Ports White Paper

Written in collaboration with
ARCHES Ports Working Group

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Foreword

The Alliance for Clean Hydrogen Energy Systems (ARCHES) is a public-private partnership organized to accelerate renewable, clean hydrogen projects and infrastructure in California. California has a pivotal opportunity to decarbonize important sectors of the state's economy, to achieve the State's ambitious greenhouse gas reduction goals, as well as build a domestic, robust, and resilient source of energy.

New technology and large-scale deployment will be needed to achieve these goals. Clean hydrogen made from renewable sources, ranging from renewably powered electrolysis to agricultural biomass, offers enormous promise to advance a zero-carbon economy and reduce the costs of clean hydrogen. Innovative electrolysis and fuel cell technologies as deployed through ARCHES can help decarbonize sectors like heavy-duty freight, shipping, ports, and energy generation and offer the promise of cleaner air for all communities and new good jobs. To this end, in late 2022, ARCHES commissioned a series of white papers spanning multiple thematic working groups meetings convened topically, and across sectors, charged with developing a clean hydrogen roadmap and blueprint to inform, stimulate and scale up clean hydrogen activities across California.

Drawing upon the knowledge and expertise of academic, government, industry, nonprofit, and labor representatives, the ARCHES Clean Hydrogen White Papers are the culmination of over two years of regular meetings and discussions. Each white paper is co-authored by a Working Group Chair from the University of California, with two or more co-chairs and/or facilitators, with contributions from working group members. Key recommendations that would support overall development of a clean hydrogen economy include:

- Coordinate an **aligned state and federal definition of clean hydrogen**
- Devise hydrogen pricing programs that ensure **transparency, consistency, longevity, and adaptability**
- Develop hydrogen **transportation and storage infrastructure for both gas and liquid**
- Ensure that local, state and federal agencies that oversee emissions, safety, and permitting generate **aligned and adaptable standards and regulations** and
- Promote **collaboration and communication among stakeholders**, including communities, industries, regulatory agencies, and workforce development programs

Executive Summary

The Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) Ports Working Group created this document as a tool to inform legislators, community members, the seaport industry, and other stakeholders about the potential for renewable hydrogen use at seaports, the benefits of fuel cells as zero-emission power sources, and the related challenges and opportunities of implementing hydrogen technologies. The primary focus of this working group is the land-side activities of seaports: cargo handling equipment, facility and on-berth power, and drayage trucks and locomotives that regularly enter seaports to distribute goods along the international supply chain.

Seaports around the world are primary hubs for global commerce. Three of the ten largest container ports in the United States are located in California including the Port of Los Angeles, the Port of Long Beach, and the Port of Oakland. Seaports use a wide variety of mechanical equipment and vehicles for their operations including but not limited to: top and side loaders, port yard trucks, and drayage trucks.

Globally, and in California, seaports are demonstrating fuel-cell technologies for port operations including zero-emission versions of the above-mentioned vehicles.

Additional conceptual uses of hydrogen for ports include stationary fuel-cell systems and/or linear generators for power resiliency and provision of shore power for ships (also known as cold ironing), and support for hydrogen fueling and fuel bunkering for large ocean-going vessels, passenger ferries, tugboats, and patrol vehicles.

In short, the size and scale of shipping operations through ports in California and worldwide provide ample opportunity for projects focused on energy efficiency and resilient, cleaner fuel sources.

Opportunities for Hydrogen and Fuel Cells at Ports

Hydrogen generated from renewable sources and otherwise low-emission systems can be produced near ports or at other fueling locations to power ancillary port equipment, reducing fuel transportation costs and increasing resiliency by reducing reliance on traditional fuels.

Challenges for Hydrogen and Fuel Cells at Ports

Seaports are complex sites that vary in size and focus and include a wide variety of facilities and equipment as well as complicated operational, ownership, and oversight structures. Some offer a wide range of operations with highly varied cargo while others are more specialized, focusing on specific goods or operations. For fuel cell applications, the most advanced are fuel-cell electric drayage trucks, currently in prototype/pilot testing and early commercialization.

The primary challenges for deployment of these and other classes of port equipment and related technologies in seaport settings include:

- Proof of concept for operating these technologies that would build confidence in adoption among seaport tenant organizations;
- Somewhat low technology readiness level (TRL) ratings for most applications, with drayage trucks being the most advanced but still early in commercialization;
- Difficulties with the provision of hydrogen fueling at port locations where space is constrained and hydrogen production may be a significant distance away, introducing additional transport/delivery costs and emissions;
- Economic challenges around the capital cost of equipment and fuel costs; and
- Addressing community concerns about hydrogen through education and the safe operation, handling and use of hydrogen technologies.

Recommendations for the Advancement of Hydrogen and Fuel Cells at Ports

Several policy and regulatory actions could assist the adoption of hydrogen and fuel cell technologies at seaports. These primarily involve the advancement of technology progress and shared learning, continued investment toward commercialization, workforce development, codes and standards, permitting, community engagement, and broader state regulatory issues.

1. **Address technical challenges by:**
    a. Developing better mechanisms for information sharing and lessons learned amongst ports within the U.S. and internationally;
    b. Continuing to invest in the demonstration of hydrogen technologies at ports to assure commercial readiness and prove out technologies; and
    c. Continuing to engage the private sector to understand commercialization timelines.
2. **Address workforce challenges by:**
    a. Providing training and guidance for port applications to enable scale-up, leveraging additional resources and information sharing, as well as expanding on existing expertise and processes; and

b. Utilizing related training programs including solar, advanced lighting controls, electric vehicle infrastructure, high-pressure gas, microgrids, and others offered by joint labor and management apprenticeship centers, as well as new programs responding to emerging technologies and industries.

3. **Improve permitting timelines and guidance by:**
    a. Expediting the creation and evolution of appropriate codes and standards for new and existing hydrogen systems and applications;
    b. Educating permitting agencies, including fire departments and Coast Guard, on codes and practices that ensure the safety of human health and the environment; and
    c. Building on California's updated (2020) and useful Hydrogen Station Permitting Guidelines document and extend to additional sectors and applications.

4. **Build community trust by:**
    a. Fostering collaboration among working groups engaging with port-impacted communities to ensure procedural equity creates pathways for two-way dialogue throughout the process of deploying hydrogen systems; and
    b. Being transparent and providing education with facts to fill in knowledge gaps as well as direct experience onsite of projects where feasible, offer realistic assessment of risks and how they will be mitigated, and highlight successes and key lessons learned.

5. **Address financing risk for drayage trucks and other seaport equipment by:**
    a. Developing innovative financing models and
    b. Using incentives and grants to subsidize the purchase of hydrogen fuel itself as the primary challenge to ongoing operations of hydrogen equipment is the high cost of fuel in the near term.

6. **Include port equipment and hydrogen in California Air Resources Board (CARB) regulations by:**
    a. More explicitly including port equipment in the Low-Carbon Fuel Standard (LCFS) program for credit generation;

b. Ensuring that hydrogen/fuel cell technologies are appropriately addressed in CARB cargo-handling equipment regulations; and

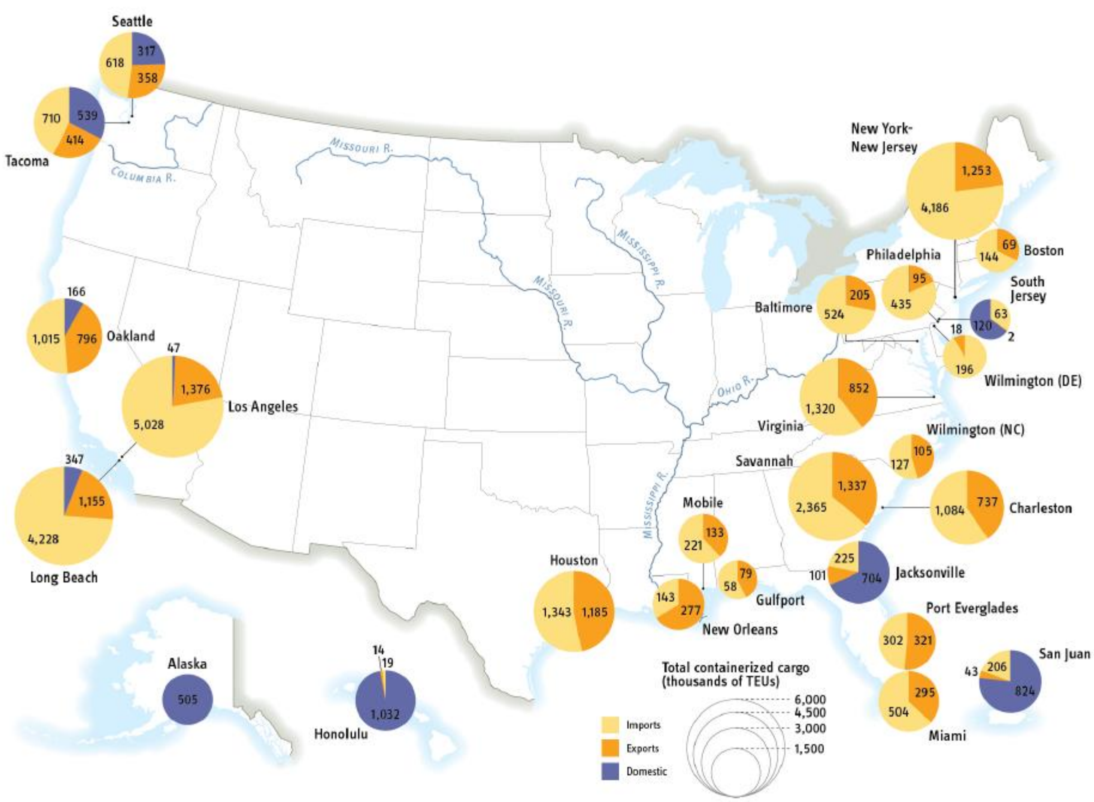
c. Ensuring that relevant vehicle models are included in Hybrid and Zero Emission Vehicle Incentive Program (HVIP) eligibility and that the program is accessible to small fleet operators with limited time, capital, and language resources.

Section 1: Sector Overview

1.1. Port Sector Overview

Three of the ten largest container ports in the U.S. are located in California: the Port of Los Angeles, the Port of Long Beach, and the Port of Oakland. These three California ports represented 36.1% of the total goods throughput of the top 20 ports in the U.S. in 2024.[1] Port throughput volume is measured in "twenty-foot equivalent units" or TEUs, where one TEU is the volume of a standard shipping container that is 20 feet long, 8 feet wide, and 8.5 feet in height. A map of the 25 largest ports in the U.S. is shown in Figure 1 below, along with their annual TEU statistics in thousands of TEU.

Figure 1: The Largest and Busiest Ports in the United States (2022)



Source: U.S. Department of Transportation (DOT) Bureau of Transportation Statistics[2]

[1] American Journal of Transportation, https://www.ajot.com/premium/ajot-top-us-container-ports-post-gains-in-24

[2] U.S. DOT Bureau of Transportation Statistics, *Port Performance Freight Statistics Program: Supply Chain Feature*, 2022, https://doi.org/10.21949/1524417

Seaports use a wide variety of mechanical equipment on land. There are also additional high-energy systems to support ocean-going marine vessels, such as shore power (also known as cold ironing) and fuel bunkering operations.

Much of this equipment continues to operate on diesel fuel, but the industry is increasingly adopting cleaner fuels including hydrogen and electricity, as well as battery-electric and fuel-cell electric technologies, to replace incumbent combustion systems. Table 1 provides an overview of the primary equipment used at seaports, along with approximate technology readiness levels (TRL) and key features. TRL is a measure of the relative level of development and commercialization status of emerging technologies, on a 1-9 scale ranging from basic technology research to full commercialization.[3]

Table 1: Applicability of Hydrogen Technologies for Operations at CA Seaports

Application	Tech. Readiness (TRL)	Deployment Readiness	Feasibility
Heavy-Duty Forklifts 	Battery electric: TRL = 7-8 Hydrogen fuel cell: TRL = 5-6	Hydrogen fuel cell at the demonstration phase Battery electric demonstrated and commercial units available	Battery weight and volume are a significant constraint for battery electric Changes in operating profile or duplicate equipment required near-term Hydrogen fuel cell with operational advantages and potentially lower overall ownership costs after 2030-2035 Electric infrastructure limitations to charging
Top Handlers 	Battery electric: TRL = 6-7 Hydrogen fuel cell: TRL = 5-6	Pre-commercial pilot for hydrogen fuel cell at POLA Commercial product ~2025	
Yard Tractors 	Battery electric: TRL = 8-9 Hydrogen fuel cell: TRL = 6-7	Commercial pilots for battery electric in late 2010s (POLB, Port of New York) and initial hydrogen fuel cell demo units in 2023 (POLA) Commercial hydrogen fuel cell products ~2025+	

[3] For further details see: https://www.energy.gov/sites/prod/files/em/Volume_I/O_SRP.pdf

Rubber Tire Gantry (RTG) Cranes 	Grid electric: TRL = 8-9 Hydrogen fuel cell: TRL = 5-6	Grid electric solution commercially available Hydrogen fuel cell at demo stage; commercial ~2026/27	Both platforms feasible Hydrogen has packaging and logistics advantage
Drayage Trucks 	Battery electric: TRL = 8 Hydrogen fuel cell: TRL = 8	Commercial products for both hydrogen fuel cell and battery electric at the pilot stage Multiple OEMs have announced product launches in near future	Both platforms feasible Hydrogen has superior fueling logistics Electric infrastructure limitations to charging

Source: Modified from UCI APEP[4]

1.2. Current Role of Hydrogen in the Port Sector

Today, the commercial status of hydrogen and fuel cell technologies relevant for seaports is at an early stage due to delayed market penetration which is discussed in more detail in Section 3. However, seaports are currently demonstrating the use of hydrogen and fuel cell technologies for port operations throughout California.

These include zero-emission heavy-duty drayage trucks powered by hydrogen that deliver port containers to inland destinations. For example, at the POLA, ten drayage trucks manufactured by Kenworth using Toyota fuel-cell electric technology were deployed as part of a demonstration. At the Port of Oakland, thirty Hyundai fuel-cell electric drayage trucks are operating at full commercial capacity.

To support the refueling of fuel cell electric drayage trucks, convenient infrastructure must be deployed. Three hydrogen fueling stations capable of serving zero-emission heavy-duty trucks, including the largest of its kind, are in service or under construction adjacent to the Port of Oakland. Two hydrogen fueling stations are open in the San Pedro Bay area, including one on Port of Long Beach property. An additional hydrogen fueling station intended to serve heavy-duty trucks has also opened in Ontario, California, a major inland cargo destination, along the I-10 freeway to ensure bookend

[4] Advanced Power and Energy Program, UC, Irvine, Renewable H2 Roadmap for the Ports of San Pedro Bay, September 2022.

fueling is available to goods movement operators. These assets have been supported in part by incentive funding from State and local agencies, and the Bay Area and South Coast Air Quality Management Districts.

Additional demonstrations are proving the feasibility of fuel cell yard trucks in collaboration with Toyota. Terminal operators are seeking to better characterize duty cycles and fuel consumption rates of these vehicles. The POLA/POLB is also demonstrating the use of hydrogen fuel-cell versions of equipment such as top loaders and RTGs.

Additional conceptual uses of hydrogen include:

- Stationary fuel cell systems and/or linear generators, both using hydrogen as a fuel input, for onsite power, power resiliency and the avoidance of utility grid transmission upgrades;
- Shore power for ships; and
- Support for hydrogen fueling and fuel bunkering for large ocean-going vessels, passenger ferries, tugboats, and fleet vehicles of all sizes used in port operations.

1.3. Future Vision for Hydrogen in the Port Sector

The prospective outlook for the hydrogen economy includes global distribution of hydrogen. Hydrogen produced in areas with advantageous conditions could be transported by barges from onshore production sites to major ports. From there, applications may range from port operations to inland goods movement, heavy-industry and utility sector use cases. Conversely, pipelines from inland clean hydrogen production facilities could carry fuel products to ports for local use or export. Figure 2 presents one concept based on the vision of the Port of Rotterdam.

Figure 2: Port-Centered Hydrogen Economy Concept

Source: Port of Rotterdam[5]

In California, SoCalGas continues to advance Angeles Link by exploring global best practices — particularly regulatory and commercial frameworks from countries such as Germany and the Netherlands — to inform the development of clean hydrogen infrastructure tailored to the state's decarbonization goals. Angeles Link is envisioned as a non-discriminatory, open-access, pipeline system in the U.S., transporting 100% clean renewable hydrogen from various California production and storage areas to the greater Los Angeles region, including POLA and POLB and other end-users.[6] An open access framework would foster price transparency, competition, and lower transportation costs, ultimately supporting the development of robust hydrogen markets.

Other pipeline owners near California ports are also in the early stages of considering repurposing their fossil fuel pipelines to accommodate hydrogen. Leveraging existing infrastructure and rights-of-way could minimize the construction footprint and timeline otherwise associated with building new pipelines.

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[5] See: https://www.portofrotterdam.com/sites/default/files/2021-06/hydrogen-economy-in-rotterdam-handout.pdf

[6] https://www.socalgas.com/sustainability/innovation-center/angeles-link

1.4. Expected Impact of Hydrogen at Ports

California seaports are major centers of economic activity but are closely embedded into the communities in which they reside. Pollution burden around port areas is a major concern where documented human health impacts are likely linked to port activities.

Transitioning port equipment to cleaner technologies, such as those based on fuel cells, translates directly into improved health outcomes for residents adjacent to ports and throughout communities with freight corridors. Hydrogen produced from renewable and otherwise low-emission systems can be produced near ports or at other fueling locations to power ancillary port equipment, with potentially low direct and lifecycle emissions of GHGs and criteria air pollutants, alleviating the pollution burden currently observed around ports. Hydrogen technologies can also provide increased energy resiliency and more stable fuel pricing for port equipment, helping to mitigate the potential impacts of electricity disruptions and volatility in fuel prices.

1.5. Workforce Implications of Hydrogen in Port Sector

As the adoption of hydrogen and fuel cell technologies at ports increases, so will the need for training and upskilling technical professionals and mechanics to install, operate, and maintain the equipment. This includes the end-use technologies themselves as well as the hydrogen refueling systems needed to power them.

This will create new job opportunities and maintain jobs across the value chain, including direct labor trades (e.g., longshore workers, electricians, ironworkers, plumbers, sheet metal, boilermakers, asphalt, etc.), as well as roles in construction management, inspection, engineering design, project development, maintenance, sales, technology development, technology operations, manufacturing, longshore work, and truck driving and maintenance.

The process to identify gaps in the needed labor force is on-going. The State Building and Construction Trades Council and the American Federation of Labor and Congress of Industrial Organizations (AFL-CIO) provide a strong resource to leverage relationships throughout the state. Similarly, the Pacific Maritime Association and International Longshore and Warehouse Union (ILWU) collaborate on workforce acquisition and development, with training facilities in Wilmington and Oakland. Specific to port operational concerns, additional key aspects include:

- Identifying critical jobs and skill sets (e.g., hydrogen fuel cell electric truck mechanics, trained cargo handling equipment operators, etc.);

- Working with original equipment manufacturers (OEMs), project developers and contractors to additionally identify port-specific workforce implications and staffing/training needs; and
- Identifying opportunities for synergy in workforce training and development with truck fleet owners, transit system operators, and other potential hydrogen users.

1.6. Intersection of Ports with Other Sectors

Ports are the epicenters of overlapping sectors that can transition to hydrogen technologies. A regional clean hydrogen hub is generally defined as a network of clean hydrogen producers, consumers, and connective infrastructure located in close proximity. The contiguous maritime domain, including commercial ports and operating areas for vessels operating using hydrogen or hydrogen-derived fuels, embodies this close proximity with potential interconnected systems as shown in schemes such as in Figure 2.

Ports: A Catalyst for the Development of Hydrogen Hubs

Leveraging the maritime nexus can increase efficiencies for renewable hydrogen and hydrogen derivative storage and distribution across sectors. Because ports are intermodal sites for co-located transportation systems, leveraging them as storage locations can readily support renewable hydrogen fuel supply at stations for highway trucks, rail, and even nearby airports. Ports can also be hubs of sites for bunkering of fuel for large volume uses for sea-going maritime operations including use of tugboats, patrol boats, barges, passenger ferries, and large ocean-going vessels that connect other cities, regions, and countries.

Using the maritime nexus as connective infrastructure additionally allows massive quantities of renewable hydrogen and hydrogen-derived fuels to be distributed efficiently over great distances. This can be done by using ships that run on as well as transport these fuels and capitalizing on the quick creation and flexibility of shipping routes compared to highway transportation and pipelines.

In general, port end-uses will need to intersect with hydrogen transmission and distribution to address the challenges of limited available space around ports for hydrogen production. Developing this distribution infrastructure, which can deliver safe, reliable, and cost-effective renewable hydrogen at scale, will be critical to enabling greater adoption and use of hydrogen at the ports.

Port Intersection with Maritime Green Shipping Corridors

Port operations intersect with the concept of green shipping corridors (GSCs) and other similarly structured clean energy marine transportation operations, particularly focused on the transoceanic voyage itself. GSCs are emerging as key tools for accelerating decarbonization initiatives in marine transportation as well as linking broader regional energy transition initiatives, including connecting regional hydrogen hubs into a national/international renewable clean hydrogen network. Dozens of GSC initiatives have been announced and others are in the works. An innovative "green shipping corridor matchmaker" tool with route maps and other information has been established to help assist with further development of this concept.[7] It should be noted that many GSCs are focused on hydrogen-derived fuels such as methanol and ammonia and need to ensure compatibility of fuels and fueling at both ends of the GSCs.

Port Intersection with Land Transportation Sector

Port operations also intersect with the land transportation sector, including Class-8 drayage trucks and switcher locomotives that connect ports with major rail lines. Multi-use hydrogen fueling stations, as mentioned, could be located near ports to fuel port-based vehicles as well as fuel-cell electric transit buses, delivery vans, and light-duty vehicles.

Other Potential Ways Ports Intersect with Renewable Hydrogen Activities

Additional opportunities where key existing facilities and infrastructure can readily support, and be retrofitted to meet, the needs of future renewable hydrogen hubs include:

- Offshore wind for offshore renewable power to generate green hydrogen;
- Subsea pipelines, power cables, operating equipment, and geological storage features;
- Port facilities for onshore hydrogen production/storage/use/distribution (including bunkering barges/vessels) and hydrogen-derived fuel;
- Harbor, river, and waterway infrastructure for supporting movement of hydrogen and hydrogen-derived fuels; and
- Shipyards and waterfront manufacturing facilities that can support construction/deployment of clean energy technology in the maritime domain.

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[7] Mission Innovation, *Green Shipping Corridor Route Tracker*, http://mission-innovation.net/missions/shipping/green-shipping-corridors/route-tracker/

Section 2: Hydrogen Applications at Ports

2.1. Drayage Trucks

Heavy-duty drayage trucks are Class 8 trucks (over 33,000 pounds of gross vehicle weight rating) that transport cargo containers between seaports, border areas, or intermodal terminals. Much of this cargo is transported within the South Coast Air Basin, up to approximately 100 miles, but some cargo may be transported several hundred miles within the State or to neighboring states. Fuel-cell electric vehicles in this class are now entering into commercial production after several years of prototype testing. Fuel-cell electric drayage trucks currently fall into two groups:

- Ground up new builds where cab chassis and hydrogen powertrain are designed as one cohesive unit; and
- Hydrogen fuel cell retrofits of traditional diesel ICE class 8 trucks either for new modified designs or for trucks already on the road.

Figure 3: Commercial Fuel-cell Powered Drayage Truck

Source: Hyundai

Commercialization Status of Drayage Trucks

Commercial status of fuel cell drayage trucks is relatively high compared with other hydrogen-based port equipment, currently in prototype testing and early commercialization. Multiple OEMs intend to fully commercialize these vehicles by the 2026-27 timeframe.

2.2. Top and Side Loaders

Top and side loaders are types of heavy-duty lift trucks that can lift cargo containers and move them short distances, organizing them around port facilities and placing them on trucks or rail cars for further delivery.

Figure 4: Fuel Cell Powered Electric Top Loader at Port of Los Angeles

Source: Center for Transportation and the Environment

Commercialization Status of Top and Side Loaders

Hydrogen powered top loaders are in prototype stages. Hydrogen fuel cell retrofits of ICE diesel top loaders may show promise, but retrofits are complicated because of incompatible computer control technologies and are not the current focus of many manufacturers. Commercial penetration for more conventional warehouse medium-duty forklifts could aid in eventual penetration for heavier-duty top loaders.

Yard Trucks

Yard trucks or terminal tractors are heavy-duty trucks that operate on port terminals to move cargo containers short distances, typically not operating on public roads. Fuel cell powered yard tractors seem to still be 2 to 3 years away from commercial deployment but are currently being tested in a few locations. Unlike drayage trucks, yard tractors do not leave port facility and hence need on-site dedicated hydrogen fueling capability.

Figure 5: Fuel-cell Powered Yard Truck Prototype

Source: REV Group[8]

2.3. Rubber-Tired Gantry Cranes

These large cranes can lift and stack cargo containers while operating on rubber tires, allowing considerable flexibility of movement around port yards. They typically have very demanding duty cycles, operating 10-20 hours per day, and are heavily polluting when operating on diesel fuel. Hydrogen RTGs are in prototype stages of commercial development. Along with economic considerations, the obstacle to further use of these technologies includes the provision of hydrogen fuel, common to other port applications. As a near-term possibility, some promise has been shown in retrofitting diesel combustion-engine models while purpose-built fuel cell RTGs are reaching full commercialization.

[8] REV Group, "Capacity Trucks Introduces First North American Hydrogen Fuel Cell Electric Hybrid Truck Built From The Ground Up," 2021, https://revgroup.com/capacity-trucks-introduces-first-north-american-hydrogen-fuel-cell-electric-hybrid-truck-built-from-the-ground-up/

Figure 6: Hydrogen Fuel Cell Powered Rubber-Tired Gantry Crane

Source: Port of Los Angeles

2.4. Heavy-Duty Forklifts

These forklifts are capable of lifting loads up to over 30,000 pounds in the heaviest class and are widely used around ports for various cargo handling operations. Heavy-duty forklifts running on fuel cells are still in a pre-commercial phase, but Toyota is now producing a medium-duty model, with several dozen of these operating at various plants, including Motomachi in Japan. The model has a lifting capacity of 5,000 pounds and can be quickly refueled with hydrogen stored at 350 bar (5,000 psi).

Figure 7: Medium-Duty Fuel Cell Powered Forklift

Source: Toyota[9]

2.5. Switcher Locomotives

Switcher locomotives are used to move rail cars over short distances and at low speeds, to assemble them into larger arrays of cars for longer-distance transport. They typically operate on diesel fuel and may idle for significant periods of time, producing emissions even when not in use.

A fuel cell-based switcher locomotive uses a fuel cell unit and a battery unit to provide the electric power to electric motors on the axles of a retrofitted diesel switcher locomotive. When hydrogen is used as the fuel for the fuel cell, GHG emissions are commensurate with production and distribution methods. If the hydrogen is produced using renewable clean resources these emissions are very low.[10] Since hydrogen combines with oxygen to produce water in a fuel-cell based system, there would be no local pollution at the port.

[9] Toyota Materials Handling, https://www.toyotaforklift.com/resource-library/blog/energy-solutions/hydrogen-fuel-cell-forklifts-an-alternative-energy-solution

[10] The DOE Clean Hydrogen Production Standard proposal establishes “a target of 4.0 kgCO2e/kgH2 for lifecycle (i.e., "well-to-gate") greenhouse emissions associated with hydrogen production,” https://www.energy.gov/eere/fuelcells/articles/clean-hydrogen-production-standard

General advantages of fuel-cell based switcher locomotives include:

- Eliminate local PM and NOx pollution from switcher operations at the ports;
- Requires less electric energy capacity of the ports compared to battery electric options; and
- Fuel cell locomotives can be refueled in a matter of minutes, whereas their battery-electric counterparts take many hours to recharge.

Commercialization Status of Switcher Locomotives

Sierra Northern Railway (SERA) is developing a California Energy Commission (CEC) funded "Zero Emission Hydrogen Fuel Cell Switcher Locomotive" project. This machine is a retrofitted diesel-electric locomotive with the diesel engine removed. The locomotive design will replace the traditional diesel power system with advanced fuel cells, hydrogen storage, an advanced battery system, and advanced control technologies. The system will supply electric energy to the electric motors on each of the four axles. When fully developed, this technology could be used to replace all the switcher locomotives at ports and eventually all of the 260 switcher locomotives in California, enabling the advantages of hydrogen use to be available at all locations. As a part of the grant from the CEC, SERA will be providing a replication study and currently has its own plans to convert its entire fleet of 41 diesel locomotives to run on zero-emission hydrogen fuel cells. The company has recently been awarded $15.6 million to convert three additional switchers to hydrogen fuel-cell technology, along with enhancements to test track and hydrogen fueling capabilities.[11]

[11] https://calsta.ca.gov/-/media/calsta-media/documents/port-and-freight-infrastructure-program-pfip-annual-report-finala11y.pdf

Figure 8: Hydrogen Switcher Locomotive Concept

Sierra Northern Railway Zero Emission Hydrogen Switching Locomotive

Source: Sierra Northern Railway[12]

The initial SERA fuel cell switcher has onboard hydrogen fuel capacity more than 200 kg at a pressure of 5,000 psi (350 Bar). SERA expects to refuel with hydrogen approximately once a week based upon the duty cycle. Many other high-volume ports (both ocean ports and inland ports) may/will have larger duty cycles that may require refueling to occur more frequently. If a port uses 10 switchers daily nearly continuously, the units will need about 2,000 kg every other day, or about 1 MT (metric ton) per day of hydrogen on average. The refueling and dispensing station for the units can be located at the rail yard, hence not crowding the unloading port side location.

Fuel-cell switcher locomotives will need infrastructure development for hydrogen supply and further support for testing, qualification, and commercialization of the technology. CARB approved an In-Use Locomotive Regulation in April 2023 that would have included zero-emission requirements for locomotives operating after 2030, as well as air district-specific reporting requirements for locomotive activity.[13] However the regulation implementation has been paused as the U.S. Environmental Protection Agency (EPA) has not yet granted the necessary waiver needed at the Federal level.

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[12] Sierra Northern Railway, https://www.prnewswire.com/news-releases/sierra-northern-railway-unveils-new-hydrogen-powered-zero-emission-switching-locomotive-design-concept-301618654.html

[13] CARB, *Notice of Decision In-Use Locomotive Regulation*, September 2023, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/locomotive22/locomotive_nod.pdf

2.6. Shore Power

Shore power, traditionally known as cold ironing, is a means by which ocean-going vessels can be powered from shore while they are at berth, allowing them to turn off onboard power generators and reduce port emissions. This method is typically grid powered but could be powered by stationary fuel-cell systems in the future, particularly in areas where grid power capacity is limited, or grid-tied electrical infrastructure is too costly or difficult to construct.

The advancement of hydrogen fuel cell technologies to TRL 8 to 9 has resulted in the commercialization of large hydrogen fuel cell generators (e.g. 250 kilowatt (kW), 500 kW, 1 megawatt (MW), 1.5 MW) that can be either mobile, portable, and/or placed in fixed installations.

With the advent of a growing hydrogen infrastructure for California's ports, such large fuel-cell generators are now commercially available. Their in-port applications can provide sustainable power resiliency, as well as green power where grid upgrades/expansions are either unavailable, costly, too time consuming, or where the need for power is intermittent (e.g. seasonal).

Various California port power needs have traditionally been met with grid electricity that is in large part generated in power plants that burn fossil fuels. With cost-effective and readily available renewable hydrogen fuel sources, fuel-cell generators can meet the same needs with fewer interruptions and with zero emissions. Applications range from shore power to powering port operations and equipment to recharging stations for EVs–or even a combination of backup power and EV charging stations.

These fuel-cell systems can be deployed more quickly than traditional grid-connected shore power systems, which require extensive infrastructure. For example, Los Angeles Department of Water & Power (LADWP) representatives have indicated that a minimum of seven years is a reasonable amount of time to allow for new onshore power to be installed at the Outer Harbor because the project would involve significant underground trenching to lay conduit. The project involves constructing a 35-kilovolt station and switchgear along with 11 kilovolt-amp switchgear, outlets, and cable management systems. Alternatively, hydrogen fuel cell-based shore power systems, especially somewhat smaller ones on the order of 1-2 MW, might be permitted and installed in less time, one the order of 1-2 years.

Besides shore power and backup power, hydrogen fuel-cell generators can support EV charging as the adoption of battery electric port equipment and drayage trucks increases and further strains the grid. Although stationary batteries can provide supplemental energy and power for EV charging stations, port operations require a high level of uptime and hydrogen fuel cells can provide a more energy-dense solution than stationary batteries. Because of this capacity restriction, marine terminal operators may be faced with replacing a single diesel-powered piece of equipment with two very expensive battery EV pieces of equipment due to charging downtime. In terminals where space is already scarce, this requires twice the space previously needed for the same mission equipment, on top of the space required by the charging infrastructure. Companies such as Plug Power and GenCell have developed grid-independent EV charging solutions based on hydrogen fuel cells and, in the case of GenCell, using ammonia as an energy carrier and with systems that can power up to 10 75-kW fast chargers.[14]

Table 2: Hydrogen Fuel Cell Generator Use Cases

Application	Duty Cycle
Shore Power - Container Vessel	1-2 MW max for newest class vessels, 3-4 days at a time[15]
Shore Power - Cruise Vessel	12 MW max for newest class vessels, max hotel load rarely exceeds 8MW, 10h, 4d per week[16]
Shore Power–RoRo Vessel	1.5 MW peak power draw for 3h per day, remaining hotel load 200-300kW[17]
Shore Power–Reefer Containers	Varies but one system is 23 kW start-up, 16 kW continuous[18]
Emergency Backup Power	Varies by application, building loads[19]
EV Equipment Charging	500 - 1.5 MW+, frequency of use varies

Source: Rehlko

2.7. Additional Applications

- **Dredging vessels**–and fuel cell barges that can supply power to dredgers. These are large power users and there is at least one example globally of a hydrogen-

[14] *Green Car Congress*, https://www.greencarcongress.com/2022/09/20220916-evox.html
[15] Interviews with CMA-CGM
[16] Interviews with Port of Los Angeles per Carnival and NCL
[17] Interviews with Toyota Logistics Services/K-Line and SSA Marine
[18] Interview with ESL Power Systems, Reefer shore power connector manufacturer
[19] Rehlko subject expertise

powered trailing suction hopper dredge, that is currently being built and intended to be used to maintain the coastline in the Netherlands.[20]

Port-based hydrogen production–due to the high demands of shore power and battery-electric equipment, California ports are already power constrained, with limited capacity to perform onsite electrolysis. Onsite solar and wind power production is limited by the nature and locations of port operation. However, there may be some adjacent biogas opportunities for ports (e.g., EBMUD and Port of Oakland) where biogas could be reformed into hydrogen and delivered by truck or pipeline.

Section 3: Challenges of Hydrogen in Ports

3.1. Technical Challenges

California State policy requires carbon neutrality economy-wide by 2045 and increasingly demands stationary and mobile applications to transition to zero emissions. Given this, it is useful when examining the technical challenges of applying renewable hydrogen to port applications to compare these to battery-electric technologies, which currently are the only other zero-emissions option with potential to fully decarbonize. Battery and fuel-cell systems are both viable for most port applications, with pros and cons. Fuel-cell systems, on the one hand, presently have lower TRLs and less operational experience while offering potentially longer ranges of operation and faster refueling times. Fuel-cell equipment is more expensive and renewable hydrogen fuels are available in extremely limited supply. Installing charging systems for battery-based equipment is more disruptive to port operations, requiring trenching for electrical conduit from transformers to charging stations, whereas hydrogen fueling can be more centralized with no need for trenching across port operational areas unless pipelines are installed.

In addition to logistical challenges, electrical upgrades for battery-based equipment can present major economic challenges for ports. The Electric Power Research Institute conducted a recent electrification study for the POLA and found that current upgrade plans will be insufficient to meet future demands of electrified CHE. Grid upgrade levels in a 100% electrification scenario of up to 277 MW with unmanaged equipment charging and 133 MW with managed charging of CHE were estimated in the 2030 timeframe, relative to existing port power demands of 119 MW–meaning port power access would need to increase by approximately 1-2x over present levels. A preliminary

[20] Marine Log, Royal IHC is developing hydrogen-fueled TSHD, April 2021, https://www.marinelog.com/inland-coastal/dredging/royal-ihc-is-developing-hydrogen-fueled-tshd/

assessment of the use of hydrogen for some electrification efforts entailed significantly lower grid upgrade levels.[21]

Furthermore, all CHE at ports must be able to operate for two consecutive shifts, with less than one hour between shifts to fuel or charge the equipment. Integrated battery-electric CHE have struggled to meet this two-shift requirement, though some swappable-battery automated systems are in use at marine terminals. Hydrogen-powered equipment can potentially address duty-cycle concerns with greater energy storage and faster fueling times than battery-electric platforms. However, fuel-cell-based equipment has also encountered packaging challenges with respect to fuel tanks, and heavy-duty hydrogen fueling standards (J2601/5) are currently evolving to accommodate hydrogen tanks with capacities greater than 10 kg.

Additionally, most port cargo handling equipment today is fueled by mobile diesel fuel trucks. This allows operators to bring fuel to the equipment, increasing the operational time of the CHE. This is particularly important for RTGs that have high utilization and fuel consumption but are impractical to regularly move back to a central fueling/charging facility. Consequently, mobile fueling solutions will be important to improve the operational viability of hydrogen-powered CHE.

Currently, there are very few examples of hydrogen/fuel cell systems being used in port applications, while battery-based technologies, which were incentivized years ago, are gradually being incorporated. For example, Table 3 shows the penetration of battery-electric technologies at the POLB. As the table illustrates, a wide variety of equipment is already operating on electrical power.

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21 EPRI, *Zero-Emission Planning and Grid Assessment for the Port of Los Angeles*, June 2023, https://www.epri.com/research/products/000000003002025783

Table 3: Cargo Handling Equipment Vehicle and Fuel Types at the Port of Long Beach

Equipment	Electric	Propane	Gasoline	Diesel	Total
Forklift	10	80	25	108	223
RTG crane	9	0	0	64	73
Side handler	0	0	0	5	5
Top handler	2	0	0	201	203
Yard tractor	1	0	136	509	646
Sweeper	2	7	0	13	22
Other	262	7	2	64	335
Total	**286**	**94**	**163**	**964**	**1,507**
Percent of Total	**19%**	**6%**	**11%**	**64%**	

Equipment	2022 Electric Count
Automated guided vehicle	102
Automatic stacking crane	69
Cone Vehicles	3
Crane	7
Forklift	10
Man Lift	1
RTG crane	9
Ship to shore crane	75
Sweeper	2
Top handler	2
Truck	5
Yard tractor	1
Total	**286**

Source: Starcrest Consulting Group LLC[22]

As mentioned above, the TRL is a measure of the relative level of development and commercialization status of emerging technologies. The following is a general assessment of the TRLs of battery and fuel cell applications for the various segments of major port equipment and current major limitations and opportunities presented by both types of technologies.

[22] Starcrest Consulting Group LLC, "Port of Long Beach, Air Emissions Inventory–2022," August 2023

Yard Tractors

- Battery Yard Tractors: TRL of 8-9.
  - Current limitation is ability to complete two (2) shifts per day with a full charge cycle in between.
  - Current demonstrations indicated that it is difficult to complete 2 full shifts due to insufficient battery capacity. Opportunity charging can extend operating times but require high-power charging systems and long charging times.
- Fuel Cell Yard Tractors: TRL of 6-7. Two major current limitations are:
  - Lack of OEMs that can produce prototypes that can complete the duty cycle of conventional diesel Yard Tractor.
  - Access to fuel/refueling hydrogen infrastructure.

Top Handlers

- Battery Top Handlers: TRL of 6-7. Limitations are:
  - BEV Top handlers require a massive battery pack for both power/energy and ballast (~1000 kilowatt-hour and ~5 tons).
  - Difficult to complete 2 full shifts as battery charge times are large and with high system performance demand.
- Fuel Cell Top Handlers: TRL of 5-6. Opportunities are:
  - Logical path to technology penetration is future retrofitting near zero emissions (NZE) diesel hybrid electric top handlers to allow H_2 fuel infrastructure time to be rolled out and mature.
  - Diesel engines can be swapped for H_2 fuel cell systems as technology matures.

Rubber Tire Gantry (RTG) Cranes

- Battery RTG Cranes: TRL 8-9.
  - Grid Electric RTG cranes seem most feasible zero-emission technology.
  - Currently the most complete and robust zero-emission, heavy-duty equipment at seaports.
  - Greatest challenge to wide scale adoption is electric infrastructure needed to provide reliable power.

- Fuel Cell RTG Cranes: TRL of 5-6.
  - Technology is viable but practical implementation is questionable.
  - Grid Electric zero-emission RTG Cranes already perform the duty cycle as well as other more traditional types (diesel / diesel electric). An apparently logical path to technology penetration is the future retrofitting of NZE diesel hybrid electric RTGs by replacing the diesel generator with a fuel-cell generator.

Large Capacity Forklifts

- Battery Forklifts: TRL of 7-8 (for large capacity). Port of Stockton shows the technology is ready, but duty cycle not the same as SPBP (larger seaports).
- Fuel Cell Forklifts: TRL of 6-7 (for large capacity). OEM interest is hard to gauge. Prototype demonstrations will be required to move TRL up to 8+.

Shore Power Systems

- Fuel Cell-Based Shore Power: TRL 8 to 9.

Although hydrogen fuel-cell based shore power has yet to be field installed and tested, equivalent systems used in stationary emergency backup and prime power applications do exist at a TRL of 8-9, fully commercial in some applications. These systems can be applied in the same way and scaled to the multi-megawatt scale with onboard paralleling controls for low-voltage applications and paralleling switchgear for medium-voltage applications.

Figure 9: Rehlko 100kW Hydrogen Fuel Cell Generator in 10-Foot ISO Container

Source: Rehlko

Challenges do exist, such as the continual need to better understand duty cycles and how hydrogen fuel-cell systems are best supported by suitably trained personnel. While the infrastructure required for fuel distribution to various H_2 FC generators is a work-in-progress–there is rapid progress as the hydrogen ecosystem expands across various applications.

Containerized hydrogen fuel-cell generators are housed in boxes that are familiar to terminal operators, and that are easily moved by current cargo handling equipment. Such systems can be placed on truck trailers or on MAFI roll trailers (in mobile or portable versions)

Regulatory challenges exist in that authority having jurisdictions (AHJs) may be unfamiliar with hydrogen fuel-cell generators - especially as codes and standards are still being adopted. Connecting AHJs who have experience with permitting hydrogen and fuel cell systems with those that are less familiar can be a useful strategy to help address this challenge.

Other Port Related Applications:

- Fuel Cell Tugboats: TRL of 5
- Fuel Cell Dredger Boats: Low TRL for fuel cell powered vessels
- Fuel Cell Fire and Pilot Boats: TRL of 6-7

Overall Considerations

Additional key technical challenges relate to important operational considerations, including the following points:

- **Multiple daily duty cycles:** Port duty cycles for various types of equipment can be challenging with two or even three shifts per day and limited potential for downtime for vehicle fueling/charging, giving hydrogen fuel cell technologies a potential advantage over battery-based systems.
- **Limited space for refueling at scale onsite will require coordinated planning:** In the near-term, technologies for hydrogen refueling such as mobile refuelers and hydrogen fueling on delivery skids can be used to support relatively small numbers of vehicles as they are initially deployed. But larger numbers of vehicles will require larger capacity and more permanent fueling arrangements, with potential challenges due to the limited space for refueling around ports, affecting all types of vehicle and fuel systems.
- **Mobile fueling solutions need further development:** Systems capable of transporting and dispensing hundreds of kilograms in less than one hour to accommodate fueling of CHE between shifts.
- **Refinements are needed in hydrogen tank packaging on space constrained equipment:** For example, in yard trucks these are needed to provide sufficient range without impacting operational safety or capability.

Fueling systems for drayage operations will primarily be sited outside of marine terminal boundaries, either adjacent to the terminals on port-controlled land, or more distant along key corridors. This requires coordination of a large network that includes related goods-movement sectors or other transportation sectors. At the ports themselves, one could consider the concept of “hydrogen ecosystems” at port areas, with multi-faceted applications and complementarity with grid-tied equipment where appropriate. For hydrogen this may imply different storage solutions and dispensing pressures for various types of equipment.

3.2. Market Challenges

Market challenges for hydrogen/fuel-cell port equipment are evidenced above with relatively immature commercialization status for the various types. Fuel-cell systems for light-duty vehicles and stationary applications are fully commercial, and adapting to port solutions would involve minimal technology development but on-board packaging and fueling logistics will require development. None of the mobile technologies reviewed above are at a full TRL level of 9, but drayage trucks are approaching that level. This slower advancement of fuel-cell mobile equipment is partly the result of early incentive funding going toward battery electric, rather than fuel-cell electric, technologies.

The largest challenges in this sector are the development of cost-effective fuel-cell based equipment and the provision of relatively low-cost, renewable hydrogen at port locations. Battery-electric and hydrogen fuel-cell electric cargo handling equipment cost significantly more than traditional diesel equipment and the availability of hydrogen fuel to power demonstration fuel cell equipment at ports is already challenging.

Another key market challenge is financing for port-based hydrogen drayage trucks, and potentially also for cargo handling equipment (CHE). For example, many independent truck drivers do not have the credit required to purchase a $500,000+ vehicle. Additionally, existing incentive schemes are challenging for non-native speakers and require the purchaser to pay sales taxes for the full amount of the vehicle. The costs of insurance and maintenance are also much higher than for diesel-powered equipment.

3.3. Policy Challenges

There is not yet an explicit mandate for hydrogen to be 100% renewable or zero carbon by 2045, unlike for retail electricity sales through Senate Bill (SB) 100[23]. However, Assembly Bill (AB) 1279[24] and CARB's 2022 Scoping Plan target require reaching carbon neutrality economy-wide by 2045, which will mean hydrogen has to decarbonize by that date.

Over the past two decades, California Air Resources Board (CARB) regulations have been enforced in accordance with the Diesel Risk Reduction Program adopted in 2000. Revisions have been made to the regulations to strengthen requirements, incorporate technology advancements, and address greenhouse gas emissions in alignment with the CARB Scoping Plan[25]. Major recent policy actions for advancing zero-emission technologies were the adoption of CARB's Advanced Clean Truck rule in 2020, followed by the Advanced Clean Fleets (ACF) rule in 2023, which included accelerated action for drayage trucks. However, full implementation of the ACF rule requires a waiver from the U.S. EPA and the waiver request was withdrawn in early 2025, so the regulation currently only applies to State and local government fleets. CARB was also planning for a revised cargo handling equipment (CHE) regulation that was anticipated to set

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[23] *SB 100*, September 2018,https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100
[24] *AB 1279*, September 2022, https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1279
[25] CARB, *Scoping Plan for Achieving Carbon Neutrality,* December 2022, https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents

timelines for achieving zero-emission operations in the port terminals, but this regulation is currently on hold.

Meanwhile, the low-carbon fuels standard (LCFS) regulation currently does not explicitly include hydrogen/fuel cell port equipment except forklifts and yard trucks, where more battery technologies are included, although CHE technologies are not prohibited from generating LCFS credits. To gain credits, interested entities must apply for an Energy Economy Ratio (EER)-adjusted CI pathway in which the EER developed for the equipment is part of the application process. For both electricity and hydrogen, credits are generated by reporting the fuel dispensed into the CHE. For stationary fuel cells operating at ports, it could be possible for a project with electricity generated from fuel cells derived from different feedstocks to apply for a Tier 2 pathway in the LCFS. However, if any entity wants to utilize biomethane as the feedstock for the fuel cell, the biomethane must be directly supplied to the fuel cell generating the electricity.[26] This electricity could be used onsite or exported onto the grid where the attributes from the generated electricity may be matched to dispensed electricity for any transportation application.

More generally, there are also questions for ports about jurisdiction and who has decision-making authority. As ports in California serve as landlords, Port Authorities do not own or operate equipment. Port Clean Air Action Plans, such as the one jointly adopted by the POLA/POLB, present goals and strategies to be implemented by the Ports to encourage emission reductions. Strategies implemented by ports include lease terms, incentive programs, and securing grant funds for demonstration and deployment of zero-emission equipment. The CEQA process required for terminal expansions can include mitigation measures, such as implementation of zero-emission technologies, to address significant impacts. Furthermore, grants and incentives are potential sources that can assist in transitions to zero-emissions, and authorities having jurisdiction (AHJ) can be utilized to assure compliance.

Additionally, sometimes policy conversations silo hydrogen and hydrogen fuel cell electric solutions and battery electric-based solutions as separate or even as a competition. Better alignment between hydrogen and battery electric pathways, and understanding how to optimize them, is important to show that both can contribute simultaneously to meeting the state’s ambitious decarbonization goals.

3.4. Social Challenges

Hydrogen technologies at ports are unfamiliar to community members and present new safety risks. There are multiple streams of information around hydrogen that

[26] The requirements for low-CI process energy are specified in section 95488.8(h) of the LCFS regulation.

community-based organizations (CBOs), environmental advocacy groups, and community members are receiving, in some cases dismissive of the overall hydrogen "value proposition." The goal of hydrogen use at ports is to provide zero-emission alternatives to conventional equipment that meets duty cycles and economic and infrastructure considerations. Furthermore, the establishment of renewable hydrogen fuel use at ports will stimulate an ecosystem that embraces related, hard-to-abate equipment like trains and vessels.

To this end, ARCHES must undertake a comprehensive education and two-way listening plan to address these concerns, sharing the most recent and technically sound information in platforms that are accessible to communities, including those who are traditionally underrepresented. This process can leverage best practices on community engagement learned through the AB 617[27] process. Education should continue to carefully outline the pros and cons of hydrogen implementation in as unbiased a manner as possible. It should be sure to continue to respect and address the legitimate concerns that these organizations have around hydrogen implementation in the state. Many community stakeholders embrace battery electric technology, and the effort should acknowledge that battery-based solutions will play a dominant role in the future. Simultaneously, hydrogen-based solutions have a role to play in a number of key applications as well. Both solutions can and need to be implemented in parallel, playing on the strengths that each provides, not either/or.

Additionally, as with the earlier adoption of battery electric technologies, first responders need immediate training to address real hydrogen safety risks and allow for successful permitting of hydrogen projects in their communities. Once trained and comfortable with hazard mitigation strategies related to hydrogen, first responders can help communities grow comfortable with these new technologies.

3.5. Workforce Challenges

Fundamentally, there are workforce supply issues along with limited education opportunities and public awareness gaps. Technical skills and knowledge required for the ARCHES hydrogen hub already exist in various sections of the labor market but need to incorporate hydrogen-specific training into established programs. A particular need is for qualified truck and forklift operators who are willing to be trained to operate hydrogen/fuel cell vehicles.

Union apprenticeships provide a labor workforce and have robust community outreach and advertising mechanisms. There are resources and mechanisms for instructors, classrooms, curriculum, outreach, etc. to scale the workforce very quickly. Community

[27] *AB 617*, July 2017, https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180AB617

colleges routinely adjust curriculum to address advancing technologies and prepare students for specialized trades. The multi-core craft curriculum (MC3) for some trades meets math requirements and enables applicants to bypass the testing process. Graduates from MC3 are known to have a high placement rate.

Workforce training progress steps include better guidance on workforce development needs, both for industry and specific training centers. An expanded and trained workforce for maintenance workers and technicians is needed. This includes technicians for fueling stations as well as trucks and CHE, potentially building on transit bus training programs that have some similarities.

In addition to specialized training for hydrogen systems including high pressure gasses and cryogenic systems, there is also a general shortage of electricians in the United States.[28] This is not specific to the port sector but remains an important concern given the large amount of electrical work implied by the developments to come.

Furthermore, there is an important opportunity for a "just" transition and equitable, diverse, and inclusive workforce development to be integrated into this effort. Projects built in impacted communities will likely include project labor agreements (PLAs) with a local hire component. Many ports already have PLA requirements for construction work. Emphasis should be placed on union apprenticeships and related programs composed of workers from diverse backgrounds, including from DACs. Some trades have minority caucuses that help prepare under-represented minorities and other individuals from DACs to both enter apprenticeship programs and succeed once in the program.[29] See Section 4.4 for concepts for workforce development programs based on a large array of existing and emerging programs.

Section 4: Moving Forward

4.1. Overcoming the Challenges

Among the most important near-term needs for this sector is proving that hydrogen and fuel cell technologies can work well in port settings through extended pilots and trials.

Critical here is the development and real-world validation of concepts for dispensing and storage of hydrogen and hydrogen-derived fuels at ports given land use requirements and safety considerations. Examples include emerging solutions like liquid hydrogen storage and potential innovative energy carriers, such as ammonia and

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[28] WSJ, *America Is Trying to Electrify. There Aren't Enough Electricians*, February 2023, https://www.wsj.com/articles/america-is-trying-to-electrify-there-arent-enough-electricians-4260d05b?mod=Searchresults_pos1&page=1

[29] Electrical Workers Minority Caucus, https://www.ibew-ewmc.com/

other liquid carriers with high energy density, that could potentially serve multiple hydrogen and fuel cell applications from port cargo handling equipment to shore craft to large ocean-going vessels.

Figure 10: Liquid Hydrogen Terminal in Kobe, Japan

Source: Kawasaki Heavy Industries

Ammonia is currently the world's second most widely traded commodity, used mainly in agriculture, and has an energy density that is 4x that of compressed hydrogen (at 350 bar). Ammonia is typically stored at a relatively low pressure of 10 bar or liquified at a temperature of -30° C (compared to -250° C for liquid hydrogen). The current global market for ammonia is around 200 million metric tons per year, this is expected to more than triple by 2050, with the majority of ammonia being used as a fuel or hydrogen carrier in 2050. Moreover, close to 200 ports around the world already store and handle ammonia. However, ammonia is toxic to humans and to marine environments if released or spilled, and communities near California ports that have not handled large amounts of ammonia have voiced strong opposition. The same outreach necessary for the acceptance of hydrogen technologies, along with specialized handling and safety protocols, will be needed to advance ammonia at California ports.

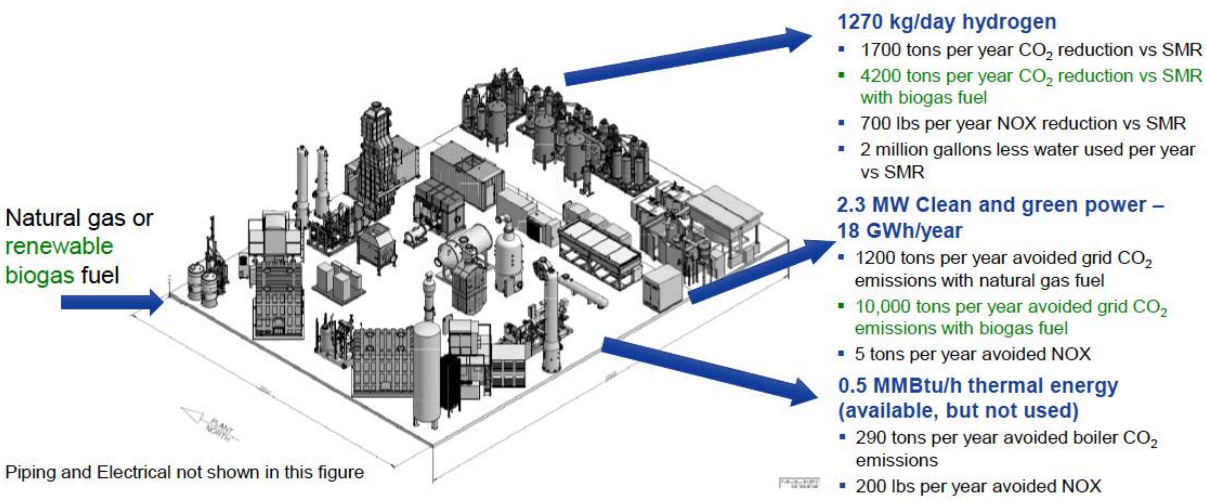
Methanol, once derived from hydrogen, can be stored as a liquid at ambient temperature and has lower toxicity concerns than for ammonia. Methanol can be directly combusted in ship engines or reformed into hydrogen for use in fuel cell-based port applications.

In the big picture, an increasing focus on the pollution around port communities has led to various grant programs at the state and national levels to address these concerns. Some of these are specifically targeting hydrogen and fuel cell solutions, while others are more technology agnostic.

Infrastructure Case Study: Port of Long Beach

As one example of an innovative approach to providing hydrogen fueling for port-based drayage trucks as well as renewable electricity, Toyota Logistic Services and FuelCell Energy are working together on an advanced tri-generation project located at POLB. In the project that is currently nearing completion, 1,270 kg of hydrogen will be produced per day based on the use of directed biogas as a feedstock, along with 2.3 MW of electrical power for export to Southern California Edison. The hydrogen produced will be used to fuel light-duty vehicles, such as Toyota Mirais, that are imported through POLB, as well as a fleet of 20 or more heavy-duty drayage trucks.

Figure 11: FuelCell Energy SureSource Hydrogen Tri-Generation Schematic



Source: FuelCell Energy

There are critical challenges for seaports due to their locations adjacent to dense urban areas and with pollution concerns. The community benefits plans being developed under ARCHES will be of high importance in meaningful engagement with these communities as further details of project implementation become available. Community engagement is critical at all stages of these efforts, from project conception and design through to implementation and ultimate operational experience.

Workforce and training needs are addressed in separate sections; however, union contracts often specify which labor groups are designated to perform certain tasks or operate certain equipment. The introduction of hydrogen technologies may necessitate reopening of contract negotiations to address new tasks. Once these designations are established, they usually carry on to subsequent contract negotiations.

4.2. Achieving Commercialization

Seaport operations involve large, specialized equipment that is often custom-built and very expensive. Achieving critical mass in this sector is an evolutionary process where new technologies will start out at a pilot scale as their features are better understood and then may move into wider implementation, and, finally, full commercialization within the sector.

The journey is just beginning for hydrogen and fuel cell technologies with their initial deployment at seaports for drayage trucks, top handlers, cranes, and large forklifts. Other applications discussed in previous sections may follow in the near and medium term as additional operational experience is gained and practical hydrogen fueling solutions for port applications are realized. In the near future, there will be a mix of zero-emission and conventional combustion technologies as traditional equipment is phased out. In the longer term, zero-emission technologies are expected to dominate due to policy directives and other factors, but with uncertain splits between battery-based and fuel cell-based technologies.

The split between battery-electric and fuel cell technologies is hard to predict and may be dynamic for the next couple decades as operational needs and economic factors stabilize. For all zero-emission technologies, initial funding support will be needed to achieve cost parity for capital, operational, and fuel costs until purchasing is scaled up and the equipment is cost competitive with incumbent technologies. This is unlikely to occur prior to 2030. Instead, hydrogen and fuel-cell technologies could proliferate more widely in this sector without significant public financial support by 2035.

4.3. Working Together

While every port in California is unique, there are common elements. In-terminal equipment is similar from port to port, as are on-road vehicles and other equipment that operates along goods movement and supply chains. This creates opportunities for shared learning and information across ports and for early adopters to transfer lessons learned across their operations.

Furthermore, in the context of the U.S. Department of Energy (DOE) hydrogen hubs, the California ports can collaborate with the Pacific Northwest ports as both regions have received award notifications with expectations of multi-year awards. As California is already leading with implementation of hydrogen technologies and has the first and second busiest ports in the U.S., it can be expected to be the main initial proving ground for advanced technologies. The Northwest Seaport Alliance in the Seattle/Tacoma area is the seventh-largest port in the U.S., handling a diverse array of cargo, including approximately 4 million TEUs annually, and is operating under strong directives for sustainability. Thus, the California and Pacific Northwest ports are well positioned to work together in a variety of ways to enable further implementation of hydrogen and fuel cell technologies.

4.4. Workforce Development

California has 125 joint apprenticeship and training committees (JATCs) within its labor union and construction trades, more than any other state. Instructors, classrooms, and labor/management apprenticeship committees are already in place. In addition, the state has curriculum development expertise to support training needs.

Constructive concepts include retraining programs, working with relevant labor unions, such as the International Longshore and Warehouse Union (ILWU), the Boilermakers Union, and learning from relevant example programs such as the Electric Vehicle Infrastructure Training Program (EVITP) for example.

Significantly, there are many additional resources in California for workforce training and development. The state's community colleges are an important resource. For example, Rio Hondo college offers a mechanics course focused on light-duty (passenger) fuel cell vehicles (FCVs), which could be adapted for port-related applications. Long Beach City College, in partnership with Long Beach Utilities, provides electric vehicle and high-voltage training. Additional programs are offered by Fresno City College and the "California State University 5" (CSU5), which includes CSU Los Angeles, CSU Long Beach, CSU Northridge, CSU Dominguez Hills, and California State Polytechnic University, Pomona. Certification programs, leveraging transit bus efforts, include those by Sunline Transit and the College of the Desert, provide a strong foundation. Their existing compressed natural gas training programs could be modified to encompass hydrogen systems.

In a significant recent development, in spring of 2023, POLA, POLB, and the ILWU announced the nation's first training facility specifically targeted at the goods movement sector. The Goods Movement Training Campus will provide a centralized location to attract, recruit, and retain workers in the sector. The partnership also includes the California Workforce Development Board and the Pacific Maritime Association. The ports will equally split the initial $110 million in project cost while working to secure additional funding for equipment and curriculum.[30][31]

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[30] International Longshore and Warehouse Union, *ILWU, Port Community, Gather to Celebrate $110 million funding for future social training center*, https://www.ilwu.org/ilwu-port-community-gather-to-celebrate-110-million-funding-for-future-socal-training-center/

[31] Pacific Maritime, *LA-Long Beach Ports' Goods Movement Training Campus Nets Funding*, April 2023, https://pacmar.com/la-long-beach-ports-goods-movement-training-campus-nets-funding/

Companies in the hydrogen and fuel cell sector in California are also key resources for workforce development for port applications and beyond. Symbio North America, for example, recently received a $9 million award from the CEC to establish a new hydrogen fuel-cell manufacturing and assembly facility based in Temecula. As part of the project, Symbio is collaborating with UC Riverside, California State University - LA, and Cerritos College to develop hydrogen academic programs that leverage support and existing contents developed in Europe. The resulting programs will be made available to the incumbent technicians in the Michelin Commercial Service Network, with an objective to train at least 185 professionals, students, technicians, and fleet operators by 2025.

Another relevant industry effort for workforce training is the Avantus Cleantech Career Academy, based in Los Angeles. The academy offers 24-week programs for young participants (16-24 years of age), focusing on communities of color and those who have historically lacked access to vocational training programs. The first 12 weeks of the program are paid work-based learning opportunities followed by a 12-week internship program with industry sponsors in the clean technology sector.

Finally, ports have initiatives for educating their communities. Ports provide scholarships and internships, provide in-class presentations, job fairs, and other activities that encourage young residents to join the workforce. POLB partners with two local high schools and its community college, all in disadvantaged neighborhoods, to advance academic curriculum with industry-relevant training and information to support academic and career development. More about these programs can be found at https://polb.com/community/education.

Section 5: How to Make Hydrogen Feasible in the Port Sector

5.1. ARCHES

ARCHES can help to improve the progress and demonstrate the feasibility of hydrogen in the ports sector in a variety of ways.

For example, ARCHES can:

- **Promote connections among potential hydrogen end-users**, such as the ports, potential producers, and potential distributors to help expedite conversations, planning (both near-term and long-term) and cross-collaboration to help the development of hydrogen infrastructure that can better meet the needs of end-users/producers and facilitate the longer-term vision of California's hydrogen market;

- **Share information on supply and demand centers collected by ARCHES for the DOE application** to support the development of California's hydrogen connective infrastructure;
- **Provide technical information about the relative benefits of hydrogen/fuel cells for port applications relative to other zero emission technologies**; and
- **Offer scalability models for expanding networks, centered around ports but also with synergies around larger transportation and power sector concepts.**

ARCHES can provide step-by-step frameworks for logical expansion of production and deployment, with information about economies of scale in hydrogen delivery costs. Critical early implementation and proof-of-concept information can provide increased ability for end-users to gain trust in the technologies. This is especially important for mission-critical applications such as marine port operations, many components of which are relatively low profit margin and already under significant pressure from recent supply chain disruptions and increased costs of operations.

5.2. The State of California

The State of California can have a supporting role with ARCHES to help understand the role of hydrogen and fuel cells at port settings, in addition to the policy actions described above with regard to the various State agency regulatory and funding programs.

Include and clarify roles and definitions of clean hydrogen
There is in particular some uncertainty around the role of hydrogen sources derived from biomass sources, along with electrolysis from renewable electricity, to contribute renewable and clean hydrogen for use in the port sector. Biomass sources include biosolids from wastewater treatment, biogas from the digesters themselves, forest waste, and municipal solid waste among others. Some definitions of renewable hydrogen include only electrolysis, but biomass-based sources can produce hydrogen with low or even negative carbon intensity depending on the pathway and conversion process. The state should clarify the role of these additional renewable sources, educate stakeholders on the life-cycle benefits of creating hydrogen from biomass, and incentivize the development of sustainable sources of hydrogen in the state.

In 2022, the Legislature passed SB 1075, which called for CARB, in collaboration with the CEC and CPUC, to produce a comprehensive report on hydrogen, to cover the development, deployment, and use of hydrogen across all sectors as part of achieving the State's climate, air quality, and energy goals. The report is expected to be published by the end of 2025.[32] The State began a series of workshops in 2023 to gather community and stakeholder feedback in developing this report.

Incentive funding for demand-side equipment

The State has provided incentive funding for battery-electric port equipment and hydrogen and fuel cell-based systems. Battery-electric technologies developed earlier and there are currently fewer market offerings for hydrogen technologies.[33] As these technologies reach commercialization, the State should consider a fuel-agnostic approach through its incentive and grant funding programs and let the market decide on the best options.

5.3. The Higher Education Sector

California universities and community colleges can help by further developing hydrogen curricula and concepts and educating students to ready them to join the workforce and contribute to advancing the progress of the overall hydrogen ecosystem in California. The universities can help to develop information around best practices for the application of hydrogen in port settings and promote the dissemination of these materials as neutral third parties. Of course, universities can also conduct and partner with industry on both basic and applied research on topics such as hydrogen production process efficiency and emissions, improving the performance, durability, and economics of fuel cell systems, further developing hydrogen distribution and storage technologies (including dedicated and mixed CNG pipelines), and other technical, economic, and policy-related topics. Additional workforce training aspects, and particularly roles for community colleges, are discussed in the workforce training and development sections of this paper.

5.4. Labor

The trades are generating significant experience with implementing hydrogen and fuel cell solutions in California through the state's efforts for transportation and building electrification as well as implementation of fuel cells and microgrids for electricity grid resilience. For example, the installation of stationary fuel cell systems at port logistic centers for power resiliency could be combined with shore power electrification in a larger site-level planning effort for the longer term, combined with energy efficiency improvements on the load side to "right size" the future power systems. The growing experience for these types of modern power solutions in various sectors can be of direct benefit to the seaports sector as well.

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[32] https://ww2.arb.ca.gov/our-work/programs/sb-1075-hydrogen/about

[33] California CORE, *Cargo-Handling Equipment (CHE)*, https://californiacore.org/equipment-category/cargo-handling-equipment-che/

ILWU members are beginning to get hands-on training in the operation and maintenance of fuel-cell cargo handling equipment as demonstrations are rolling out. Feedback and collaboration between ILWU users and equipment OEMs is critical to the success of fuel-cell technologies at seaports. Pacific Maritime Association partners with ILWU to provide training and will incorporate hydrogen and fuel-cell operation and handling procedures to ensure operators and maintenance workers can safely and successfully integrate fuel-cell cargo-handling equipment into regular operations.

5.5. Other Organizations

The maritime industry has diverse stakeholders, including unions representing mariners and port workers, marine industry groups for different sectors of the maritime industry, and regulatory agencies such as the Coast Guard, the Maritime Administration, the U.S. EPA, the Bureau of Safety and Environmental Enforcement (BSEE), and local port authorities, and their neighboring communities. It is imperative that learnings, knowledge, and news are shared inclusively. Regions and project-specific locations should engage and include qualified opportunity zones and qualified community entities engaged with each project to ensure environmental justice is properly accounted for.

Section 6: Recommendations

Recommendation 1: Address Technical Challenges

1. **Develop better mechanisms for information sharing and lessons learned** amongst ports within the U.S. and internationally (e.g., applied conferences, webinars, etc.).
2. **Demonstrate/pilot hydrogen technologies at ports within the next two to three years** to assure commercial readiness and prove out technologies prior to mandates.
3. **ARCHES should continue to engage the private sector to understand commercialization timelines** for what is possible for hydrogen-fueled port technologies in the soonest time frame to achieve economies of scale with multiple applications and sectors.
4. **Balance speed of the transition with realism about unavoidable limitations**–e.g., push technologies but not too far beyond normal replacement intervals; and be cognizant of realistic manufacturing and supply chain limitations in realizing actual project development timelines.

Recommendation 2: Address Workforce Challenges

1. **Provide training and guidance for port applications to enable scale-up**, leveraging additional resources and information sharing, as well as expanding on existing expertise and processes. Technical skills and knowledge required for hydrogen hubs already exist in various sections of the labor market, but also needed are efforts to incorporate hydrogen-specific related training into established programs. ARCHES can leverage and expand its continued collaboration with organized labor–state building trades, local unions, union contractor associations, union workers, etc.
2. **Leverage joint labor and management apprenticeship training programs and emerging technology training initiatives.** Unions have developed or adopted training programs for other sustainability technologies like solar, advanced lighting controls, electric vehicle infrastructure, microgrids and much more. Many of these apprenticeship programs already teach the skills required for hydrogen hub development. Joint labor and management committees meet regularly to keep curricula up to date, incorporating safety and industry specific skills. Importantly, these union programs offer structured pathways for career advancement, provide paid upgrade training, help connect workers to employment, and support strong wages and benefits.

Recommendation 3: Improve Permitting Timelines and Guidance

1. **Standardize permitting processes for hydrogen seaport technologies**, including CEQA, and ensure that AHJs that review and permit projects, as well as their safety agency partners, have training and access to information and tools needed to protect human health and the environment.
2. **Build on California's updated (2020) and useful Hydrogen Station Permitting Guidelines document to provide further needed guidance.** As noted in the document, implementation experiences and rules can vary widely even within California based on jurisdiction.[34]
3. **Distinguish between hydrogen station permitting (somewhat streamlined under SB1291) and other permitting issues at seaports** related to implementation of hydrogen and fuel-cell systems
4. **Encourage project proponents to engage early and collaboratively with local AHJs in the project development cycle** as part of a comprehensive strategy and

[34] GO-Biz, *Hydrogen Station Permitting Guidebook*, September 2020, https://business.ca.gov/wp-content/uploads/2019/12/GO-Biz_Hydrogen-Station-Permitting-Guidebook_Sept-2020.pdf

partnership to build familiarity with the proposal and relevant codes. Project proponents should recognize that AHJs may require external support and may also initiate outreach to broader stakeholders to gather background information and subject matter expert input during their review process.

5. **Address remaining gaps in codes and standards** through national and international organizations, including other AHJs with hydrogen project review experience.
6. **Provide additional guidance and resources to support successful hydrogen station deployment**, including:
    a. Real-world implementation experiences from across California, particularly from transit agencies installing large-scale hydrogen stations for heavy-duty vehicles;
    b. Best practices and considerations for sites without prior fuel dispensing operations;
    c. Concepts and updates related to standardized and evolving codes and standards;
    d. Mechanisms for AHJs to coordinate and share permitting practices; and
    e. Clarification on the authority responsible for inspecting hydrogen fueling stations, perhaps using models and examples being developed in Europe.

Recommendation 4: Build Community Trust

Cross collaboration among working groups engaging with port communities is essential to address concerns, build trust, and provide benefits that align local priorities. This is a critical step for advancing hydrogen infrastructure both at ports and in surrounding connective areas. As described above, ports are often surrounded by extensive urban landscape and communities that have shouldered the burden of pollution. Community engagement efforts must ensure procedural equity by involving a diverse group of stakeholders, including those historically marginalized and underrepresented, in genuine, two-way dialogue throughout the process. This engagement must provide education to fill in knowledge gaps and offer opportunities for direct, on-site experience. Finally, transparent communication about potential risks, mitigation strategies, and ongoing sharing of successes and lessons learned will be vital to building long-term trust.

Recommendation 5: Include Port Equipment and Hydrogen in CARB Regulations

1. **More explicitly include port equipment and hydrogen-derived fuels in the LCFS program for credit generation**, with the least possible regulatory/reporting burden.
2. **Make sure hydrogen/fuel cell technologies are appropriately addressed in CARB CHE regulations.**

Recommendation 6: Address Financing Risk for Port Drayage Trucks and Cargo-Handling Equipment

1. **Develop innovative financing models**, such as trucking as a service, taking advantage of low or zero interest rate financing programs.
2. **Develop policies to address the new clean-vehicle sales tax issue,** similar to what has been done for zero-emission buses for transit agencies.
3. **Incentives/grants should include funds to subsidize the purchase of hydrogen fuel itself,** as the primary barrier to ongoing operations of hydrogen equipment is the high cost of fuel.
4. **Revisions to the HVIP should be considered** to ensure that as many relevant vehicle models are included in eligibility, potentially including hydrogen-fuel cell retrofits if they can be certified to provide reliable performance, likely needing OEM involvement. Also consider support mechanisms for HVIP applications for small fleets with lower levels of computer skills and potential language barriers.

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