federal government to work with international bodies to set standards.
2. **Install cable management systems for shore power.** Everyone knows the experience of untangling extension cords when appliances are too far from outlets, but plugging in a vessel is not so simple. Different vessels install their ship-side plugs in different configurations, and vessels sometimes dock too far from shore power equipment. For this reason, ports are increasingly installing cable management systems that allow the shore power cable to move to the ship, rather than the other way around. Cables can be hung from small cranes or moved up and down a berth on a conveyer. While the optimal cable management system may vary based on the berth and vessel type, cable management in shore power systems should be standard.
3. **Study universal emission inventory guidance.** As the federal government weighs legislation like the Clean Shipping Act, the IMO calls on the shipping industry to decarbonize, and governments across the continent and globe form green shipping corridor agreements, there is an increasing need for the maritime sector to "speak the same language" when it comes to emissions. If ports are to track progress on emissions mitigation, apples cannot be compared to oranges, and emissions need to be tracked by the same methodologies. While federal mandates can often be heavy-handed, the Federal Government and leading non-profit organizations have a role to play in studying whether a universal system of port emissions inventories would be beneficial to port authorities and their partners.

## E.IV Federal Grants

1. **Sustain funding beyond BIL and IRA.** While the two pieces of landmark legislation are allowing ports to pursue decarbonization projects they never thought feasible, this funding is due to expire in 2026 or 2027, depending on the program. Congress should not consider the job done when this legislation expires. Port infrastructure needs are extensive, and with cargo volumes expected to grow in the years to come, capacity will need to expand, with or without decarbonized technologies. The Federal Government should view transportation, especially port infrastructure, as a public good and a necessary investment and continue funding port infrastructure and decarbonization projects at a high level.
2. **Institute policies to reforming permitting laws at every level.** It takes far too long to permit the construction of ports and related infrastructure. Between transmission lines, rail and truck access, in-water construction, charging infrastructure, and more, obtaining federal, state, and local permits requires navigation of a patchwork of agencies, consultants, and studies. While the Fiscal Responsibility Act (link) enacted significant permitting reforms that will be implemented in the White House Council on Environmental Quality NEPA Phase Two Rule (link), further comprehensive permitting reform is necessary to achieve port decarbonization at the pace envisioned by advocates.
3. **Build America Buy America (BABA)**
   a. Provide more predictability and flexibility for Build America Buy America (BABA) waivers. While the BIL ushered in a generational investment in port infrastructure, it also instituted strict requirements that grant funding to purchase infrastructure made in

America. Unfortunately, due to a variety of policy and macroeconomic factors, very little port equipment is made in America, and very few models of zero-emission port equipment have even a single American manufacturer. BABA rules allow for waivers when grantees can show that the item in question is not available from American manufacturers at a reasonable price, but in practice, individual waivers are often rejected by regulators, and the need for a waiver can make grant applications less competitive. The Federal Government should make the BABA waiver process efficient and easy to understand for all grant applicants.

b. Do not classify engines and mobile equipment as "infrastructure" for BABA purposes. BABA rules require "infrastructure" purchased with federal grants to be purchased from American manufacturers. The U.S.DOT interprets these rules so that engines and mobile equipment are classified as "infrastructure," severely limiting the extent to which ports can use federal grants. The EPA, on the contrary, does not consider engines and mobile equipment to be infrastructure. In the guidelines for the DERA Program and the Clean School Bus Program (available to school districts to purchase electric school buses), grantees have latitude to purchase equipment from abroad. DOT and other Federal Agencies should adopt EPA's interpretation.

c. Grant broad waivers to BABA for public good reasons. Federal Agencies are permitted to issue broad waivers from BABA rules when certain conditions are met. One of these conditions is the ability to issue a waiver when doing so is in the public good. Based on federal decarbonization and environmental justice goals and policies, it is clearly in the public good that ports install low and zero-emission infrastructure. The Federal Government should therefore issue a public good waiver to make it easier for ports to purchase electric, alternative-fueled, and hybrid equipment.

4. **Allow the purchase of hybrid equipment with federal grants.** While much of the decarbonization conversation centers around zero-emission electric and hydrogen-powered equipment, ports can often make progress much faster by utilizing hybrid equipment. Among other advantages, hybrid equipment is easier to procure from manufacturers, can better withstand the rigors of heavy lifting and hauling, is easier to charge and to fuel, and the technology is better tested than zero-emission alternatives. For some classes of equipment, like many harbor craft, zero-emission alternatives are not yet commercially available. Ports can make massive progress in emissions mitigation by instituting hybrid equipment today, rather than waiting years or decades for zero-emissions alternatives to become commercially available or even technologically viable. One of the most anticipated grant programs, the Clean Ports Program, can only be spent on zero-emission port equipment. In future funding opportunities, Congress and state governments should allow funding for hybrid equipment to yield immediate decarbonization results.

# F. CONCLUDING REMARKS AND FURTHER STUDY

This survey uncovered broad challenges in the port decarbonization landscape:

- Transmission lines and charging infrastructure are being built at too slow a pace.
- Public funding is far too low to achieve advocates' and ports' decarbonization goals.
- Technologies are not yet developed enough to allow one for one replacement of traditionally powered equipment.

In both written responses and in interviews, this report also uncovered tremendous opportunity in the port decarbonization landscape. Even with the absence of strict regulation, ports are finding ways to work with their public and private stakeholders to build out new decarbonization projects. New models of electric, hydrogen, biofuel and other alternatively-powered equipment are being deployed across the country. Through these deployments, ports are moving cargo and passengers, powering vessels and mitigating emissions. Not only are these projects supporting the American economy and having positive environmental impacts, but they are also working out the kinks in new classes of equipment that have never been used before. With each new generation of equipment, manufacturers are improving energy efficiency, horsepower, range and more.

Ports' private terminal operator partners are working tirelessly to procure and implement these technologies, and the public sector has made so much of this progress possible by making billions of dollars in funding available. The public sector also has a regulatory role to play, and our survey reveals that the federal and state governments should approach heavy-handed regulation with caution.

This report also shows the need for future study. Among questions that this report did not address, but would be valuable to have answered are:

- How has the performance of low- and zero-emission equipment improved over time and in different conditions, including range, charging time and duty cycles?
- What is the total cost of ownership of various types of equipment, and can low- and zero-emission equipment save money over diesel in the long run?
- What is the economic benefit of port decarbonization, including energy savings, cargo-throughput and local health cost savings?
- Through further standardization and economies of scale, can the cost of low- and zero-emission equipment be reduced?
- Can the cost of charging and fueling port equipment be brought down through greater efficiency in transmission infrastructure build out?
- Would the availability of alternative fuels at American ports confer a global economic competitiveness?

Above all, this report and the scope of questions it studied reveal the fast-developing and critical importance of port decarbonization and study of its progress. The port and maritime industries are advancing at a rate not seen perhaps since the advent of containerization. If one thing is clear, America's port professionals are dedicating immeasurable hours and attention to port decarbonization, and the future of this field contains immense opportunities for economic development, environmental protection, and global trade.

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