ELECTRIC POWER RESEARCH INSTITUTE

Houston Area Ports Equipment Electrification Assessment

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EPRI Project Manager

A. Rogers

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

THE FOLLOWING ORGANIZATION, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

Starcrest Consulting Group, LLC

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Starcrest Consulting Group, LLC
P.O. Box 434
Poulsbo, WA 98370

Principal Investigator
K. Bishop

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ABSTRACT

Today, the United States is served by publicly- and privately-owned marine facilities located in approximately 360 commercial sea and river ports. The ports rely in large part on diesel engine-fueled equipment specialized to various types of cargo. As oil prices continue to rise, ports are exploring the possibility of lowering costs by reducing the use of diesel fuel through electrification. The objective of this research is to assess the extent of current electrification efforts as well as the possibilities for additional electrification at three ports in Texas: the Ports of Houston, Galveston, and Freeport. This research highlights current opportunities for U.S. ports to increase operational efficiency and reduce emissions through electrification.

Keywords
Ports
Electrification
Cargo handling
Emission reduction

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INTRODUCTION

Seaports around the world are served in large part by diesel engine-fueled equipment specialized to various types of cargo. As oil prices continue to increase, ports at which fuel for equipment is a major budget item are increasingly willing to explore creative options for reducing costs by eliminating diesel fuel altogether. Electrification is a key strategy in this regard, and cargo handling equipment is an increasingly attractive target for application.

Port electrification efforts and their promise are not entirely new. U.S. ports began converting large ship-to-shore cranes from diesel to electric in the 1970s and continued until the few remaining diesel cranes became a rarity. In addition, new marine terminals throughout the country are either installing shore power for ships or planning for its future installation.

At the other end of the spectrum, smaller port equipment such as forklifts and passenger vehicles have found increasing applications for ever-improving battery and battery charging technologies. In particular, lithium ion technology with all of its variants boasts high energy densities, long life, and resilience to rapid charge and discharge cycles, although currently at a cost that makes it only marginally cost effective for all but the most ideal applications.

Electrification of cargo handling equipment is a near-term option that can provide broad-based benefits to ports, including potential emissions reductions and cost efficiencies. The objective of this paper is to assess the future potential for electrification at three ports in Texas: the Ports of Houston, Galveston, and Freeport.

Background

Cargo handling operations at seaports are being assessed both internally as a potential means of operational efficiency and externally by regulators as a means of air emissions reductions. As domestic cargo throughput in the U.S. continues to soar, with total volume of cargo shipped by water expected to double by 2020 compared to that of 2001,[1] cargo handling efficiencies on both the economic and environmental side of the equation become even more critical.

Conversion from diesel engine to electric drive is currently possible for many types of cargo handling equipment, including wharf cranes, gantry cranes, terminal tractors, forklifts, and other equipment critical to port operations. In addition to cargo handling operations, vessels can also benefit from electrification through the use of shorepower a technology that utilizes power from the dock to provide ships at berth with needed power for lights, pumps, refrigeration, etc. Other opportunities for electrification also exist, including those related to other marine vessels and on road heavy and light duty vehicles.

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[1] http://www.prnewswire.com/news-releases/new-forecasts-predict-us-water-freight-volume-to-double-2001-to-2020-166909466.html

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CARGO HANDLING EQUIPMENT

Cargo handling equipment varies by port and terminal according to what type of cargo is being loaded and unloaded. A review of commonly seen cargo handling equipment at ports is provided below.

Forklift - a very common piece of equipment at ports of all sizes, forklifts are used for both container and non-container handling activities. Forklifts, also called lift trucks, may be equipped with cushion tires for inside use or on flat surfaces, or pneumatic tires for use on rough terrain or outside. Forklifts are commonly available in gas or diesel, liquefied petroleum gas (LPG) and electric models from a variety of manufacturers.

Side Loader and Reach Stacker - typically move and stack containers. Side loaders and reach stackers are predominantly powered by diesel engines, but recently are also available in electric or hybrid electric drive. Hubtex is marketing an electric side loader that has reported lift capacities up to 20 tons[2] and Konecranes has a hybrid reach stacker available with a lifting capacity of 45 tons.[3]

Rubber-tired Gantry Crane (RTG) – these large cranes move containers to and from container stacks at ports. The RTG straddles stacks of containers and has room for a heavy-duty truck/yard tractor to pull under and move containers between stacks and vehicles. It is also used to consolidate container stacks as containers are added and removed from the terminal. RTGs have historically utilized diesel engines for power, but recently several demonstration projects have proved the efficiencies of electric and hybrid electric drive systems for these important pieces of equipment.

Electric feed for the electric RTG can occur in a variety of ways, including the overhead busbar system like that being demonstrated by Konencranes at the Port of Savannah,[4] or the cable reel system in which the electric cable is attached to the crane, as was demonstrated at the Port of Los Angeles. Hybrid electric RTGs, like the Eco-Crane by MJ EcoPower Hybrid Systems,[5] have been demonstrated at several ports, including Houston and Los Angeles, and have been adopted on a widespread basis by terminals such as APM Terminals.[6] This hybrid crane uses lithium-ion (Li-ion) batteries to store energy for crane power.

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2 http://www.hubtex.com/english/products/sideloader.html

3 http://www.konecranes.com/resources/media/releases/2013/konecranes-presents-the-worlds-first-hybrid-reach-stacker

4 http://www.gaports.com/corporate/tabid/379/xmmid/1097/xmid/7804/xmview/2/default.aspx

5 http://www.ecopowerhs.com/

6 http://www.apmterminals.com/aboutus.aspx?id=14099

Figure 2-1
Electric Rubber-tired Gantry Crane in Savannah, Georgia

Rail-mounted Gantry Crane (RMG) - a large mobile gantry crane running on two rails. The RMG moves and stacks cargo containers using an attached spreader. The extensive infrastructure associated with RMGs makes its cousin, the RTG, a more economical solution for many ports.

Yard Truck – also called yard hostlers, terminal tractors, and yard goats, these are heavy-duty, often off-road port equipment designed for moving cargo containers. They are the most common type of cargo handling equipment used at container terminals. Normally the yard hostler is connected to a trailer which it uses to help transport containers within the yard. There are several electric yard trucks being tested, but not yet commercially available on the market, including:

- US Hybrid
- Balqon Battery Electric E20 Nautilus
- Capacity Plug-in hybrid electric
- Vision Motor Corp's H2 fuel cell/plug in

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ON-ROAD LIGHT DUTY FLEETS: PLUG-IN ELECTRIC VEHICLES

It is an exciting time for vehicles powered by electricity. During the past several years, there has been a significant upsurge in the sales of plug-in electric vehicles (PEVs). In addition to the economic (lower fuel costs) and environmental (lower emissions) benefits of PEVs, this demand is being driven by a combination of regulatory requirements and a variety of incentives, including state and/or federal tax credits and buy-downs.

Plug-in electric cars offer performance, safety and versatility, and can be charged from the electric grid, providing convenient, low-cost, at-home charging. At the U.S. national average price of 11.9 cents per kilowatt-hour (kWh), buying electricity is approximately equivalent to buying gasoline at $1 per gallon. With time-of-use rates offered by some utilities, plug-in electric vehicle drivers can save even more. Displacing gasoline with electricity also lowers emissions and decreases petroleum use. On a typical day, half of all drivers log less than 25 miles, so plug-in electric vehicles, if widely adopted, could reduce petroleum fuel consumption by 70% to 90%. The following descriptions are of three types of light duty fleet vehicles currently in the market place.

Hybrid Vehicles

Hybrid vehicles are powered by an internal combustion engine assisted by a battery and electric motors. They are not plug-in electric vehicles. Hybrid vehicles, such as the Toyota Prius and the Ford Fusion hybrid, operate like conventional vehicles and are fueled with gasoline or diesel. A battery provides additional power during acceleration. It is charged by the gasoline engine and when the driver applies the brakes. Hybrid vehicles cannot be recharged from the grid. Generally, hybrids are more efficient than conventional vehicles since they use technologies that turn off the gasoline engine at a stop and use regenerative braking, which captures braking energy and stores it in the battery for use during acceleration. Further, hybrids improve miles per gallon by enabling the internal combustion engine to operate at a higher efficiency.

Plug-in Hybrid Electric Vehicles

Plug-in hybrid electric vehicles are powered by an internal combustion engine and electric motor(s). They have a larger battery pack than hybrid vehicles, and can be recharged from the grid. This combination allows the vehicle to drive on electricity alone using battery energy, and after the lithium-ion battery is discharged, continue driving using gasoline much like a hybrid vehicle. The Ford C-MAX Energi and Chevrolet Volt are examples of plug-in hybrid electric vehicles; Chevy calls the Volt an extended-range electric vehicle. A vehicle with a 38-mile electric range such as the Volt operates on electricity for most daily driving – as long it is plugged in to recharge the battery. When driven this way, it will use up to 70% less gasoline than a hybrid vehicle. A PHEV will not save as much gasoline if it is not regularly plugged in to recharge the battery. Typical charge time for 38 miles of range is roughly 10 hours with a conventional 120V wall outlet, or 3 to 4 hours with a 240V connection

Battery Electric Vehicles

Battery electric vehicles are powered by an electric motor and battery alone. BEVs can travel farther on electricity alone than plug-in hybrids, but their range is limited by the size of their batteries. BEVs never use gasoline. Most models, such as the Nissan LEAF, are designed to travel 80 to 100 miles between charges. This range is greater than the distance driven by average Americans on over 90% of driving days, but it could be a limitation for some drivers who frequently drive long distances. The Tesla Model S travels more than 200 miles on a charge. Most people charge their electric vehicle at home overnight, using a 240V charging station. Some simply use a standard 120V wall socket since their daily driving patterns use only a portion of the battery's energy. With 120V charging, the full recharge time is much longer – roughly 15 to 20 hours. While the availability of public and workplace charging infrastructure is currently limited, many cities, states, and companies are working to provide charging locations so plug-in electric vehicles can charge when they need to. In addition, fast charging infrastructure is growing, allowing properly equipped electric vehicles to recharge to 80% full in roughly 30 minutes.

Vehicle Availability and Sales

More than 15 models of light-duty battery electric and plug-in hybrid electric vehicles are currently available in the United States. The table below provides an overview of 2014 PEV models and estimated range[7].

Table 3-1
Overview of 2014 PEV models and estimated range

PEV Model	EV Type	Base MSRP (without incentives)	Range (miles)
BMW i3	BEV	$41,350	81
Cadillac ELR	PHEV	$75,000	Up to 37 miles EV mode, 340 mi. combined
Chevrolet Spark EV	BEV	$26,685	82
Chevrolet Volt	EREV	$39,145	Up to 38 miles EV mode, 380 mi. combined
Fiat 500e	BEV	$32,500	87
Ford C-Max Energi	PHEV	$32,950	Up to 21 miles EV mode, 620 mi. combined
Ford Focus EV	BEV	$39,200	76
Ford Fusion Energi	PHEV	$38,700	Up to 21 miles EV mode, 620 mi. combined
Honda Accord	PHEV	$38,780	Up to 13 miles EV mode, 570 mi. combined
Honda Fit EV	BEV	$259/mo on 3 year lease	82
Mitsubishi i-MiEV	BEV	$29,125	62
Nissan LEAF	BEV	$28,800	84

[7] Table data collected from Plug-in America Vehicle Tracker http://www.pluginamerica.org/vehicle-tracker? and individual manufacturer information via telephone inquiries as well as from the Electric Drive Transportation Association website, www.goelectricdrive.com

Table 3-1 (continued)
Overview of 2014 PEV models and estimated range

PEV Model	EV Type	Base MSRP (without incentives)	Range (miles)
Porsche Panamera S E-Hybrid	PHEV	$99,000	Up to 16 miles EV mode, 540 mi. combined
Smart ED	BEV	$25,000	68
Tesla Motors Model S	BEV	$79,900	265
Toyota Prius Plug-in	PHEV	$32,000	Up to 11 miles EV mode, 540 mi. combined
Toyota RAV4EV	BEV	$49,800	100

Sales of plug-in electric vehicles have been growing steadily since they were first introduced in December 2010. As of February 2014, more than 180,000 vehicles have been sold. Over the past two years a number of interesting trends have emerged:

- Sales are fluctuating around 8,000 to 10,000 per month. The leading models are the Nissan Leaf and Chevrolet Volt, although the plug-in Toyota Plug-in Prius has and the Ford C-Max and Fusion Energi have also had some strong months.
- While initially lagging plug-in hybrid sales, battery electric vehicle sales have caught up and are now close to parity with PHEVs.
- Plug-in electric vehicles are selling at a faster pace (nearly three times) than hybrid electric vehicles when they were introduced a decade ago.

Vehicle Range and Charging

The advertised range of battery electric vehicles varies by model from about 84 miles (Nissan LEAF) to 265 miles (Tesla Model S). Range depends heavily on the driver's individual driving habits, weather, and environmental conditions. As a starting point, a new battery electric vehicle driver can to expect to achieve about 80% of the advertised range.

The advertised electric driving range for plug-in hybrid electric vehicles varies from 13 to 40 miles between charges, depending on battery size and vehicle design, and about 300 to 400 miles on gasoline. If the vehicle is plugged in every day, as recommended, it may be possible to drive 1,000 to 2,000 miles or more between gasoline fill-ups.

Studies show that the limited range of the battery is less problematic for most electric vehicle drivers than they initially expected. Most drivers find their daily driving is well within the vehicle's range. On days with more driving, they use public or workplace charging during the day or swap cars with another member of their household. Many drivers become comfortable enough with the vehicle's range to drive for a couple of days between charges.

A factor that may affect vehicle performance is ambient air temperature. Heating and cooling needs require the use of energy otherwise available to power the vehicle. In cold weather, electricity is needed to heat the passenger cabin and defrost or defog the windows – plus the vehicle's battery is a little less efficient at low temperatures. In hot weather, significant electricity is needed for the air-conditioning system, although its energy use is less than that required to accelerate the vehicle and maintain highway speeds. In short, during very hot or very cold weather, and in certain driving conditions such as being stuck in traffic, the range of an electric vehicle will be reduced. Automakers continue to make progress on technologies that reduce the extreme temperature effect.

Plug-in electric vehicles can be charged from a standard 120V outlet. While vehicles typically come with a 120V charging cord, many owners choose to install a dedicated 240V charging station at home for faster charging. Dedicated 240V charging stations with capacities of 3kW to 7kW—about the same power draw as a residential clothes dryer or an air conditioning system—are available and can fully charge most vehicles in 3 to 8 hours, or about 8 to 12 miles per hour of charging. All vehicles except Tesla are equipped with standard plugs, known as connectors.

Drivers can charge the battery at any time they have access to a charging station, but most drivers charge at home. Sometimes drivers need to recharge during the day, away from home, especially if they've experienced a detour on the road or other unexpected event that requires them to drive more than they planned. The number of public and workplace charging stations is growing rapidly, especially in markets where plug-in electric vehicle sales are robust. Today's plug-in electric vehicle drivers can use the services of one of many subscription charging service providers, such as ChargePoint or Blink, and take advantage of a wide array of in-vehicle software and external smartphone apps that locate charging stations and guide them to the nearest station from their current location.

Fast-charging station networks are also expanding across the country. A fast charger can charge an electric vehicle to 80% full in 30 minutes or less. Tesla has developed its own fast-charging Supercharger network to solely serve Tesla drivers. Public and private ventures are supporting fast-charging networks in the Pacific Northwest, California, and other parts of the country.

Economic and Environmental Considerations

With manufacturer lease options, utility time-of-use rates, and government purchase incentives, plug-in electric vehicles can be less expensive to operate over their lifetime despite costing more upfront. A study from the Electrification Coalition reported that "electric vehicles help Houston Save $110,000 annually". The Director of Sustainability for the City of Houston shared information on their fleet: "Houston first began using electric vehicles for the environmental benefits they offer, but now we are planning to add even more EVs to our fleet because of the cost savings they bring. We project that electric vehicles will save the city $110,000 per year in reduced fuel and maintenance, costs that we would otherwise have to spend on gas-powered vehicles."[8]

The federal government offers a tax credit of up to $7,500 toward the purchase of a qualified plug-in electric vehicle. Many states also offer vehicle purchase incentives and rebates. In some regions of the country, incentives are also available for the purchase or installation of a charging station. In some urban areas, plug-in electric vehicles are granted access to carpool lanes with a single driver. Other perks, such as free or priority parking and free charging are available in many cities. All of these incentives, which are designed to entice consumers to consider purchasing a plug-in electric vehicle, are subject to limitations and may change over time as the market develops.

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[8] http://electrificationcoalition.org/LovelandHoustonPresser

For more information, read EPRI publication, “Total Cost of Ownership for Current Plug-in Electric Vehicles: Update to Model 2013 and 2014 Model Year Vehicles” (Product ID 3002004054). Non-monetary incentives such as access to carpool lanes or preferential parking may be offered in your region.

In addition to economic considerations are the environmental benefits. Grid-powered vehicles have lower emissions than gasoline-powered vehicles, even in areas where much of the power is generated by fossil-fueled plants, such as coal or natural gas. For more information, read EPRI publication, “Environmental Assessment of Plug-In Hybrid Electric Vehicles” (Product ID 1015325).

On the regulatory side, federal fuel economy requirements are driven by the Corporate Average Fuel Economy (CAFE) [9] standards. Enacted in 1975 to improve gasoline mileage following the Arab oil embargo, CAFE standards have become more stringent over the past three decades. The most recent change, in 2012, raised the average fuel economy standard to 54.5 miles per gallon by 2025.[10] As anticipated, automakers are adding cleaner vehicles to their portfolio to help offset the production of less fuel efficient, but potentially more profitable, trucks and sport utility vehicles.

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[9] Corporate Average Fuel Economy or CAFÉ regulations “require vehicle manufacturers to comply with the gas mileage, or fuel economy, standards set by the Department of Transportation (DOT). CAFE values are obtained using the city and highway fuel economy test results and a weighted average of vehicle sales.” http://www.epa.gov/fueleconomy/regulations.htm

[10] http://www.usnews.com/news/articles/2012/08/29/545-miles-per-gallon-for-all-cars-by-2025-not-exactly

4

TEXAS PORTS: HOUSTON, GALVESTON AND FREEPORT

The Ports of Houston, Galveston and Freeport are among the dozen-plus ports in Texas, and are closest to the Houston Metropolitan area. These three ports have operational similarities, as well as differences, with some of the following cargo terminals in operation:

- *Roll on /Roll off (Ro/Ro) Cargo* – This cargo includes anything transported on wheels, including cars, tractors, and railcars, that can be rolled or moved on and off of ships instead of lifted by crane. The Ports of Houston and Galveston currently have Ro/Ro facilities. Cargo handling equipment used in this type of terminal operation includes ro/ro tractors - similar to yard trucks - which are used to carry cargo on and off the ship via attached ramp.
- *Container Cargo* – This type of cargo is stored on ships in shipping containers. These containers, which can be refrigerated or not, are lifted on and off of the ship using large cranes. Containers are then picked up by one of several types of equipment, including an RTG crane or other container handler, and moved to a container stack. Containers may later be moved from the stack to truck or rail by a yard truck. The Port of Houston has two large container terminals, and the Ports of Galveston and Freeport also handle containerized cargo but to a smaller extent than Houston. Cargo handling equipment at container terminals differs from that operating at other terminals in that there is heavy use of cranes, dedicated container handlers such as top picks, reach stackers, etc., and other larger horsepower equipment for heavy lifting. Forklifts are not typically found in large quantities at these types of terminals.
- *Bulk (break, dry, liquid) Cargo* - Bulk cargo, or cargo that is not containerized, is handled at specific terminals at Houston, Galveston and Freeport. Dry bulk terminals handle cargo such as grain, fertilizer, coal and minerals. Liquid bulk terminals handle a variety of liquids, including fuels such as liquid natural gas and petroleum. Each type of bulk cargo requires cargo handling equipment specific to the cargo, although the predominant type of equipment seen at these types of terminals is the forklift. The three Ports discussed in this report all contain bulk terminals.
- *Passenger Terminals* – cruise ships terminals exist at both the Ports of Houston and Galveston, the only two such terminals in the state. Passenger terminals do not typically have much in the way of cargo handling equipment, but would likely have a small number of both forklifts and smaller tractors.

Port of Houston

Figure 4-1
Port of Houston

The Houston Port Authority, along with over 150 private companies, operates multiple terminals along the Houston Ship Channel, including:

- Barbours Cut
- Bayport
- Turning Basin
- Sims Bayou
- Southside Wharves
- Jacintoport
- Manchester Wharves
- CARE

Cargo: Primary cargo at Houston includes imports of petroleum and petroleum products; iron and steel; crude fertilizers and minerals; organic chemicals; wood and articles of wood. Primary exports include petroleum and petroleum products; organic chemicals; cereals and cereal products; plastics; animal or vegetable fats and oils. Approximately 200 million tons of cargo is moved port-wide annually.[11] The Port of Houston handles approximately 70% of containerized cargo in the US Gulf of Mexico.[12]

Equipment[13] (in 2007): Port of Houston (Port and tenant) cargo handling equipment includes:

- Forklifts: 451
- Yard tractors: 306
- RTGs: 70
- Other: 69
- Container handler: 39
- Crane/crane truck: 31

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[11] http://www.portofhouston.com/

[12] http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5105194

[13] *2007 Goods Movement Air Emissions Inventory*, Port of Houston. Starcrest Consulting Group, 2009.

Port of Galveston

Figure 4-2
Cruise terminal in Galveston, Texas

Facilities: The Port of Galveston is a landlord port, 850 acres in size, at the mouth of Galveston Bay. Just 30 miles from the Gulf of Mexico, the Port's major tenants include Del Monte and ADM Grain Company.

Cargo: Imports include wind power equipment, bananas, agricultural equipment, machinery, vehicles, fertilizer products, lumber products, and military-related cargo. Exports include bulk grains, containers, machinery, vehicles, linerboard and paper, carbon black, and light fuels. Approximately 8 million tons of cargo move through the port annually, with the majority of imports and exports being bulk, non-containerized cargo.[14] The Port of Galveston also has a large cruise terminal facility, with over 460,000 passengers disembarking each year.[15]

Equipment (partial list):[16]

- Forklifts:[17] 100+ (assumption that 75 of these are non-electric)
- Cranes: 10
- Terminal tractors: 10

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[14] http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5105192

[15] *Texas Ports 2013-2014 Capital Funding Program.* Texas Department of Transportation.

[16] Includes MetroPorts and Gulf Stevedoring at Port of Galveston.

[17] Including propane, diesel/gas and electric

Port Freeport

Figure 4-3
Forklift removing goods from long haul trucks

Facilities: Port Freeport facilities are located three miles from the Gulf of Mexico via a 45-foot deep channel. The Port has several berths, including one that is 70-feet deep, and several with a maximum water depth of 36 feet. Also part of the facilities is an on-dock container freight station for stuffing and stripping intermodal equipment. Freeport also serves transshipment of US East Coast cargo.

Cargo: Primary imports include aggregate, chemicals, clothing, foods (fruit), crude, LNG, paper goods, plastics, and wind turbines. Primary exports include autos, chemicals, clothing, foods, paper goods, resins, and rice. Approximately 27 million tons per year move through the port's public and private docks,[18] including transshipment of US East Coast cargo. Dole and Chiquita, both fresh fruit import operations, are large tenants of Port Freeport.

Equipment (partial list):[19]

- Forklift (propane, gas, electric): 20
- Golf carts/gators (electric or gas): 15
- Yard trucks: 4
- Gottwald 110-ton crane: 1
- Container handler: 1

[18] *State of the Port 2011: Diverse Operations Spur Record Year for Port Freeport Tonnage, Revenue. Port Freeport*. March 2012.

[19] Electronic communication from Scott Brooks and Jesse Hibbetts, Port Freeport. May 2014.

5

OPPORTUNITIES FOR ELECTRIFICATION

Based on activity and equipment at each of the three ports, there may be several opportunities for equipment electrification with the potential for economic, operational, and environmental benefits.

Port of Houston

According to the Port of Houston's (PHA's) cargo handling inventory, 56% of its equipment has been upgraded to cleaner engines, leaving potential opportunities to upgrade the remaining 44% of the fleet to newer, cleaner engines.[20] Among the cleaner engine options for cargo handling equipment, electric drive is an option that may align with the port's goals, as outlined in the Clean Air Strategy Plan of 2011. As presented in this Plan, potential future actions at the Port may include:[21]

- install/upgrade electric infrastructure to support electrification of PHA Barbour Cut wharf cranes
- electrification (and demonstration) of trucks and yard trucks at Bayport and elsewhere may be considered
- demonstrations related to new technologies and alternative fuels
- shorepower studies at PHA terminals
- shorepower demonstration at Bayport for cruise ships
- electrification of near port truck parking areas with electrification terminals
- hybrid tugboat demonstration

The Port of Houston's two major container terminals, Bayport and Barbours Cut, are undergoing either expansion or upgrades. Bayport, constructed over a period of over a decade, is not yet at full build out and is still adding equipment regularly to support new development. When fully developed, it will include a cruise terminal, 376 acres of container yard and 123 acres of intermodal facility and will be able to handle 2.3 million TEUs. Bayport currently contains 544 440 volt refrigerated container slots and the electric infrastructure to offer shore power to some vessels. Barbours Cut, Houston's original container terminal, currently offers 392 440-volt reefer slots and has 36 RTGs operating on site. This terminal is undergoing a $700 million upgrade that will include dock improvements and new cargo handling equipment. As part of this expansion, up to 10 electric ship to shore cranes, with associated substation upgrades and construction, are planned at Barbours Cut.

[20] http://www.portofhouston.com/static/gen/inside-the-port/Environment/CASP-2011.pdf

[21] *Port of Houston Clean Air Strategy Plan, 2011.* Environmental Affairs Department, Port of Houston Authority, 2011.

As these two terminals are developed and upgraded, the Port will likely require additions to its crane fleet, including RTGs, among other container handling equipment. Future electric equipment options may involve these new equipment additions to the fleet, including electric or hybrid electric RTGs. The Port has recently demonstrated a hybrid electric RTG called the Eco-Crane at a location at Barbours Cut Terminal, with plans to install four additional hybrid systems with improved Li-ion batteries on other RTGs at a future date.[22]

In addition to electric cargo handling equipment possibilities, several other options exist for electrification at the Port of Houston, including:

- Electric power for vessels at berth, or shorepower as it is known, may be something to consider as Bayport continues to develop because the infrastructure to support such technology has already been incorporated into the design of this ultra modern terminal.
- The Port of Houston has identified a hybrid tug demonstration as a possible future action. A Foss Maritime project at the Ports of Long Beach and Los Angeles demonstrated a hybrid tug by Foss Maritime that utilizes a combination of electric batteries, generators and main engines.[23] According the 2007 Port of Houston Emissions Inventory, there are approximately 1,000 “tow” boats – including assist tugs and tow boats - operating in the Port of Houston area, representing 90% of the harbor vessels that operate within area.[24] Demonstrating the benefits of a hybrid electric technology on some of these vessels would be a great option as battery technology – in the case of the Foss tug, a lithium polymer battery - continues to improve and be more cost effective.[25]
- Several electric class 8 vehicle options may be available,[26] including a compressed natural gas (CNG) fueled plug-in hybrid class 8 vehicle by US Hybrid. This truck combines a dedicated CNG engine with hybrid efficiencies and 100 kilowatt hours of battery storage allowing for CNG or all electric operation.[27]

Port of Galveston

Today, containerized cargo at the Port of Galveston represents a relatively small portion of its total cargo. Current plans for the redevelopment of the Port’s West End will likely include additional container piers and Ro/Ro facilities, both of which will likely lead to additional cargo handling equipment at the Port. Other potential future plans at the Port of Galveston include the Pelican Island development, where the following may occur: construction of a container yard, depending of the ship channel to allow larger ships; and expansion of the cruise terminal.[28] With an anticipated 11,500 additional shipping containers per week once the West End project alone is

[22] “Eco-Power Hybrid Systems.” Port Strategy August 12, 2013.

[23] http://www.aapa-ports.org/files/PDFs/09MTMT_KevinM_RoseS.pdf

[24] *Goods Movement Air Emissions Inventory at the Port of Houston, 2007.* Starcrest Consulting Group LLC, 2009.

[25] Tyler, David. “Foss’s Second Hybrid Tugboat Employs New, More Powerful Lithium Polymer Batteries.” Professional Mariner. Sept. 2012.

[26] http://www.portoflosangeles.org/environment/zero.asp

[27] http://www.fleetsandfuels.com/fuels/cng/2013/04/us-hybrid-for-a-cng-hybrid/

[28] 2013/14 Goals and Objectives Workshop, Board of Trustees of the Galveston Wharves, courtesy of Diane Falcioni, Port of Galveston.

constructed, larger cargo handling equipment such as RTGs and other cranes may be on the horizon for the Port of Galveston.

If and when additional RTGs are added to its fleet, equipment efficiencies may be found with non-diesel options such as electric and hybrid electric RTGs. Electric RTGs, like those being demonstrated at the Port of Savannah with Konecranes, as well as hybrid electric RTGs like that being demonstrated at the Port of Houston and which are discussed above, may be good options for the Port to consider. In addition to possibilities for electric and hybrid electric RTGs, forklifts are an obvious choice for electrification at the Port of Galveston because of the large number that operate there. Many forklift manufacturers offer electric drive models, with lifting capacities up 12,000 lbs.

The Port of Galveston may also consider electrification technologies on vessels as it moves into the future. Hybrid tugs, discussed above, and LNG barges that utilize liquid natural gas to fuel generator-sets powering the barge, are two options available to vessel operators looking to reduce diesel fuel use.[29] The LNG barge is particularly interesting as an option if the Port of Galveston has plans to increase barge freight movement in the future.

Finally, because the cruise ship industry at the Port of Galveston is extensive, and has the possibility of becoming larger with potential cruise terminal expansion, shore power for cruise vessels is something that may be considered by the Port. Shorepower may be a good option not only for cruise ships at Galveston, but also cargo ships such as those that come into Port carrying Del Monte refrigerated cargo. These types of shorepower faculties have recently been installed in California, at the Port of San Diego, for example, with help from the Carl Moyer funding program.[30] Shorepower can be provided by installing infrastructure at the dock, which is perhaps a viable alternative for the Port of Galveston given its expansion plans. However, an alternative to this type of installation is the LNG hybrid power barge, based on the same system described above for the LNG barge. This barge, which has been utilized by the Port of Hamburg in Germany to provide electric shorepower to cruise ships, provides up to 7.5 MW of portable power produced by five onboard generator-sets fueled by LNG.[31] It should be noted that at the Port of Galveston, with redevelopment and expansion plans a real possibility, electric infrastructure and battery charging for any electrification projects may be built into current development plans with resulting infrastructure cost efficiencies possible.

Port Freeport

Similar to the Ports of Houston and Galveston, Port Freeport is also looking at the potential for expansion and upgrade. The Port will be working with a heavy lift company to ensure that heavy duty, specialized project cargo can be handled at its facilities.[32] Barge operation between Houston and Freeport to transport containers has also been identified as a possible future opportunity.

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[29] "A Cleaner Way through the Sea." Diesel and Gas Turbine Worldwide. April 2014.

[30] http://www.portofsandiego.org/environment/clean-air/1636-port-commissioners-give-approval-to-fund-shore-power-projects-for-cruise-and-cargo-ships.html

[31] A Cleaner Way through the Sea." Diesel and Gas Turbine Worldwide. April 2014.

[32] *Welcome to Port Freeport.* State of the Port Address, 2013.

Port Freeport also has plans for a new multimodal facility with five rail tracks, as well as the new Velasco Terminal, currently underway as part of a multi-year phased development which will include a container ship terminal and breakbulk cargo facilities. With this new development, an additional 730 container ships per year are expected to be unloaded at the port.[33]

All of this potential new development at Port Freeport will require additional cargo handling equipment. Port facilities may see not only additional smaller equipment such as forklifts but also larger container handling equipment such as cranes and yard trucks. Electric opportunities for these types of equipment are available. In addition, given that Port Freeport has an LNG terminal on site, the LNG yard truck demonstrated but not yet commercially available may be something to consider.[34]

Non-cargo handling equipment electrification possibilities also exist at Port Freeport, including shorepower for cargo ships at berth. At the Port of San Diego, California, Dole has recently begun using shorepower for some of the refrigerated container ships that carry their produce into port. Shorepower may be cost effective at Port Freeport as the Port further develops and upgrades its facilities.

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[33] http://www.mccarthy.com/locations/houston/port-freeport-velasco-terminal/

[34] LNG Yard Hostler Demonstration and Commercialization Project, Final Report. CALSTART for Port of Long Beach, August, 2008.

6 ELECTRIFICATION BENEFITS AND COST CONSIDERATIONS

The benefits and cost considerations for some of the equipment options described above are discussed further below. Because all three ports are undergoing expansion or redevelopment projects, the cost of electric infrastructure required to support any of these electric equipment options can potentially be reduced as those infrastructure requirements are added to the construction process.

Electric RTG

Fuel costs for a conventional diesel RTG can be substantial, up to several hundred thousand dollars per year depending on use. Cost savings with electric RTGs are likely in most scenarios, depending primarily on the costs of electricity and diesel and the annual hours of operation. A recent EPRI study on an electric RTG demonstration project at the Port of Savannah conservatively showed that a cost saving of $19,000 per year, per crane can be realized.[35] This included the annualized cost of electric infrastructure as well as differential operational costs.

The environmental benefits of the electric RTG can also be substantial, with zero tailpipe emissions, and overall emission reductions when compared to a diesel RTG of 90-95% for pollutants including NOx and particulate matter, and reductions of 69% for carbon dioxide.[36] It should be noted that overall environmental benefits for electric RTGs and all other electric equipment, is in part dependent on how the electricity used is generated.

Hybrid RTG

Substantial emission reductions may be realized with this recently verified technology, with up to 90% reductions for particulate matter, 88% for NOx, and 65% for carbon dioxide (CO_2), expected.[37] With an anticipated 3-4 year return on investment and fuel consumption reductions of 70%,[38] this battery electric crane has promising potential benefits.

Electric Forklift

An EPRI study has shown that operating costs of electric forklifts compared to propane and diesel forklifts are 20-25% lower, with up to $7,000 per year per truck in savings based on equipment ownership of 10 years. This reduction in operating cost is largely a function of the cost of electricity compared to propane and diesel, but also includes factors such as lower

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[35] *Evaluation of Electric Rubber-Tired Gantry Cranes at the Port of Savannah.* Electric Power Research Institute. June 2014.

[36] Ibid.

[37] *High Performance Accumulator for Hybrid Power Plant to Repower RTG Cranes in Port of Houston.* MJ EcoPower Hybrid Systems. June 28, 2013.

[38] *RTG EcoCrane: In-Use Emissions and Fuel Economy Test Program at POLA.* 2013 PEMS Conference and Workshop. Energy and Emissions Technology Consulting and MJ EcoPower Hybrid Systems. April 10, 2013

maintenance costs for electric forklifts. Electric forklifts can also result in substantial emission reductions, including CO_2 savings of 7-9 tons per year per unit.[39]

Hybrid Tug

The Foss hybrid electric tug has estimated emission reductions of 27% CO_2, 73% particulate matter, and 51% NOx. In addition to environmental benefits, economic benefits include an estimated 20% reduction in fuel costs.[40]

Electric Container Handling Equipment

The electric viability of this type of equipment, including side picks and reach stackers discussed above, has been challenging for manufacturers because of the duty cycle and lifting requirements involved. Because of their limited commercial availability, cost information on this equipment is not yet available. Environmental benefits of container handling equipment would be similar to other electric equipment of similar size and duty cycle, with zero tailpipe emissions and substantially reduced CO_2, particulate matter and NOx, with actual reductions depending on several variables.

Electric Yard Truck

Cost information on the electric yard truck is not known, as commercial availability is not present. In general, the cost effectiveness of electric yard trucks is greatly impacted by high capital costs of equipment, with the expectation that an electric yard truck will have a higher incremental cost compared to diesel, along with battery pack replacements every 6 years. On the other side of the equation, operating costs are estimated to be less than half of what it takes to operate a diesel yard truck. The emissions benefits of this type of equipment include an estimated 93% reduction in NOx and particulate matter.[41]

Non-Electric Equipment: LNG Yard Truck

An LNG terminal exists at Port Freeport, but in order to utilize this for refueling yard trucks, or any other equipment at the port, a refueling facility permit would be required. If such a path were pursued, LNG yard trucks could be refueled at the port. LNG yard trucks, as previously discussed, are not yet commercially available but the technology has been demonstrated at the Port of Long Beach, CA. This demonstration revealed that LNG yard trucks utilize 30% more diesel gallon equivalents than diesel yard trucks, making for increased fuel required, though at a lower cost compared to diesel. The result is a slightly lower refueling cost for the LNG yard truck, along with a purchase price expected to be 1.5 times that of a diesel yard truck. The emissions benefits of this vehicle were positive for some pollutants, but included an increase in NOx emissions when compared with diesel.[42]

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[39] EPRI Lift Truck Ownership Cost Comparison; http://et.epri.com/LiftTruckComparison_with_cap.html

[40] Tyler, David A. *Foss's Second Hybrid Tugboat Employs New, More Powereful Lithium Polymer Batteries.* Professional Mariner, Aug 22, 2012.

[41] http://www.aapa-ports.org/files/PDFs/09MTMT_KevinM_RoseS.pdf

[42] http://www.aapa-ports.org/files/PDFs/09MTMT_KevinM_RoseS.pdf

On Road Vehicles: CNG Class 8 Plug in Hybrid Truck

The US Hybrid CNG plug-in hybrid vehicle is expected to have ample power availability, with enhanced performance using a combination of CNG and plug-in hybrid systems, and will reduce greenhouse gas emissions by up to 60% with an operational cost savings of over 50%.[43]

Port-Specific Benefits of Electrification

Port of Houston

The Port of Houston and its tenants have an emissions profile that includes over 100 tons per year of particulate matter, 900 tons per year of NOx and almost 110,000 tons per year of CO_2 that can be attributed to the three most commonly seen types of equipment: yard trucks, RTGs and forklifts (Table 6-1).[44]

Table 6-1
Port of Houston emissions from specific equipment types[45]

Equipment	Count	2007 Emissions (tons per yr)		
		NOx	PM	CO_2
Yard Truck	306	318	40	40,000
RTG	70	270	20	28,000
Forklift	451	334	45	39,000
Above Total	827	922	105	107,000

With some of this equipment converted to electric or hybrid electric, the Port may see reductions in both operating costs and emissions. If, for example, the Port's 70 RTGs were converted from diesel to electric, approximately $1.3 million in operational cost savings and 90-95% reductions in RTG-associated NOx and particulate matter emissions may be realized per year (Table 6-2).

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[43] http://www.fleetsandfuels.com/fuels/cng/2013/04/us-hybrid-for-a-cng-hybrid/

[44] "2007 Goods Movement Air Emissions Inventory." Port of Houston Authority, January 2009 prepared by Starcrest Consulting Group.

[45] Ibid.

Table 6-2
Potential Benefits of Electrification at Port of Houston

	Potential installs*	Emissions Reductions (%)			Fuel /cost savings
		NOx	CO_2	PM	
Electric RTG	70	90-95%	69%	90-95%	$1.3 million operational cost savings
Hybrid RTG	70	78-90%	NA	62-70%	3-4 yr ROI + reduced fuel consumption of 78%
Electric Forklift	450**		3,150 tpy savings		25% reduction in operating costs
Electric Yard Truck	306	93%	NA	93%	50% reduction in operating costs

Port of Galveston

The benefits associated with some of the electrification projects identified above at the Port of Galveston could be significant for the Port. For example, using the EPRI forklift calculator[46] for a mix of 75 propane and diesel forklifts, we can estimate that CO_2 reductions with a conversion of these 75 forklifts to electric would be approximately 525-675 tons per year. Although Port of Galveston forklift emissions have not been inventoried, for comparison, the Port of Houston has inventoried emissions for its 451 forklifts, with estimates of 39,000 tons per year CO_2 for this equipment category.[47] The cost savings associated with Galveston's 75 conversions could be as high as $510,000 per year, based on 10 years of equipment ownership.

Although the most common piece of equipment at the Port of Galveston is currently the forklift, the Port may require larger cargo handling equipment types if and when increased containerized cargo throughput occurs. RTGs and yard trucks, for example, may be on the horizon for the Port, and utilizing electric or hybrid electric drive as opposed to diesel in these equipment types may provide benefits. A hypothetical number of 20 RTGs and 10 yard trucks (shown in Table 6-3 below) may, for example, result in NOx and particulate matter savings of 62-95% compared to similar diesel equipment, as well as cost reductions associated with fuel consumption and general operating costs. As stated above in the Port of Houston discussion, a recent EPRI study has shown that potential cost savings of up to $19,000 per RTG – or $380,000 for 20 RTGs - may be realized annually when diesel RTGs are converted to electric.[48]

Other non-cargo handling equipment – such as the LNG barge and the CNG plug-in hybrid class 8 truck discussed above – and shorepower for vessels may also be considered by the Port of Galveston for potential cost and emissions benefits.

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[46] EPRI Lift Truck Ownership Cost Comparison; http://et.epri.com/LiftTruckComparison_with_cap.html

[47] Port of Houston. 2009. "2007 Goods Movement Air Emissions Inventory." Port of Houston Authority, January 2009 prepared by Starcrest Consulting Group.

[48] *Evaluation of Electric Rubber Tired Gantry Cranes at the Port of Savannah.* EPRI 2014.

Table 6-3
Potential Benefits of Electrification at Port of Galveston

	Potential installs	Emissions Reductions (%)			Fuel /cost savings
		NOx	CO_2	PM	
Electric RTG^	20	90-95%	69%	90-95%	$380,000
Hybrid RTG^	20	78-90%	NA	62-70%	3-4 yr ROI + reduced fuel consumption of 78%
Electric Forklift	75*		525 tpy savings		25% reduction in operating costs
Electric Yard Truck	10	93%	NA	93%	50% reduction in operating costs

^currently there are no RTGs. The number here reflects an estimate of what may be required in the future. *this is an estimate of non-electric drive forklifts at the Port.

Port Freeport

At Port Freeport, cargo handling emissions have not been documented, and what is known about their numbers indicate that their inventory is too small to make extrapolations as was done for the Port of Galveston. It should be noted, however, that the same emission reduction rates and fuel/cost savings rates that were reported in the above tables for Houston and Galveston may also apply at Port Freeport.

7
CONCLUSIONS

The above discussion highlights some of the opportunities that are available to ports, including the Ports of Houston, Galveston, and Freeport, for equipment electrification. Many of these options provide potential economic and environmental efficiencies when compared to diesel equipment. As technology advances in batteries and other related equipment continue to move forward, cost efficiencies for many types of electric port equipment may be even greater, making equipment electrification at ports more widespread.

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com