# Non-road Vehicles Sector Baseline

## ALLIANCE 50X50 COMMISSION
ON U.S. TRANSPORTATION SECTOR EFFICIENCY

ALLIANCE TO SAVE ENERGY
using less. doing more.

Report by the Non-road Vehicles Technical Committee

September 26, 2018

# PREAMBLE

The Alliance to Save Energy launched the 50x50 Commission on U.S. Transportation Sector Efficiency (the "50x50 Commission") to lay out the regulatory, policy, and investment pathways to significantly improve energy efficiency in the U.S. transportation sector. Comprising executives and decision makers from a range of key stakeholder groups — including vehicle manufacturers, utilities, federal and subnational governments, technology developers and providers, environmental advocates, and targeted customers — the 50x50 Commission established the goal to reduce energy consumption in the U.S. transportation sector by 50 percent by 2050 on a pump-to-wheel (PTW) basis, relative to a 2016 baseline.

The 50x50 Commission work is complementary to that of the Alliance Commission on National Energy Efficiency Policy, which recommended energy efficiency policies and practices that could lead to a second doubling of energy productivity by 2030. As transportation represents roughly one-third of overall energy consumption in the U.S., the transportation sector offers enormous potential for gains in both energy efficiency and energy productivity.

The outputs of the 50x50 Commission include a foundational white paper that outlines its goals and scope of the Commission's work, a set of five "sector baseline" reports that assess the current state of energy efficiency within the transportation sector, and a suite of policy recommendations outlining the types of government support, at all levels, necessary to achieve the 50x50 goal.

This report, Non-road Vehicles, is one of the five sector baseline reports that identifies the general market trends for efficient transportation technologies and explores opportunities and challenges related to deploying those technologies. This report and the sector baseline reports covering the other four technology areas: Light-duty Vehicles; Heavy-duty Vehicles & Freight; ICT, Shared Mobility, & Automation; and Enabling Infrastructure helped inform the 50x50 Commission's policy recommendations.

## Technical Committee

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While many Alliance to Save Energy staff assisted with the development of this document, special recognition is given to Laura Van Wie McGrory and Mikelann Scerbo for their significant contributions to this sector baseline.

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# INTRODUCTION

Non-road vehicles (NRVs) account for approximately 10 percent of energy consumption in the U.S. transportation sector; they represent the second largest energy consuming sub-sector after on-road vehicles, which account for approximately 76 percent of U.S. transportation energy use.[1]

This report defines NRVs as any non-military, non-recreational mobile machinery used to transport people, plants, animals, or material goods across spaces that are not regulated as public roads. The report specifically focuses on NRVs in ports, which are defined as spaces serving as connective nodes for air, sea, and land transportation. Aircraft, locomotives, ships, recreational off-road vehicles, landscaping equipment, construction equipment, and agricultural/farming equipment are not addressed in this report.

As the U.S. population continues to grow, ports will continue to play a pivotal role as key connectors among goods, services, and people. The U.S. population is projected to increase to more than 398 million people by 2050, and the number of metropolitan areas with populations exceeding one million is expected to grow from 51 to 70 by 2042.[2,3] This growth provides opportunities for the development of sustainable regional economies as hubs for new development and innovation. This will require significant changes to the status quo regarding conventional fuel use at ports in order to meet emerging economic and infrastructure demands and avoid significant air quality challenges near ports. To effectively serve the growing economy and increased energy demands – and adapt to changing climatic conditions – ports also will need to continue to improve operational efficiency and resilience.

# OBJECTIVES AND SCOPE

This report provides a baseline assessment of the most commonly used NRVs within ports, and outlines opportunities and challenges confronting the near-term adoption of energy efficiency solutions for NRVs within ports that can help achieve the 50x50 goal. While the report highlights the infrastructure opportunities and challenges associated with a range of technology solutions, a primary focus is placed on electrification and automation, as these two trends seem likely to supersede many other vehicle powertrain and operational efficiency technologies by 2050. A more detailed analysis of automation opportunities is provided in the Information and Communications Technology (ICT), Shared Mobility & Automation Sector Baseline Report.

The opportunities and challenges to achieving the 50x50 goal in the NRV sector involve energy-related, economic, operational, environmental, and social factors. Because ports serve critical roles in providing around-the-clock services to the modern metropolis, the resilience and adaptive capacity of port operations in the face of extreme events (e.g., inclement weather, interruptions of power, fuel-price spikes, labor strikes) will need to remain priorities in the push for optimization and efficiency. In an ideal future, the ports of 2050 will be more energy efficient and more profitable, will operate more smoothly, will be more resilient, will emit less pollution, and will enable innovation in transportation.

While the metric used for the 50x50 goal is energy (e.g., lower consumption of gallons of diesel, BTUs of gas, or kW at ports), there are several other indicators of success and co-benefits of reducing energy consumption in the NRV sector. These include:

- Economic benefits: Higher profits generated per unit of energy consumed or operational services provided (e.g., decreased expenses and increased revenues)
- Operational benefits: Higher quantity or quality of services provided (e.g., passengers and cargo moved, aircraft turned around, passenger-miles flown) per unit of energy consumed

- Environmental benefits: Lower levels of pollution released (e.g., water contaminants, carbon equivalent emissions, air particulate matter, decibels of noise) per unit of energy consumed or operational services provided

- Social benefits: Increased number of employees hired, retained, retrained, or reallocated.

Assessing the factors that impact the 50x50 goal also requires consideration of the intersection of the NRV sector with other relevant sectors. For example, technology advancements in light-duty vehicles will provide opportunities for efficiency improvements in ground-support NRVs. In addition, since heavy-duty vehicles and freight often travel to and from ports, it will be important to coordinate advances in their fueling or charging infrastructure with that of NRVs. Finally, ICT and automation play a key role in revolutionizing logistics and optimizing operations at ports. Please reference the other 50x50 Sector Baselines for more details on energy efficiency opportunities in other sectors.

# SUMMARY OF KEY FINDINGS

## Fleet Turnover

Rapid fleet turnover from conventional internal combustion engine (ICE) vehicles to alternative fuel vehicles is critical to reducing energy consumption and emissions at ports. Fleet turnover will require significant investments in alternative fueling infrastructure (including charging infrastructure for plug-in electric vehicles, PEVs) and in alternative fuel vehicles themselves. Additional research and development (R&D) will be required to extend the range and capacity of PEVs and to address potential grid impacts.

## Electrification Benefits

The electrification of NRVs can significantly enhance efficiency and reduce pollution at ports. Benefits of electrification can include reducing maintenance costs, providing flexibility in primary energy sources, reducing waste heat, reducing air and noise pollution, and reducing ventilation requirements in confined spaces at ports.

## Automation Benefits

NRV automation has the potential to improve throughput, operational efficiency, and safety at ports.

## Preparing the Workforce for the Advent of New Technologies

The rise of automated and electrified NRVs will require workforce training and reallocation of jobs to minimize reductions in the workforce at ports.

# NRVs WITHIN AIRPORTS

# NRVs WITHIN AIRPORTS

NRVs play an important role in ground handling and support operations at airports. This section provides a baseline assessment of the utilization of NRVs at airports, and outlines opportunities for and barriers confronting the near-term adoption of energy reduction solutions for NRVs at airports. More specifically, this section addresses how alternative fuels and automation for NRVs at airports can provide opportunities to reduce the industry's energy consumption and improve energy efficiency—with economic, operational, environmental, and social benefits—while still supporting the operational requirements for projected growth in air travel demand. The scope of this section includes NRV operations that occur between the aircraft doors (airside) and the on-road vehicles (landside) entering or leaving airport property. In other words, the energy efficiency of the aircraft themselves and the light-duty vehicles and heavy-duty vehicles entering/leaving airports is outside the scope of this report.

Non-road vehicles at airports are most commonly classified as ground handling and support equipment (GSE) and generally provide the following services:[4]

- For airside operations:
  - ground power and air distribution
  - aircraft movement
  - aircraft turnaround services
  - passenger loading and unloading
  - baggage and cargo handling
  - airport operational services
- For landside, curbside, and terminal operations:
  - people movement
  - baggage movement
  - maintenance

Airport GSE is primarily powered by diesel and gasoline. However, approximately 10 percent of GSE units in the U.S. are electric.[5] Other alternative fuels such as liquefied petroleum gas (LPG), ethanol, methanol, and hydrogen also are being considered by the Airport Cooperative Research Program (ACRP) as viable energy sources for GSE operation.[6] According to an ACRP 2012 report, there are approximately 108,578 GSE units in the U.S. today.[7] The types of airport GSE units, their service areas and their power sources are summarized in Table 1.[8]

Due to the increasing focus on reducing emissions and improving air quality, and the need to comply with the National Ambient Air Quality Standards (NAAQS) set forth in the Clean Air Act, lower emission alternative fuel vehicles and PEVs (including hybrids and battery electric) are being considered more frequently for use at airports. The transition from conventional-fuel to alternative-fuel and electric GSE can occur through the acquisition of new "purpose-built equipment" or the retrofitting of existing equipment.[9]

## Table 1. Summary of Predominant NRVs at Airports

| Area of Operation | Category of Services | Equipment Type | Primary Power Types |
|---|---|---|---|
| Airside | Ground Power and Air Distribution | Ground Power Unit | Diesel and Gasoline |
| | | Air Starter | Diesel and Gasoline |
| | | Air Conditioning Units | Diesel and Gasoline |
| | Aircraft Movement | Pushback Tugs/Tractors | Diesel, Gasoline and LPG |
| | Aircraft Turnaround Services | Catering Truck | Diesel and Gasoline |
| | | Cabin Service Vehicles | Diesel and Gasoline |
| | | Lavatory Service Vehicles | Gasoline, Diesel and Electric |
| | | Potable Water Trucks/Carts | Diesel and Gasoline |
| | | Aviation Fuel Trucks; Hydrant Dispenser Trucks/Carts | Diesel and Gasoline |
| | | Hydrant Pit Cleaners | Diesel and Gasoline |
| | | Maintenance Vehicles | Diesel, Gasoline and LPG |
| | | De-icing/Anti-icing Trucks | Diesel and Gasoline |
| | Passenger Loading and Unloading | Boarding Stairs | Diesel and Gasoline |
| | | Shuttle Bus | Compressed Natural Gas (CNG), Diesel and Gasoline |
| | Baggage and Cargo Handling | Baggage Tugs | Gasoline, Electric, Diesel and LPG |
| | | Belt Loaders | Gasoline, Diesel, and Electric |
| | | Cargo/Container Loaders | Diesel and Gasoline |
| | | Cargo Transportation/Tractors | Diesel and Gasoline |
| | | Forklifts | LPG, Gasoline, Diesel and Electric |
| | | Conveyors | Diesel, Gasoline and Electric |
| | Airport Operational Services | Snow Removal Equipment (Snow-Plows, Snow-Sweepers, Snow-Blowers) | Diesel and Gasoline |
| | | Foreign Object Debris (Fod) Removal | Gasoline and Diesel |
| Landside, Curbside and Terminal | People Movement | On-Airport Shuttle-Buses | CNG, Diesel and Gasoline |
| | | Other (Inter-Terminal Light Rail Systems, Golf Carts, Guided Wheel Trams, Trackless Wheel Trams, etc.) | Diesel, Gasoline and Electric |
| | Baggage Movement | Conveyor Belt Systems | Electric |
| | Maintenance | Cars/Pickups/SUVs/Vans | Diesel and Gasoline |

## Opportunities for Energy Efficiency: Alternative Fuel and Electric NRVs

To increase efficiency and improve their ability to meet the mobility needs of future populations, goods, and services, airports will need to balance the use of existing infrastructure and new technologies and practices. The adoption of electrified NRVs at airports to date has been driven primarily by the need to meet emission reduction and air quality goals; this is particularly important for airports located near nonattainment or maintenance areas.[10] According to an ACRP 2015 report, a nonattainment area is an area considered to have air quality worse than the U.S. National Ambient Air Quality Standards (NAAQS) requirements defined in the Clean Air Act Amendments of 1970; a maintenance area is an area transitioning from a nonattainment to an attainment area.[11] In addition to the emission reduction benefits, electrification of NRVs at airports offers potential for operational efficiency benefits which translate to cost savings.

Fuel costs account for 20-25 percent of heavy equipment operating costs; the use of alternative fuels can reduce fuel consumption and electrification can further reduce energy use.[12] Based on experience with small-scale deployment of alternative fuel and electric NRVs at airports to date, fleet managers have found that these NRVs also have lower maintenance and operating costs than equipment powered by conventional fuels.[13] Maintenance costs for electric and alternative fuel buses, for example, are 40-50 percent lower than the maintenance costs for conventionally fueled buses.[14]

The opportunities for energy savings, efficiency improvements, and optimization of airport NRVs will grow with the wide-scale installation of PEV recharging infrastructure in parking garages and public waiting areas. There are opportunities to use PEV shuttle buses for passenger and employee transfer around the airport. There are a variety of commercial PEV buses available today in 30- to 45-foot options.[15] Moreover, PEV shuttle buses are quieter than ICE vehicles and do not emit pollutants. Although the initial investment costs of acquiring PEV buses are generally higher than their conventional counterparts due to lower volume production levels, lifecycle costs tend to be lower than conventional diesel buses.[16] Additionally, PEV buses are equipped with regenerative braking systems that provide significant cost savings in brake maintenance.[17]

### Deployment of Available Technologies

Commercially available electric GSEs include electric pushback tractors, belt loaders, and baggage tractors.[18] Alternative fuels available for use in ICEs that power NRVs include compressed natural gas (CNG), liquefied petroleum/propane gas (LPGPP), hydrogen fuel cells, methanol, biodiesel, and ethanol. In addition to fuel cost savings, the use of alternative fuels in place of diesel or gasoline would also reduce emissions, decrease overall dependence on fossil fuels, and help improve energy security.[19]

Conventionally fueled NRVs currently have lower acquisition costs than electric vehicles, but the cost difference is not necessarily prohibitive. Electric GSE costs an estimated 8-26 percent more than conventional diesel or gasoline-powered equipment.[20] Equipment retrofits are possible; however, because the engine often is a large portion of the purchase price, the cost to retrofit the engines of existing equipment may be similar to that of purchasing new GSE equipment.[21] Retrofits are also more expensive if done on a piecemeal basis compared to fleet purchases of new equipment.[22]

## Table 2. Estimated Cost Comparisons for Airport GSE[23]

| Equipment Type | Fuel | Acquisition Cost |
|---|---|---|
| Ground Powering Units | Diesel | $17,000 |
| Baggage Tractor | Gasoline | $26,000 |
| | Diesel | $28,000 |
| | Electric | $35,500 |
| Belt Loader | Gasoline | $28,500 |
| | Diesel | $32,500 |
| | Electric | $35,500 |
| Pushback Tug | Diesel | $86,200 |
| | Electric | $93,000 |
| Cargo Load | Diesel | $475,000 |

Other alternative fuel vehicles also are more costly than gasoline or diesel vehicles in similar categories across all weight classes—for example, CNG trucks can cost on the order of $40,000 more than diesel-fueled trucks—but tend to have lower operating costs.[24,25,26]

The conversion of GSE fleets from fossil fuel to electricity—particularly when paired with automation—offers opportunities for improving energy efficiency while also meeting growing operational needs and supporting sustainable growth. For example, the installation of grid-powered pre-conditioned air (PCA) units at terminal gates to serve parked aircraft can result in significant energy savings.[27] Alaska Air Group expects to save $15 million in fuel costs due to installations of grid-powered PCA units.[28] In addition, electric NRVs may last longer than their conventional fuel counterparts. Long-term durability simulations suggest that battery electric buses may last 18 years compared to the 12-year service life of conventional diesel-fueled buses.[29] Finally, maintenance costs for battery electric buses can be significantly lower than the costs of maintaining conventional vehicles. The Catalyst BEV Bus manufactured by Proterra requires little downtime for maintenance activities as it never needs oil changes, nor "exhaust after-treatments."[30] This bus has "30 percent fewer parts than traditional buses" and a carbon-fiber reinforced composite body with a BEV powertrain designed for quick and easy access during maintenance, thus reducing technician labor hours. [31] (Buses and other on-road vehicles are discussed in more detail in the Light-duty Vehicle and Heavy-duty Vehicle & Freight Sector Baselines.)

Due to their financial, maintenance, operational, environmental, and social benefits, airports are increasingly shifting to alternative fuels and electrification for their operations. Dallas Fort Worth International Airport uses CNG-powered shuttle buses and Denver International Airport uses 40 CNG bag tugs, nine electric bag loaders, and four electric cargo tractors.[32] Charlotte Douglas International Airport replaced ten diesel-engine tugs with battery-powered equivalents, reducing $N_2O$ emissions by 70 tons, and Portland International Airport continues to replace gasoline and diesel-powered vehicles with trucks and forklifts powered by CNG and propane to supplement its fleet of 27 NRVs powered by biodiesel.[33]

Effective planning for charging infrastructure installations to support electric NRVs also can have operational efficiency impacts. For electrified equipment supporting short-distance airside operations—such as belt loaders—charging infrastructure can be placed at aircraft gates to provide convenient charging when the vehicles are not in use.

Many government funding sources exist to support investments in alternative fuel and electric NRVs. Airports located in nonattainment areas are eligible for funding through the Federal Aviation Administration's Voluntary Airport Low Emissions (VALE) and Zero Emissions Vehicles (ZEV) grant programs as well as the Federal Highway Administration's Congestion Mitigation and Air Quality Improvement (CMAQ) grants program; these programs can significantly offset the incremental cost of vehicle replacement and related infrastructure projects.[34,35,36] Many states also offer additional incentives for energy efficiency and emission reduction projects.

### Leveraging Opportunities in Other Sectors

The NRV sector can leverage technology innovations and new deployments in other transportation sectors. For example, an alternate fueling station designed to serve freight trucking at an airport can also serve alternatively fueled GSE. Also, as rising demand for PEVs in other transportation sectors brings down manufacturing costs, lithium-ion batteries are expected to become more commercially available, causing their application in NRVs to become more economically feasible.[37] While these batteries have higher capital costs compared to lead-acid batteries, they provide faster charging, higher output, and better lifetime cycling properties; they thus offer an important opportunity to improve energy efficiency and optimize the use of NRVs at airports and in other subsectors.[38,39,40] Additional R&D to improve battery capacity can further reduce costs and enhance the appeal of PEVs.

The adoption of energy efficient solutions for NRVs through leveraging infrastructure supporting the light-, medium- and heavy-duty vehicles sectors will further reduce costs for airports. The projected installation of highway charging stations, which furthers the wide-scale adoption and deployment of electric charging infrastructure, will likely reduce the overall manufacturing costs for charging infrastructure installations. Similarly, as the cost of installing direct-current fast charging (DCFC) systems decreases, the business case for the adoption of this infrastructure at airports becomes more viable and is reinforced by the maintenance cost savings and environmental benefits associated with electric NRVs. Wide-scale deployment of DCFC also would make the operations of electric NRVs more appealing by significantly reducing recharging time.[41,42]

Finally, the installation of highway power stations serving on-road vehicles near airports might require infrastructural upgrades to the electric grid, which would also support improved electric distribution to airports. The compounded effects of the decreased manufacturing costs and government-funded transportation infrastructure upgrades over the next several decades will be critical for scaling up the adoption of electric NRVs at airports.

### Environmental Benefits

Approximately one-third of airports in the U.S. are in nonattainment areas.[43] The wide-scale adoption of alternative fuel and electric NRVs would reduce fossil fuel consumption and on-site air emissions. Improvements to air quality would positively impact human and environmental health. In addition, improved air quality would reduce the financial burden of emission mitigation costs affecting many airports.

While electrification reduces on-site emissions, the total emissions benefits of electrification in a nonattainment area will vary by region. Electric power generation emissions are not equal across all airports, since emissions vary regionally depending on the energy sources used to generate electricity.

## Challenges to Electrification

There are a number of challenges to enhancing energy efficiency at airports through electrification, including the high costs of acquiring PEVs, inadequacy of existing charging infrastructure, potential impacts on the electric grid, and restricted range of some PEVs. For example, these factors—along with poor PEV performance in extreme weather, spiked electricity rates during peak demand periods, and reductions in federal funding/incentives for PEV purchases—have resulted in a slow rate of adoption of PEV buses at airports. These challenges are discussed in more detail below.

## High PEV Acquisition Costs

While acquisition of electric GSE is becoming more financially viable, the costs of some PEV buses can be cost-prohibitive for airports. These high costs are due in part to lower manufacturing levels. The current high cost of energy efficient batteries presents an additional challenge. The price of lithium-ion batteries dropped by 73 percent from 2010 to 2016, reaching $273/kWh in 2016.[44] If future battery costs decrease to $150-200 per kWh, PEVs will achieve cost parity with conventionally fueled vehicles, which would support increased adoption of PEVs.[45]

## Inadequate Charging Infrastructure

The existing charging infrastructure at many airports cannot support the large-scale adoption of electric NRVs. However, some original equipment manufacturers (OEMs) are developing plans to deploy charging infrastructure in parallel with electric NRVs to mitigate the "chicken and egg dilemma."[46] The concurrent development and commercialization of PEVs and charging infrastructure would support the wide-scale deployment of electric GSE at airports.

The organizational structure of airports, however, presents a challenge to the expansion of supporting infrastructure. Airports and airlines are separate entities. The installation of charging infrastructure does not fall squarely within any one operating division of an airport; it often falls within the gray area between airport and airline operations. Many different stakeholders thus need to participate in strategic planning and collaborative decision-making to effectively integrate charging infrastructure into airport operations. This coordination can be enhanced by effective data sharing to facilitate data-driven decisions collectively among stakeholders.

## Impacts to the Electric Grid

Another possible challenge is the potential adverse impact of increased electric GSE use on the quality and reliability of an airport's electric power. One study found that "the penetration of large nonlinear loads in airports, such as ground power units, PCA systems, computer equipment, and the growing use of PEV chargers poses potential power quality, delivery, and energy consumption concerns for electric power providers and airports" due to potential overloading of distribution transformer and switchgear systems.[47] The nation's overall electric system is considered robust enough to serve forecasted levels of PEV adoption in the near- and medium-term. Although charging infrastructure often requires system upgrades—especially to distribution networks with a high density of PEVs—the National Academy of Sciences has concluded that PEV deployment is not constrained by transmission or generation system capacity and is instead more likely to be impeded by electricity costs.[48]

Another mitigating factor is the opportunity for adoption of microgrids at airports with some combination of on-site renewable generation and battery storage. These technologies would improve the resilience of airports since they provide independent electricity generation and potential distribution systems. Although microgrids are expensive and have not yet been adopted by airports on a broad scale, they have the potential to both increase the viability of electrification and help improve energy resiliency at airports. In addition, new models for deploying microgrids make them more appealing for a multi-stakeholder organization like an airport. For instance, the Peña Station NEXT in Denver, CO, has implemented a public-private partnership approach to deploying its microgrid that coordinates a portfolio of stakeholders and assets to achieve energy savings benefits.[49]

However, microgrids that use conventional fossil fuels may produce more emissions. Further research into the feasibility and impacts of using microgrids at airports is imperative to improving energy resiliency and developing efficient and low-emission solutions for power generation for charging infrastructure.

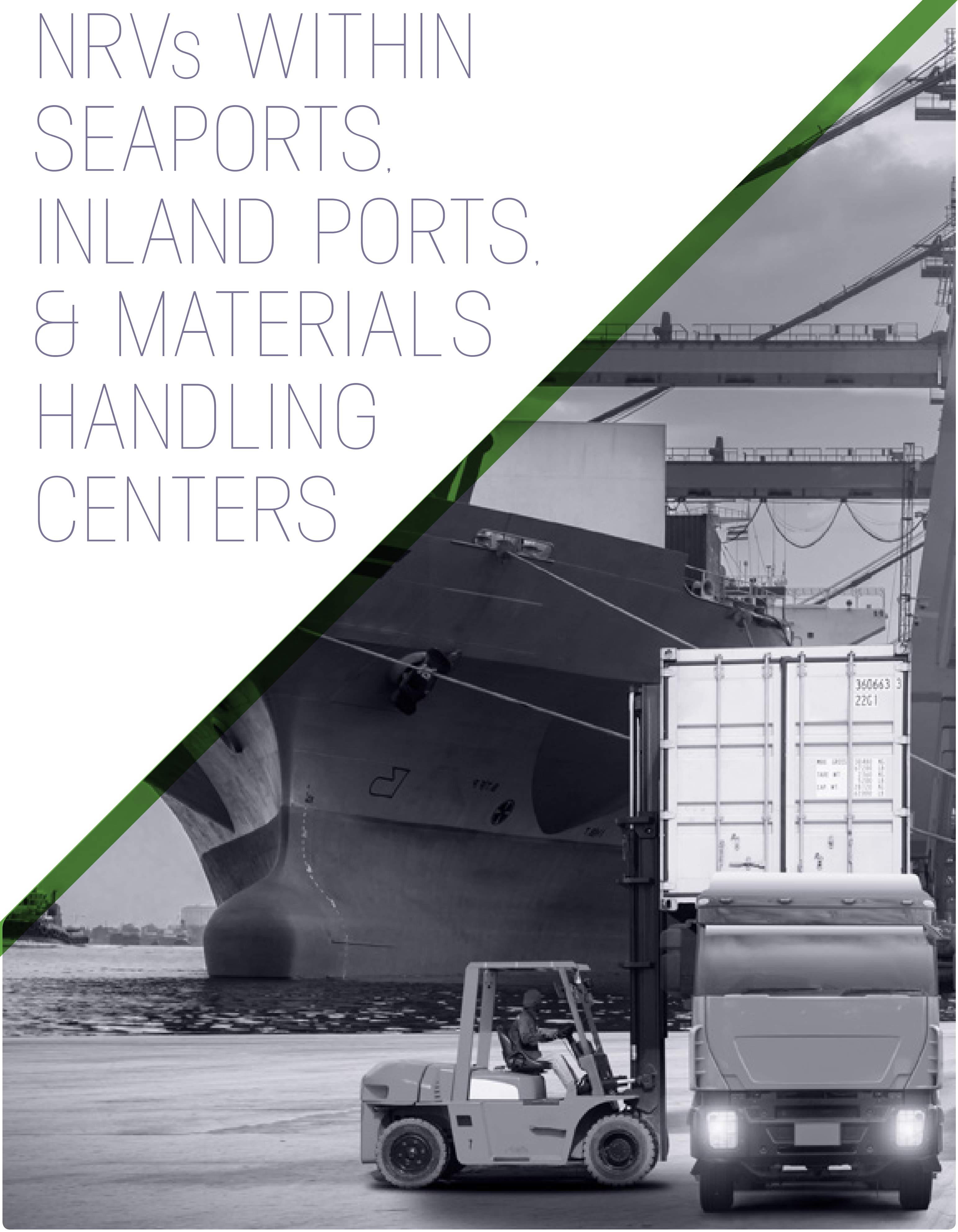
## Range Restrictions

The operational ranges of PEVs, including electric GSE, are still limited. For instance, PEV buses are typically limited to 80 to 120 miles of travel per day.[50] Range restrictions necessitate coordination of recharging time for PEVs, which can be a challenge to airport operational efficiency and optimizing the customer experience. Strategies for mitigating the effects of range restrictions include the use of hybrid vehicles, which have larger daily ranges, and installing DCFC systems, which have faster charging turnaround times. Future technology advancements in battery capacity will also increase PEV range.

## Policy Considerations

Existing federal and state government policies can facilitate the adoption of energy saving technologies at airports. For example, federal VALE grants and ZEV grants offset up to 50 percent of the installation cost of PEV charging infrastructure. Future federal investment in rebuilding transportation infrastructure may offer additional opportunities to take advantage of federal funds. PEV charging infrastructure and communication systems could be integrated into other major transportation system and data upgrades.

# NRVs WITHIN SEAPORTS, INLAND PORTS, & MATERIALS HANDLING CENTERS



# NRVs WITHIN SEAPORTS, INLAND PORTS, & MATERIALS HANDLING CENTERS

Seaports and inland ports are critical to the success of the U.S. economy; they are the "gateways for moving freight and passengers across the country and around the world."[51] There are approximately 360 commercial seaports and inland ports in the U.S. today, operated under a mix of public and private ownership.[52] According to the American Association of Port Authorities, seaports and inland ports accounted for more than 23 million jobs and approximately 26 percent of the U.S. gross domestic product (GDP) in 2014.[53]

This section discusses the current energy use by NRVs at seaports, inland ports, and materials handling centers, and identifies emerging technologies and strategies to reduce energy use. This section also discusses the critical factors that influence the adoption of efficient NRV technologies at these facilities, including cost effectiveness, availability, readiness, and social impacts.

Seaports, inland ports, and materials handling centers largely depend on conventional diesel-powered equipment for cargo handling.[54] However, recognizing the higher emissions, energy use, and operational costs associated with diesel engines, a number of these facilities have begun to adopt PEVs, hybrid vehicles, and CNG vehicles.[55]

## Opportunities for Energy Efficiency

The benefits of adopting energy efficiency improvement technologies and strategies in seaports, inland ports, and materials handling centers are similar to the benefits of applying these technologies in airports. There are numerous types of equipment at seaports, inland ports, and materials handling centers into which alternative fuel and electric technologies can be incorporated; these include materials handling NRVs such as cargo handling equipment (CHE), which are used during the loading and unloading of cargo, freight, and pallets. A common type of CHE is the lift truck. While they traditionally have been fueled by propane gas or diesel fuel, more than 60 percent of lift trucks purchased today are battery-powered.[56] Electric lift trucks are safer and more efficient than propane or diesel-powered lift trucks and offer quieter operation and increased productivity. Electric lift trucks also achieve cost savings via reduced fuel costs, lower life cycle costs, and lower maintenance costs.[57]

As in airports, operators of seaports, inland ports, and materials handling centers have been turning to electric and alternative fuel vehicles primarily due to their cost savings and emission reductions benefits.[58] For example, PEVs used in these facilities typically have lower fuel and maintenance costs compared to their ICE counterparts. These cost reductions result from the PEVs having fewer mechanical and moving components, less frequent service requirements, fewer fluids to change, and reduced wear on brake pads and rotors due to the regenerative braking capacities of electric motors.[59] In addition, using PEVs eliminates point-source emissions, which helps businesses meet sustainability goals and comply with environmental regulations, and has health benefits for employees.[60] The emissions benefits can be multiplied when combined with shore power electrification at seaports. Finally, electric power is also relatively quiet, making it easier for workers to communicate and thus improving safety.[61]

The diversity of fueling solutions as well as the wide variance in their widespread deployment illustrate how cost effectiveness and technical maturity impacts which technologies will be adopted. For example, seaports, inland ports, and materials handling centers use a variety of drayage vehicles to transport heavy loads for short distances and have begun to adopt various electric and alternative fuel technologies for these vehicles. CNG and LNG are the most cost effective, technically mature, and widely adopted, followed by PEVs. Hydrogen fuel cell technologies, by contrast, lag in cost effectiveness, technical maturity, and adoption rates.

While comprehensive data on stock inventory and energy consumption of NRVs at seaports, inland ports, and materials handling facilities often are not publicly available, this section provides examples of currently available equipment and opportunities for future deployment of energy efficient NRVs. See Appendix A for a more detailed case study of energy savings achieved by the Port of Long Beach (POLB) and the Port of Los Angeles (POLA).

## CNG and LPG NRVs

CNG and LPG vehicles can play a key role in bridging the gap between fossil fuel dependence and the need for economically viable and cleaner fuel alternatives that meet market demands. CNG and LPG often are used in high horsepower seaport applications, including large CHE and heavy-duty vehicles. CNG technologies provide seaport, inland port, and material handling facility operators with reliable and less expensive equipment, especially when compared to the upfront costs of fuel cells or electric battery storage.[62] According to a 2015 "Zero Emission White Paper" by POLA, CNG-powered trucks also offer lower acquisition costs and greater range when compared to the near zero-emission prototypes tested thus far.[63,a]

## Shore Power

At seaports, shore power can significantly reduce diesel emissions from ships at dock, resulting in on-site emissions reductions of up to 98 percent when utilizing power from the regional electricity grid.[64] Shore power connections allow the ships to sit at berth while supplying the power needed during freight loading or unloading operations. Ships can be retrofitted with vessel-side infrastructure to connect to port shore power systems. Shore power for commercial marine vessels in the U.S. is relatively new and not yet commonly available. There are currently 10 ports using high voltage shore power systems serving cruise, container, and refrigerated vessels and six ports using low voltage shore power systems that serve tugs and fishing vessels.[65]

The total emissions reductions of shore power will depend on how power is generated and how the power is used. Total emissions reductions may vary regionally depending on the mix of energy sources used for power generation, total time at berth, power consumption rate, and energy costs.

Barriers to shore power installation include infrastructure and electricity costs. Shore power requires landside infrastructure, electrical grid improvements, and vessel modifications. Shore power is more attractive when fuel costs to generate power for a ship at berth are greater than electricity costs. Although shore power technology is relatively new in the commercial sector, it has been successfully used by the U.S. Navy for decades and is a component of the Navy's Incentivized Shipboard Energy Conservation program.[66]

## Fuel Cells and Electric NRVs

Fuel cell electric vehicles (FCEVs) and PEVs offer significant emissions reduction opportunities. Fuel cells can fulfill a variety of heat and electricity service needs at ports and materials handling facilities—for example, providing storage warehouse heat and powering cranes—while reducing on-site emissions. In addition, the commercialization and widespread acceptance of electric forklift truck technology has been spurred by its benefits for indoor applications, most notably its lack of emissions.[67] The City of Los Angeles Harbor Department has invested in zero-emission technology for Non-road vehicles, including 16 zero-emission yard tractors.[68] These new technologies currently have range limitations and are expensive because of their large batteries, but are seen as an effective means to reducing emissions.[69]

In addition to fuel cell and battery electric NRVs, there is potential for the adoption of hybrid heavy-duty trucks at seaports, inland ports, and material handling centers. Hybrid trucks are equipped with a hybrid powertrain configuration which combines an electric motor with an ICE powered by conventional or alternative fuels. Hybrid configuration drayage tractors, which are currently undergoing development and demonstration at the Port of Los

a CNG and LPG vehicle applications are equipped with an engine configured to operate on natural gas (methane) fuel as opposed to conventional diesel fuel. According to the POLA "Zero Emission White Paper," these vehicles are expected to be commercially available at near-zero emission levels for a cost of about $40,000 above their conventional diesel-fueled vehicle counterparts, largely due to the cost of the natural gas fueling system and on-board fuel storage tanks.

Angeles, are expected to achieve near-zero emissions operations when optimized for only battery electric utilization.[70] The latest near-zero hybrid vehicles are designed to be able to operate on battery energy while on port property or within port-defined boundaries.[71] Currently, near-zero hybrid vehicles still have high acquisition costs associated with the expense of on-board energy storage and electric powertrain components.[72]

### Cranes: An Example of Autonomous NRVs

Both POLB and POLA are using autonomous cranes; their experience helps demonstrate how autonomous technology could revolutionize freight transport. Autonomous crane equipment offers increased efficiency, reliability, and safety.[73] It increases the speed at which ships are loaded and unloaded, thus reducing costs, energy consumption, and emissions. The autonomous vehicles (AVs) help maximize the utilization of yard capacity, thus helping the cargo terminals maintain throughput and operational efficiency. Ports are exploring the use of automation in ship-to-shore cranes, rubber-tired gantry cranes, and stacking cranes, as well as shuttle carriers, due to their increased efficiency for moving cargo and freight.[74]

Some seaports use regenerative flywheel cranes for loading and unloading freight from vessels to the yard. Similar to regenerative braking systems used in PEVs, the weight of the off-loaded freight creates a dynamic force whose energy can be captured and reused to improve overall operational efficiency.[75]

### Environmental Benefits

As previously noted, the use of electric and alternative fuel-powered NRVs at seaports, inland ports, and material handling centers presents significant opportunities for energy and emissions reductions. Automation can further yield emission reductions by reducing NRV idling and increasing operational efficiency. For example, electric and automated NRVs adopted by the Long Beach Container Terminal emit 85 percent less diesel soot, 58 percent less nitrogen oxides, and 33 percent less carbon dioxide than conventionally fueled vehicles.[76]

The U.S. Environmental Protection Agency (EPA) has supported the adoption of energy and emissions reduction technologies at ports through voluntary actions aimed at replacing old diesel equipment with new energy efficient trucks and CHE as well as through emissions standards.[77] The EPA projects that the strategic implementation of voluntary actions will reduce fuel-based particulate matter emissions from drayage trucks by 47 percent by 2020.[78] The latest EPA emissions standards for CHE, including Tier 3 and the more stringent Tier 4 standards, place limitations on nitrogen oxide and carbon dioxide emissions.[79] Based on national fleet turnover rates, CHE are expected to meet the Tier 4 emissions standards by 2030.[80] Strategies for surpassing Tier 4 standards include incorporating advanced technology options, including hybrids, alternative fuels, and electric technologies.

## Challenges to Electrification

The challenges confronting the adoption of electrification at seaports, inland ports, and materials handling centers are similar to those facing airports.

### High Cost of Initial Investment

The infrastructure required to support electric NRVs, shore power, fuel cells, or battery storage units at ports and materials handling centers is often inadequate or cost-prohibitive, and the cost of the vehicles themselves can be a barrier to adoption. Many terminals are not equipped with the appropriate power supply technologies and many ports do not have the appropriate infrastructure to connect to vessels with shore power components.[81]

For example, the POLA invested $180 million to equip 25 berths with shore-side electric power, and the Pacific Merchant Shipping Association estimates the cost of retrofitting a ship to plug into shore-side power to be $500,000 to $1.5 million."[82] A brand new, conventionally fueled vehicle costs about $135,000 while its PEV counterpart costs from $300,000 to $500,000; without government incentives, conventional diesel-fueled vehicles are thus often more attractive to seaports and inland ports.[83] Nevertheless, PEVs may reach price parity with comparable ICE vehicles in many sectors as early as 2020.[84]

The added infrastructure costs for FCEVs include costs for hydrogen fueling as well as charging equipment and can require a "sacrifice of both vehicle and system simplicity."[85] Moreover, fuel cell trucks require more than double the amount of energy needed to travel the same distance as battery electric trucks.[86] However, these vehicles do offer increased range and flexibility when compared to battery electric vehicles.[87]

### PEV Range Restrictions

While PEVs offer significant emissions reduction and maintenance cost saving benefits, many have range restrictions compared to ICE vehicles. For example, an ICE drayage truck can travel up to 600 miles, while a zero-emission drayage truck has a range of only 120 miles.[88]

As battery technology continues to evolve, it is anticipated that PEVs will achieve longer ranges between charges and longer operational periods between repairs. Long-term demonstrations of PEVs at seaports, inland ports, and materials handling centers are critical to establishing technical viability and operational reliability, and to attracting participation from vehicle manufacturers to increase production; this will help lower costs and boost the commercial availability of PEVs.

### Infrastructure Challenges

Infrastructure planning for low emission technology will require significant collaboration among multiple stakeholders. For example, ports must ensure that there is adequate power for a fleet of PEV CHE, which requires coordination with the local electric utility to prepare the power system servicing the port – for example, to ensure that each terminal using PEV yard tractors has dedicated charging areas equipped with the appropriate power supply technology.[89] In addition, any infrastructure planning efforts should account for future industry needs as technology evolves.

Smart grids will be essential for effectively electrifying ports. While recharging a large battery pack on a heavy-duty drayage truck puts a high load on the electric grid, a smart grid could schedule charging to occur during periods of reduced grid load or reduced electricity costs. According to the POLA Zero Emission White Paper, "a well-optimized grid could even allow a vehicle battery to supply energy back to the grid at periods of peak demand."[90]

## Policy Considerations

### Research

There is a need for more research that clearly quantifies potential cost and energy reductions resulting from electrification at seaports, airports, inland ports, and materials handling centers. Modeling the energy impacts of NRVs should account for lower costs and improved efficiency of distributed wind and solar power generation, as well as stationary and mobile battery electricity storage systems. Additionally, there is a need to support research, development, and demonstrations that evaluate the feasibility, emissions, and efficiency of dual-fuel and dedicated natural gas engines designed for port and materials handling applications. The research focus should be on engine technologies with the most potential to achieve higher energy efficiency and lower emission levels than the current cleanest diesel or gasoline technology(ies) available.[91]

### Support for Energy Efficient Technologies

Several policy opportunities have the potential to further the deployment of energy efficient technologies at ports and materials handling centers. For example, there is a need for policies to address PEV component supply limitations to improve the stability of the supply chain for raw material used for PEVs. This would increase the production of PEVs as well as increase demand for PEV certifiers, in turn reducing the cost of PEVs and PEV certification and supporting greater consumer adoption of this technology.

There is also a need for R&D funding and incentives to support the development and adoption of commercially available technologies that better control methane slip, improve battery systems, improve charging systems, improve durability of emission control systems, and increase fuel efficiency.[92,93]

Finally, legislative and financial support can help reduce the acquisition costs of PEV or alternative fuel NRVs for ports. Incentives designed to advance deployments of less fuel-intensive CHE can support progress on this front. Examples include the Carl Moyer Memorial Air Quality Standards Attainment Program, a grant program that funds the incremental cost of cleaner-than-required CHE engines (among other forms of transportation) in California, and the DOT's CMAQ grants.[94,95] The Port Authority of New York and New Jersey's Cargo Handling Equipment Fleet Modernization Incentive Program - Phase II is one such program that received a CMAQ grant to help fund its Cargo Handling Equipment Fleet Modernization Incentive Program - Phase II; the grant has been used to replace 100 older CHE with new and cleaner models.[96]

# BENEFITS & CHALLENGES TO THE WORKFORCE WITH THE ADVENT OF NEW TECHNOLOGIES

# BENEFITS & CHALLENGES TO THE WORKFORCE WITH THE ADVENT OF NEW TECHNOLOGIES

All ports need to consider the workforce implications of deploying electrification and automation technology. Energy efficiency improvements can increase throughput, but they also have the potential to reduce or displace jobs.

## Workforce Benefits

Applying energy efficiency solutions to ports offers opportunities for increased energy productivity (both operational and employee productivity), increased throughput (by enabling ports to effectively handle higher capacities), and more jobs and higher wages for the skilled workforce required to operate and maintain the upgraded equipment.[97] As with any technology that requires a skilled workforce, there are opportunities to educate or retrain existing employees to prepare them for new or different jobs that involve emerging technologies, that require a higher skillset, and that may provide higher wages.[98,99]

While social opportunities and benefits are hard to quantify, there may be cascading economic benefits from higher wages that could stimulate the economy in surrounding communities. In addition, increasing demand for PEVs and other efficient technologies may increase the number of manufacturing jobs available to produce alternative fuel vehicles and PEVs and their associated batteries.[100]

Furthermore, air quality improvements resulting from emissions reductions would improve working conditions at ports. The electrification and automation of vehicles can likewise yield improvements to port safety due to reduced vehicle congestion.

## Workforce Challenges

The different labor needs presented by PEVs and alternative fuel vehicles versus conventional fuel vehicles will require ports to prepare their workforce for any changes to job functions or types of jobs available. PEV and alternative fuel vehicle operators and maintenance staff will need educational and technical training on the specific operational and maintenance needs of these vehicles.[101] In addition, PEVs require less maintenance than their conventional fuel counterparts.[102] While PEVs and ICE vehicles both require maintenance of electronic systems and controls, suspensions, HVAC systems, and tires, PEV brakes require maintenance less often since electric motor regenerative braking systems reduce the use of conventional brake components (e.g., rotors, pads). In addition, PEVs have no exhaust or emissions systems, engine air filters, spark plugs, timing belts, conventional crankshafts, or transmissions to maintain. As a result, a switch to PEVs could result in fewer vehicle maintenance jobs.

Similar concerns exist related to automation. While the use of AVs offers potential for energy efficiency improvements and emission reductions, concerns also remain for automation's impact on job loss, particularly with regard to truck driver and longshoreman jobs. The number of longshoremen already has dropped by half compared to 1960, even though ports move more than 14 times as much cargo today; this change is, at least in part, a result of automation.[103]

It is thus critical for ports to anticipate changes to their workforce for any type of job affected by electrification or automation, and to consider retraining and job reallocation opportunities. This includes training for highly skilled jobs resulting from the adoption of enhanced energy efficiency technologies.

Another workforce-related challenge involves addressing perceptions and preferences with regard to electrification. For example, while some airline staff express eagerness to adopt mobile electric GSE due to its ease of operation or lack of tailpipe emissions, others may express a strong preference for keeping diesel-powered equipment due to its dependability and familiarity.[104] These two viewpoints highlight the cultural aspects that can influence the adoption of energy efficient technologies at ports.

# CONCLUSION

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Ports will continue to play a pivotal role as the main connector of goods, services, and people across regional, national, and global economic centers. To efficiently meet the demands of growing populations under increasingly severe climate conditions, ports must continue to improve operational efficiency and resilience. Barriers to improving energy efficiency of NRVs include the higher cost of acquiring PEV equipment and batteries; the inadequacy of PEV charging infrastructure in some locations; the potential adverse effects on the grid due to increased electric loads from NRVs; the restricted range of some PEVs; and the social implications of electrification and future automation, especially concerning job displacement, employee reassignment, and the need for retraining.

Due to the increasingly pressing need to reduce greenhouse gas emissions and comply with the NAAQS set forth in the Clean Air Act, many ports are electrifying their facilities and NRVs or using alternative fuels for NRVs. The use of alternative fuels in higher efficiency vehicles both reduces pollution and enhances energy security by limiting dependence on fossil fuels.

In addition to the emission reduction benefits offered by electrified and alternative fuel NRVs, port operators also have noted their potential operational efficiency benefits, including lower maintenance and operating costs. Fuel costs account for 20-25 percent of equipment operating costs, and the use of alternative fuels can reduce fuel consumption by 25 percent.[105] Maintenance costs for electric and alternative fuel buses are 40-50 percent lower than average maintenance costs for conventionally fueled buses.[106]

Wide-scale installation of PEV recharging services and support infrastructure creates significant opportunities for energy reduction, efficiency, and optimization of NRVs at ports. The successful adoption of electric NRVs in ports will be facilitated by the compounded effects of decreased manufacturing costs—as such infrastructure becomes more widely used across the transportation sector—and government-funded transportation infrastructure upgrades over the next several decades.

It is important to ensure that any new emissions associated with federally funded and approved projects and transit development activities do not negatively impact regional air quality plans or delay the region's ability to meet NAAQS. With appropriate planning, NRV upgrades at ports can result in significant air quality improvements that can help meet NAAQS and will positively impact human and environmental health. Additional benefits of improved air quality include reduced emission mitigation costs—a financial burden currently affecting many ports. Social benefits of more efficient NRVs include increased energy productivity, direct and indirect job opportunities, and higher wages for the skilled workforce required to operate and maintain upgraded equipment, as well as improved worker safety and working conditions.

# APPENDIX A: SEAPORT CASE STUDY - LONG BEACH AND LOS ANGELES

The Port of Long Beach (POLB) and Port of Los Angeles (POLA), combined, make up the largest port complex in North America.[107] CHE is the primary source of non-marine emissions at these facilities.[108]

The adoption of low-emission technologies at POLB and POLA has supported and even exceeded federal, state, and local government goals for carbon equivalent emissions reductions.[109] For example, California's Assembly Bill-32 (AB-32) set the goal to reduce carbon equivalent emissions to 80 percent of 1990 levels by 2050.[110] In 2011, the POLB and POLA drafted a roadmap for moving forward with zero-emission technologies.[111] This roadmap identified zero-emission equipment—defined as "vehicles and equipment that have zero exhaust/tailpipe emissions of criteria and [carbon equivalent] air pollutants" —as an important element that must be integrated into marine-related goods conveyance.[112] The roadmap provided the initial course of action for identifying, evaluating, and integrating zero-emission technologies into maritime goods movement, while maintaining port customer satisfaction and overall operational excellence.[113]

Since the development of the zero-emission roadmap, investment in zero-emission technologies has been supported by local governmental entities such as the Los Angeles Harbor Department (Harbor Department). The Harbor Department has provided more than $7 million in funding for both on-road and Non-road projects aimed at developing zero-emission technology for short-haul drayage trucks and yard tractors.[114] The outcomes demonstrated at POLB and POLA—where operating and maintenance costs are lower when compared to the costs associated with their conventionally fueled counterparts—will encourage additional investment in energy saving and emission reducing NRV technologies at ports. In 2017, the POLB and POLA pledged to dramatically reduce carbon equivalent emissions by phasing out internal combustion engines and replacing cargo-handling equipment by 2030 and the majority of diesel trucks with zero-emissions equivalents—typically electric vehicles—by 2036.[115]

## Additional Efficiency Efforts at POLB

In 2006, the POLB partnered with the EPA through a co-funding grant of $75,000 to conduct a study to determine the operational and economic viability of switching from using diesel yard hostlers to liquefied natural gas (LNG) yard hostlers.[116] This potential switch is of particular interest to ports because it would not require changes to existing infrastructure and would not impact fueling operations or create additional fuel safety hazards.[117] The study found that LNG yard hostlers have a life cycle cost advantage over diesel yard hostlers wherever vehicle purchase incentives are available, but otherwise life cycle cost estimates for LNG and diesel yard hostlers are comparable.[118] In addition, while LNG yard hostlers emitted 18 percent less carbon dioxide than their diesel counterparts, LNG yard hostlers also emitted 21 percent more nitrogen oxides.[119]

POLB provides a useful model of what measures can be taken to increase efficiencies, reduce emissions, and operate in a sustainable and cost-effective manner. Operational and organizational data from POLB were used to formulate recommendations on how current technologies could contribute toward energy reductions. In 2005, the POLB implemented "The Green Port Policy," an aggressive, comprehensive, and coordinated approach to reduce the negative energy impacts of port operations.[120] The Green Port Policy's five guiding principles are:[121]

- Protect the community from harmful side effects of port operations,
- Distinguish the port as a leader in environmental stewardship and compliance,
- Promote sustainability,
- Employ best available technology to avoid or reduce environmental impacts, and
- Engage and educate the community.

Using 2005 as its reference point, the POLB has improved its resiliency and significantly reduced air emissions, thus improving local air quality by improving the fuel economy of its vehicles and installing shore power.[122] According to the POLB 2012 emissions inventory, they have yielded significant emissions reductions as listed below:[123]

- Diesel particulate matter reduced by 81%,
- Nitrogen oxides reduced by 54%,
- Sulfur oxides reduced by 88%, and
- Carbon equivalent emissions reduced by 24%.

Many POLB emissions reduction efforts are supported by California's Technology Advancement Program, which is partially funded by the state's Air Resources Board.[124] Under POLB's Clean Truck Program, they replaced 11,000 diesel drayage trucks with 2007 or newer ICE models with improved fuel economy, reducing emissions by approximately 90 percent.[125,126]

As of 2017, the POLB, in partnership with terminal operators and Southern California Edison, will demonstrate and deploy projects for zero emissions CHE.[127] POLB matched their funding of $9,755,000 received from the California Energy Commission.[128] The latest POLB energy reduction strategies include demonstrating 12 zero-emissions yard tractors and an automated smart charging system as well as converting four LNG trucks to hybrids.[129]

# REFERENCES

# REFERENCES


1 Birky, A., Laughlin, M., Tartaglia, K., Price, R., & Lin, Z. (2017, Sep). Transportation Electrification Beyond Light Duty: Technology and Market Assessment (No. ORNL/TM-2017/77-R1) [PDF]. *Oak Ridge National Laboratory [ORNL]*. Retrieved from https://info.ornl.gov/sites/publications/Files/Pub72938.pdf

2 Colby, S. & Ortman, J. (2015, Mar). Projections of the Size and Composition of the US Population: 2014 to 2060: Population Estimates and Projections. *United States Census Bureau.* Retrieved from https://census.gov/content/dam/Census/library/publications/2015/demo/p25-1143.pdf

3 Cox, W. (2014, Jan 29). Moving South and West? Metropolitan America in 2042. *New Geography.* Retrieved from www.newgeography.com/content/004153-moving-south-and-west-metropolitan-america-2042.

4 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

5 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

6 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

7 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

8 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

9 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

10 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

11 Improving Ground Support Equipment Operational Data for Airport Emissions Modeling (149). (2015). *ACRP*. Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22084#

12 Birky, A., Laughlin, M., Tartaglia, K., Price, R., & Lin, Z. (2017, Sep). Transportation Electrification Beyond Light Duty: Technology and Market Assessment (No. ORNL/TM-2017/77-R1). *ORNL.* Retrieved from https://info.ornl.gov/sites/publications/Files/Pub72938.pdf

13 Birky, A., Laughlin, M., Tartaglia, K., Price, R., & Lin, Z. (2017, Sep). Transportation Electrification Beyond Light Duty: Technology and Market Assessment. *ORNL.* Retrieved from https://info.ornl.gov/sites/publications/Files/Pub72938.pdf

14 Aber, J. (2016, May). Electric Bus Analysis for New York City Transit [PDF]. *Columbia University and New York City Transit.* Retrieved from http://www.columbia.edu/~ja3041/Electric%20Bus%20Analysis%20for%20NYC%20Transit%20by%20J%20Aber%20Columbia%20University%20-%20May%202016.pdf

15 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

16 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

17 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

18 Birky, A., Laughlin, M., Tartaglia, K., Price, R., & Lin, Z. (2017, Sep). Transportation Electrification Beyond Light Duty: Technology and Market Assessment (No. ORNL/TM-2017/77-R1). *ORNL.* Retrieved from https://info.ornl.gov/sites/publications/Files/Pub72938.pdf

19 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

20 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

21 Birky, A., Laughlin, M., Tartaglia, K., Price, R., & Lin, Z. (2017, Sep). Transportation Electrification Beyond Light Duty: Technology and Market Assessment (No. ORNL/TM-2017/77-R1). *ORNL*. Retrieved from https://info.ornl.gov/sites/publications/Files/Pub72938.pdf36T

22 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

23 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

24 Airport Zero Emissions Vehicle and Infrastructure Pilot Program. (2017, Oct 27). *Federal Aviation Administration.* Retrieved from https://www.faa.gov/airports/environmental/zero_emissions_vehicles/

25 Dougherty, S. & Nigro, N. (2014, Apr). Alternative Fuel Vehicle & Fueling Infrastructure Deployment Barriers & the Potential Role of Private Sector Financial Solutions. *Center for Climate and Energy Solutions & United States Department of Energy [DOE] Office of Energy Efficiency and Renewable Energy; U.S. DOE Energy Efficiency & Renewable Energy.* Retrieved from https://www.afdc.energy.gov/uploads/publication/afv_fueling_infrastructure_deployment_barriers.pdf

26 Elnozahy, A., Rahman, A.K.A., & Ali, A.H.H. (2014, Dec). A Cost Comparison Between Fuel Cell, Hybrid, and Conventional Vehicles. Presented at the 16th International Middle-East Power Systems Conference. Ain Shams University, Cairo, Egypt, December 23-25, 2014. Retrieved from https://www.researchgate.net/publication/270758184_A_Cost_Comparison_between_Fuel_Cell_Hybrid_and_Conventional_Vehicles

27 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

28 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

29 Unparalleled Durability [Corporate Marketing].(n.d.). *Proterra*. Retrieved from https://www.proterra.com/performance/durability/

30 Unparalleled Durability [Corporate Marketing].(n.d.). *Proterra*. Retrieved from https://www.proterra.com/performance/durability/

31 Unparalleled Durability [Corporate Marketing].(n.d.). *Proterra*. Retrieved from https://www.proterra.com/performance/durability/

32 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

33 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

34 Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (78). (2012). *Airport Cooperative Research Program [ACRP].* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/download/22681#

35 Airport Zero Emissions Vehicle and Infrastructure Pilot Program. (2017, Oct 27). *Federal Aviation Administration.* Retrieved from https://www.faa.gov/airports/environmental/zero_emissions_vehicles/

36 Fixing America's Surface Transportation Act or "FAST Act." (2016, Mar 10). *U.S. Department of Transportation Federal Highway Administration.* Retrieved from https://www.fhwa.dot.gov/fastact/factsheets/cmaqfs.cfm

37 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

38 DiOrio, N., Dobos, A., & Janzou, S. (2015, Nov). Economic Analysis Case Studies of Battery Energy Storage with SAM. Golden, Colorado. *National Renewable Energy Laboratory.* Retrieved from https://www.nrel.gov/docs/fy16osti/64987.pdf

39 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

40 Albright, G, Edie, J., & All-Hallaj, S. (2012, April 12). A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications. *AltEnergyMag.* Retrieved from https://www.altenergymag.com/content.php?post_type=1884

41 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

42 Reber, V. (2016, Jan). e-Power: New Possibilities with 800-Volt Charging [PDF]. *Porsche Engineering Magazine,* (1). Retrieved from https://www.porscheengineering.com/peg/en/about/magazine/

43 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

44 Curry, C. (2017, Jul 05). Lithium-ion Battery Costs and Market: Squeezed margins seek technology improvements & new business models [PowerPoint PDF]. *Bloomberg New Energy Finance.* Retrieved from https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf

45 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

46 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

47 Rajagopalan, S., Harley, R., Lambert, F., Addy, M., Franklin, A., & Clappier, P. (2003). Power Quality Impacts Of Airport Ground Support Equipment Charging Systems. *IEEE Power Engineering Society General Meeting, (2).* Retrieved from https://ieeexplore.ieee.org/document/1270504/

48 Overcoming Barriers to Deployment of Plug-in Electric Vehicles. (2015). *National Academy of Sciences.* Washington, DC: National Academy Press. Retrieved from https://www.nap.edu/login.php?record_id=21725#

49 Bronski, P., Chacon, B., Crosby, M., Fogarty, A., Gouin, A., Jennings, T., Lang, B. & Gerdes, J. (2017, Jan). A Portfolio Microgrid in Denver, Colorado: How A Multi-Use Battery Energy Storage System Provides Grid and Customer Services through A Public-Private Partnership. *Panasonic, Xcel Energy & Younicos.* Retrieved from https://www.younicos.com/wp-content/uploads/2017/02/201702-Microgrid-White-Paper.pdf.

50 Wilcox, G. (2017, Mar 17). A Future Perspective on Future Airport and Marine Port Electrification and Automation Opportunities [PDF]. *Eastern Research Group.*

51 National Port Strategy Assessment: Reducing Air Pollution and Greenhouse Gases at U.S. Ports, Executive Summary [PDF]. (2016, Sep). *EPA Office of Transportation Air Quality.* Retrieved from https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/420s16002.pdf.

52 Houston Area Ports Equipment Electrification Assessment [Abstract]. (2014, Jun 23). *EPRI.* Retrieved from https://www.epri.com/#/pages/product/000000003002004192/?lang=en.

53 Exports, Jobs & Economic Growth. (n.d.). *American Association of Port Authorities.* Retrieved from http://www.aapa-ports.org/advocating/content.aspx?ItemNumber=21150.

54 Houston Area Ports Equipment Electrification Assessment [Abstract]. (2014, Jun 23). *EPRI.* Retrieved from https://www.epri.com/#/pages/product/000000003002004192/?lang=en

55 National Port Strategy Assessment: Reducing Air Pollution and Greenhouse Gases at U.S. Ports, Executive Summary [PDF]. (2016, Sep). *EPA Office of Transportation Air Quality.* Retrieved from https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/420s16002.pdf.

56 Lift Trucks. (n.d.). *EPRI.* Retrieved from https://et.epri.com/ResearchAreas_LiftTrucks.html

57 Lift Trucks. (n.d.). *EPRI.* Retrieved from https://et.epri.com/ResearchAreas_LiftTrucks.html

58 Non-road Transportation. (n.d.). *Edison Electric Institute.* Retrieved from http://www.eei.org/issuesandpolicy/electrictransportation/NonRoadTransportation/Pages/default.aspx

59 Maintenance and Safety of Hybrid and Plug-In Electric Vehicles. (n.d.). *United States Department of Energy [DOE] Office of Energy Efficiency & Renewable Energy.* Retrieved from https://www.afdc.energy.gov/vehicles/electric_maintenance.html

60 Non-road Transportation. (n.d.). *Edison Electric Institute.* Retrieved from http://www.eei.org/issuesandpolicy/electrictransportation/NonRoadTransportation/Pages/default.aspx

61 Non-road Transportation. (n.d.). *Edison Electric Institute.* Retrieved from http://www.eei.org/issuesandpolicy/electrictransportation/NonRoadTransportation/Pages/default.aspx

62 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

63 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

64 Shore Power Technology Assessment at U.S. Ports. (n.d.). *EPA.* Retrieved from https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-port

65 Shore Power Technology Assessment at U.S. Ports. (n.d.). *EPA.* Retrieved from https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports

66 Shore Power Technology Assessment at U.S. Ports. (n.d.). *EPA.* Retrieved from https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports

67 Powered Industrial Trucks (Forklift). (n.d.). *U.S. Department of Labor.* Retrieved from https://www.osha.gov/SLTC/etools/pit/forklift/electric.html

68 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

69 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

70 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf.

71 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

72 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf.

73 Automated Container Terminals: Automation of TraPac Terminal, Los Angeles [PowerPoint PDF]. (n.d.). *CH2MHILL.* Retrieved from http://aapa.files.cms-plus.com/SeminarPresentations/2014Seminars/14PortExecMgtMexico/Final_CH2M%20HILL%20Presentation_POLA_Automation_of_Trapac_2014.pdf

74 Automated Container Terminals: Automation of TraPac Terminal, Los Angeles [PowerPoint PDF]. (n.d.). *CH2MHILL.* Retrieved from http://aapa.files.cms-plus.com/SeminarPresentations/2014Seminars/14PortExecMgtMexico/Final_CH2M%20HILL%20Presentation_POLA_Automation_of_Trapac_2014.pdf

75 Romo, L., Solis, O., Matthews, J., & Qin, D. (n.d.). Fuel Saving Flywheel Technology for Rubber Tired Gantry Cranes in World Ports: Reducing Fuel Consumption Through Use of Flywheel Energy Storage System [PDF]. *Vycon.* Retrieved from http://www.polb.com/civica/filebank/blobdload.asp?BlobID=6915

76 Guerin, E. (2018, Feb 09). What Happens When a New Technology That is Better for the Environment Also Eliminates Jobs? *Marketplace.* Retrieved from https://www.calnetix.com/sites/default/files/Fuel%20Savings%20Flywheel%20Technology%20for%20Rubber%20Tired%20Gantry%20Cranes%20in%20World%20Ports%20April%202008.pdf

77 National Port Strategy Assessment: Reducing Air Pollution and Greenhouse Gases at U.S. Ports, Executive Summary [PDF]. (2016, Sep). *EPA Office of Transportation Air Quality.* Retrieved from https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/420s16002.pdf

78 National Port Strategy Assessment: Reducing Air Pollution and Greenhouse Gases at U.S. Ports, Executive Summary [PDF]. (2016, Sep). *EPA Office of Transportation Air Quality.* Retrieved from https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/420s16002.pdf

79 United States: Nonroad Diesel Engines. (n.d.). *DieselNet.* Retrieved from https://www.dieselnet.com/standards/us/nonroad.php#tier

80 Regulatory Background on the U.S. Mobile Source Emission Control Program: U.S. EPA Clean Air Non-road Diesel Rule. (n.d.). *MECA.* Retrieved from http://www.meca.org/regulation/us-epa-clean-air-nonroad-diesel-rule

81 Shore Power Technology Assessment at U.S. Ports. (n.d.). *EPA.* Retrieved from https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports

82 Port of Los Angeles Ready to Meet California's Shore-side Power Requirements: Port Invests $180 Million; 25 Berths Equipped with Shore-Side Electric Power. (2014, Jan 08). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/newsroom/2014_releases/news_10814_AMP-Shoreside_Power_Requirements.asp

83 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

84 An Integrated Perspective of the Future of Mobility. (2016, Oct). *McKinsey & Company and Bloomberg New Energy Finance.* Retrieved from https://www.bbhub.io/bnef/sites/4/2016/10/BNEF_McKinsey_The-Future-of-Mobility_11-10-16.pdf

85 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

86 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

87 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

88 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

89 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

90 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

91 The Feasibility, Issues, and Benefits Associated With Expanded Use of Natural Gas at Seaports and Other High Horsepower Applications. (2017, Oct). *California Energy Commission: Energy Research and Development Division.* Retrieved from http://www.energy.ca.gov/2017publications/CEC-500-2017-032/CEC-500-2017-032.pdf

92 Martin, R. (2016, Aug 29). Why We Still Don't Have Better Batteries. *MIT Technology Review.* Retrieved from https://www.technologyreview.com/s/602245/why-we-still-dont-have-better-batteries/

93 Cameron, I. (2018, Feb 22). New Technology for Faster Battery Charging? *New Power Progress.* Retrieved from https://newpowerprogress.com/new-technology-faster-battery-charging/

94 Chapter 1: Program Overview. (n.d.). *Carl Moyer Memorial Air Quality Standards Attainment Program.* Retrieved from https://www.arb.ca.gov/msprog/moyer/guidelines/2017gl/2017_gl_chapter_1.pdf

95 Chapter 5: Off-Road Equipment. (n.d.). *Carl Moyer Memorial Air Quality Standards Attainment Program.* Retrieved from https://www.arb.ca.gov/msprog/moyer/guidelines/2017gl/2017_gl_chapter_5.pdf

96 Cargo Handling Equipment Program. (n.d.). The Port Authority of New York & New Jersey. Retrieved from https://www.panynj.gov/about/cargo-handling-equipment-program.html

97 Todd, J., Chen, J., & Clagston, F. (2013). Creating the Clean Energy Economy: Analysis of the Electric Vehicle Industry. *International Economic Development Council.* Retrieved from https://www.iedconline.org/clientuploads/Downloads/edrp/IEDC_Electric_Vehicle_Industry.pdf

98 Daudon, J., Lynch, M., Whitehouse, K., Crowe, J., Shenette, E., McKeon, N., Kranich, K., & Hill, D. (2018). In Demand: Clean Energy, Sustainability and the New American Workforce. *Environmental Defense Fund.* Retrieved from http://edfclimatecorps.org/sites/edfclimatecorps.org/files/casestudy/edf_in_demand_clean_energy_sustainability_and_the_new_american_workforce.pdf

99 Fact Sheet: Energy Efficiency and Economic Opportunity. (n.d.). *American Council for an Energy-Efficient Economy.* Retrieved from http://aceee.org/files/pdf/fact-sheet/ee-economic-opportunity.pdf

100 Todd, J., Chen, J., & Clogston, F. (2013). Creating the Clean Energy Economy: Analysis of the Electric Vehicle Industry. *International Economic Development Council.* Retrieved from https://www.iedconline.org/clientuploads/Downloads/edrp/IEDC_Electric_Vehicle_Industry.pdf

101 Eudy, L., Prohaska, R., Kelly, K., & Post, M. (2016, Jan). Foothill Transit Battery Electric Bus Demonstration Results. *NREL.* Retrieved from https://www.nrel.gov/docs/fy16osti/65274.pdf

102 Maintenance and Safety of Hybrid and Plug-In Electric Vehicles. (n.d.). *DOE Office of Energy Efficiency & Renewable Energy.* Retrieved from https://www.afdc.energy.gov/vehicles/electric_maintenance.html

103 Guerin, E. (2018, Jan 22). Robots Steal Port Jobs – But They Also Fight Climate Change. *Southern California Public Radio.* Retrieved from https://www.scpr.org/news/2018/01/22/79969/robots-that-steal-port-jobs-also-fight-climate-cha/

104 Alternative Fuels Data Center. (2016, January 26). "Sea-Tac and Alaska Air Group Achieve Sky-High Results with Electric Ground Support Equipment." U.S. Department of Energy. Retrieved from https://www.afdc.energy.gov/case/2329

105 Birky, A., Laughlin, M., Tartaglia, K., Price, R., & Lin, Z. (2017, Sep). Transportation Electrification Beyond Light Duty: Technology and Market Assessment (No. ORNL/TM-2017/77-R1). *Oak Ridge National Laboratory ORNL.* Retrieved from https://info.ornl.gov/sites/publications/Files/Pub72938.pdf

106 Aber, J. (2016, May). Electric Bus Analysis for New York City Transit [PDF]. *Columbia University.* Retrieved from http://www.columbia.edu/~ja3041/Electric%20Bus%20Analysis%20for%20NYC%20Transit%20by%20J%20Aber%20Columbia%20University%20-%20May%202016.pdf

107 Rutledge, B. (2006, Dec 11). Port Yard Hostler Demo Projects: Assessing LNG & Hybrid Yard Hostlers at POLB & POLA [PowerPoint PDF]. *CalStart, WestStar & EPA West Coast Collaborative.* Retrieved from https://westcoastcollaborative.org/files/meetings/2006-12-11/YardHostlerDemoProjects.pdf

108 Rutledge, B. (2006, Dec 11). Port Yard Hostler Demo Projects: Assessing LNG & Hybrid Yard Hostlers at POLB & POLA [PowerPoint PDF]. *CalStart, WestStar & EPA West Coast Collaborative.* Retrieved from https://westcoastcollaborative.org/files/meetings/2006-12-11/YardHostlerDemoProjects.pdf

109 Barboza, T. (2017, Nov 02). L.A., Long Beach Ports Adopt Plan to Slash Air Pollution and Go Zero-emissions. *Los Angeles Times.* Retrieved from http://www.latimes.com/local/lanow/la-me-ports-air-quality-20171102-story.html

110 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf.

111 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

112 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

113 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

114 Zero Emission White Paper [PDF]. (2015, Jul). *Port of Los Angeles.* Retrieved from https://www.portoflosangeles.org/pdf/Zero_Emmissions_White_Paper_DRAFT.pdf

115 Barboza, T. (2017, Nov 02). L.A., Long Beach Ports Adopt Plan to Slash Air Pollution and Go Zero-emissions. *Los Angeles Times.* Retrieved from http://www.latimes.com/local/lanow/la-me-ports-air-quality-20171102-story.html

116 Rutledge, B. (2006, Dec 11). Port Yard Hostler Demo Projects: Assessing LNG & Hybrid Yard Hostlers at POLB & POLA [PowerPoint PDF]. *Calstart; WestStart; EPA West Coast Collaborative.* Retrieved from https://westcoastcollaborative.org/files/meetings/2006-12-11/YardHostlerDemoProjects.pdf

117 Rutledge, B. (2006, Dec 11). Port Yard Hostler Demo Projects: Assessing LNG & Hybrid Yard Hostlers at POLB & POLA [PowerPoint PDF]. *Calstart; WestStart; EPA West Coast Collaborative.* Retrieved from https://westcoastcollaborative.org/files/meetings/2006-12-11/YardHostlerDemoProjects.pdf

118 Rutledge, B. (2008, Aug). Liquefied Natural Gas (LNG) Yard Hostler Demonstration and Commercialization Project Final Report [PDF]. *Port of Long Beach & Calstart.* Retrieved from http://www.polb.com/civica/filebank/blobdload.asp?BlobID=5547

119 Rutledge, B. (2008, Aug). Liquefied Natural Gas (LNG) Yard Hostler Demonstration and Commercialization Project Final Report [PDF]. *Port of Long Beach & Calstart.* Retrieved from http://www.polb.com/civica/filebank/blobdload.asp?BlobID=5547

120 Long Beach Harbor Department Green Port Policy White Paper [PDF]. (2005, Aug 15). *Port of Long Beach.* Retrieved from http://www.polb.com/civica/filebank/blobdload.asp?BlobID=2268

121 Long Beach Harbor Department Green Port Policy White Paper [PDF]. (2005, Aug 15). *Port of Long Beach.* Retrieved from http://www.polb.com/civica/filebank/blobdload.asp?BlobID=2268

122 Charting the Course: Sustainable Emission Reduction Strategies at the Port of Long Beach [PowerPoint PDF]. Presented at the Port Stakeholders Summit, Baltimore, MD. *EPA & Port of Long Beach.* Retrieved from https://www.epa.gov/sites/production/files/2014-07/documents/summit-cameron.pdf

123 Charting the Course: Sustainable Emission Reduction Strategies at the Port of Long Beach [PowerPoint PDF]. Presented at the Port Stakeholders Summit, Baltimore, MD. *EPA & Port of Long Beach.* Retrieved from https://www.epa.gov/sites/production/files/2014-07/documents/summit-cameron.pdf

124 Ports' Technology Advancement Program. (2007). *Port of Long Beach & Port of Los Angeles.* Retrieved from http://www.cleanairactionplan.org/technology-advancement-program/

125 Clean Trucks Program to Reach Final Milestone. (2011, Nov 21). *Port of Long Beach.* Retrieved from http://www.polb.com/news/displaynews.asp?NewsID=941

126 Charting the Course: Sustainable Emission Reduction Strategies at the Port of Long Beach [PowerPoint PDF]. Presented at the Port Stakeholders Summit, Baltimore, MD. *EPA & Port of Long Beach.* Retrieved from https://www.epa.gov/sites/production/files/2014-07/documents/summit-cameron.pdf

127 San Pedro Bay Ports Clean Air Action Plan: 2017 Annual Report and 2018 Priorities Technology Advancement Program. (2018, Feb). *Port of Long Beach & Port of Los Angeles.* Retrieved from http://www.cleanairactionplan.org/documents/final-2017-technology-advancement-program-tap-annual-report.pdf/

128 San Pedro Bay Ports Clean Air Action Plan: 2017 Annual Report and 2018 Priorities Technology Advancement Program. (2018, Feb). *Port of Long Beach & Port of Los Angeles.* Retrieved from http://www.cleanairactionplan.org/documents/final-2017-technology-advancement-program-tap-annual-report.pdf/

129 San Pedro Bay Ports Clean Air Action Plan: 2017 Annual Report and 2018 Priorities Technology Advancement Program. (2018, Feb). *Port of Long Beach & Port of Los Angeles.* Retrieved from http://www.cleanairactionplan.org/documents/final-2017-technology-advancement-program-tap-annual-report.pdf/.

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