

**DRAFT**

**TECHNOLOGY ASSESSMENT:  
MOBILE CARGO HANDLING EQUIPMENT**



November 2015

**State of California  
AIR RESOURCES BOARD**

DRAFT

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## EXECUTIVE SUMMARY

This executive summary presents the Air Resources Board (ARB or Board) staff's *Technology Assessment for Mobile Cargo Handling Equipment*.

Because of its geographical location and major ports and railways, California is a global gateway for freight transport. Some of the largest ports in the world are located in California, and with increases in trade and freight activity, ports, intermodal rail yards, and warehouse distribution centers stand to experience major growth over the next two decades. In 2006, prior to the Air Resources Board (ARB) implementation of the Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards (CHE Regulation), ARB staff estimated that diesel-fueled cargo handling equipment (CHE) engines operating at ports and intermodal rail yards resulted in approximately 0.54 tons per day (tpd) of diesel particulate matter (diesel PM) and 13.4 tpd of oxides of nitrogen (NO<sub>x</sub>) emissions statewide (ARB, 2011). These facilities are often located in or near densely populated areas and neighborhoods, exposing residents to unhealthy levels of pollutants. The 2006 Diesel Particulate Matter Exposure Assessment Study for the Ports of Los Angeles (POLA) and Long Beach (POLB) (ARB, 2006) identified CHE as the third largest source of diesel PM at these two ports.

Consequently, ARB's implementation of the CHE Regulation, adopted in 2005, which requires best available control technology (BACT) for both new and existing diesel-fueled CHE at California ports and intermodal rail yards, has reduced CHE emissions significantly. From 2006 to 2014, CHE diesel PM emissions at California ports and intermodal rail yards have been reduced by 85 percent and NO<sub>x</sub> emissions by 68 percent. These reductions have been achieved as a result of intensive capital investments in clean diesel-fueled equipment by terminal and rail operators.

CHE is also used at other locations throughout California, primarily warehouse distributions centers. Equipment at non-port, non-intermodal rail yard locations is not subject to the CHE Regulation. However, much of the equipment used at warehouse distribution centers operates indoors, which precludes the use of diesel for this equipment. The equipment used indoors is primarily electric and fuel cell electric, with some propane-fueled equipment. Outdoor equipment at these facilities may be either propane or diesel-fueled.

Presented below is an overview briefly describing the CHE sector, the technologies assessed, and proposed next steps. For simplicity, the discussion is presented in question-and-answer format using questions relevant to the sector and associated technology assessment. It should be noted that this summary provides only brief discussion on these topics. The reader is directed to subsequent chapters in the main body of the report for more detailed information.

## **1. What is mobile cargo handling equipment?**

Mobile CHE is any mobile equipment used at ports, rail yards, and warehouse distribution centers to either handle freight or to perform other on-site activities, such as maintenance. Equipment that handles cargo containers includes yard trucks, top handlers, side handlers, reach stackers, forklifts, and gantry cranes. Equipment that is used to handle bulk material includes dozers, excavators, and loaders. Forklifts can be used in either container or bulk handling operations. Forklifts and other types of lifts are the primary type of CHE used at warehouse distribution centers, and may also be used for on-site maintenance operations at any of the facilities. There are approximately 4,600 CHE at California's ports and intermodal rail yards. An inventory of CHE at warehouse distribution centers has not yet been developed.

## **2. Where is mobile CHE used?**

Mobile CHE is used throughout California in almost all industries involved with the transportation of freight. The most common use of CHE occurs at intermodal facilities, including ports, rail yards, and warehouse distribution centers.

There are numerous ports in California that use mobile CHE, including Antioch, Benicia, Crockett, Humboldt Bay, Hueneme, Long Beach, Los Angeles, Oakland, Pittsburg, Port Chicago, Redwood City, Richmond, Sacramento, San Diego, San Francisco, and Stockton. Most of the ports are controlled by port authorities, but several are independently operated.

Two major railroad companies, BNSF Railway (BNSF) and Union Pacific Railroad (UP), operate several intermodal rail yards in the state that use CHE, located in cities such as Barstow, City of Industry, Commerce, Fresno, Lathrop, Long Beach, Los Angeles, Oakland, Richmond, San Bernardino, and Stockton.

Warehouse distribution centers are located throughout California. Often these facilities are located near other freight transportation facilities such as ports, intermodal rail yards, and airports. Additionally these facilities are located near population centers where there is a demand for goods.

## **3. What ARB regulations are CHE currently subject to?**

Diesel-fueled CHE at California ports and intermodal rail yards is subject to the ARB Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards (section 2479 of title 13, California Code of Regulations (CCR) article 8, chapter 9) (CHE regulation).

The CHE regulation was adopted in 2005 to reduce the diesel PM health risk to communities adjacent to California's ports and intermodal rail yards. The CHE regulation is applicable to any diesel-fueled mobile equipment used at California ports and intermodal rail yards to either handle freight or bulk material or to perform other on-

site activities, such as maintenance. The CHE regulation requires reporting, emission reductions from in-use equipment, and includes new equipment requirements.

Diesel-fueled CHE not operating at California ports and intermodal rail yards are subject to the ARB Regulation for In-Use Off-Road Diesel-Fueled Fleets (sections 2449, 2449.1, 2449.2, and 2449.3 of title 13 CCR, article 4.8, chapter 9) (In-Use Off-Road regulation).

The In-Use Off-Road regulation was adopted in 2007 and is applicable to all self-propelled off-road diesel-fueled fleets with vehicle engines rated at 25 horsepower (hp) or greater operated in California. Personal use vehicles, vehicles used solely for agriculture, and vehicles subject to the CHE regulation performance requirements are exempt from the In-Use Off-Road regulation. The In-Use Off-Road regulation requires reporting and fleet emission reductions, and includes new equipment requirements and limits on idling.

Propane and gasoline fueled CHE are subject to ARB's Off-Road Large Spark Ignition Engine Regulation (sections 2430, 2431, 2433, 2434, and 2438 of title 13 CCR, article 4.5, Chapter 9) (LSI regulation).

ARB's LSI regulation, adopted in 2006, requires emissions reductions from existing LSI fleets and prescribes verification procedures for LSI retrofit emissions control systems. The LSI regulation also established more stringent NO<sub>x</sub> and hydrocarbon engine certification standards.

#### **4. What cargo handling equipment technologies were assessed?**

ARB staff assessed a variety of alternative technologies including:

- Hybrid (electric and hydraulic),
- All electric (battery and grid source),
- Alternative fuels (hydrogen (H<sub>2</sub>), compressed natural gas (CNG)/ liquefied natural gas (LNG)),
- Magnetic levitation,
- Lower emission diesel engines (Tier 5),
- Automated container handling operations,
- Maintenance/reduced engine emissions deterioration.

#### **5. What additional work or information is needed to refine or improve this technology assessment?**

The primary data gaps are related to incremental costs for these technologies and more definitive emissions benefits for the individual technology applications. Additionally, a statewide inventory of CHE at warehouse distributions centers must be developed to determine the numbers and types of equipment in-use at these facilities. Warehouse distribution center CHE inventory development is essential to evaluating the need for and possible benefits from CHE emissions reduction strategies at these facilities.

**6. What are the main challenges to reducing emissions from cargo handling equipment?**

The main challenges to reducing emissions for CHE are assuring adequate investment recovery time associated with actions taken to comply with current CHE regulation and the availability of cost-effective next generation technologies. CHE at California ports and rail yards employs the cleanest diesel-fueled technology available due to compliance with the CHE Regulation. Consequently, further emission reductions require technologies that also provide an economic benefit to the operators in order to become cost-effective options. An additional challenge is adequately demonstrating that alternative technology will provide the same durability, reliability, and quick shift to shift turn around that diesel-fueled equipment has provided.

**7. Which technologies show the most promise and what are the next steps to develop and deploy them?**

Technologies that we see as most promising for further CHE emission reductions at ports and rail yards are automated electric equipment at container terminals and hybrid equipment at bulk terminals. The most promising technologies for CHE at distribution centers are fuel cell and battery electric fork lifts.

Automated all-electric (battery or grid-powered) equipment has been in use at port container terminals in Europe, Asia, and Australia, since as early as 1993 with the Port of Rotterdam, though it is in very limited use within the United States (U.S.). Implementing the automation of cargo handling operations requires significant infrastructure investments. However, there are significant efficiencies and safety benefits to be gained with the conversion. Next steps for encouraging the further deployment of automated electric equipment include both incentivizing the installation of the necessary terminal infrastructure and supporting the development of reliable electrical supply infrastructure necessary for the electrification of the terminals.

While automation and electrification of cargo handling operations are seen as the ultimate goal for container handling terminals, interim benefits could be achieved by the development and deployment of electric and hybrid non-automated equipment including yard trucks and container handler equipment, such as top picks and reach stackers.

Electric and hybrid cranes, battery-electric automatic guided vehicles, and hybrid straddle carriers are in use at these types of facilities, but the development of other hybrid container handling equipment is not as mature. For example, the development of both electric and hybrid yard trucks has been progressing for over five years with demonstrations of both electric and hybrid models. However, commercialization of electric yard trucks is still in the very early stage and hybrid yard trucks are still in the developmental stage. Hybrid container handling equipment under development includes fuel cell-electric and diesel-electric hybrids. A diesel-electric hybrid reach stacker successfully completed a year-long demonstration at the Swedish Port of



Helsingborg in the spring of 2014 (Konecranes, 2014a). Recommended next steps would be to support and incentivize both the demonstration and purchase of electric, fuel cell, and hybrid container handling equipment.

While hybrid vehicles have been fully deployed in the light duty vehicle market, as well as for a number of container applications, hybridization is still an emerging technology in the off-road bulk material handling equipment arena. There is a number of hybrid off-road bulk handling equipment that has become commercially available in the last few years. Operators using these new hybrids, primarily in the construction and mining industries, attest to the fuel savings provided by the hybrid technology. These fuel savings equate to greenhouse gas (GHG) emission reductions. However, the criteria pollutant reductions, specifically NO<sub>x</sub>, are less certain for these newly developed bulk material handling equipment. Next steps for encouraging the deployment of hybrid technology at bulk handling terminals include support and incentivizing hybrid equipment demonstrations at these facilities. Demonstrations should include in-use performance and emissions testing to quantify the emission benefits of the different technologies in specific applications.

The development of hybrid bulk material handling equipment may be a pathway to expanding the development of both electric and fuel cell bulk handling CHE. This could be realized by the further development of battery technology in hybrids providing similar advances for battery-electric equipment. Additionally, the emissions and energy use reductions obtained with optimized hybrid operation could be further augmented by replacing the diesel power source with fuel cells.

Opportunities for fuel cell technology at ports and intermodal rail yards may also include providing either emergency back-up or prime power generation for grid-powered electric equipment.

#### **8. What are the estimated per equipment costs of the most promising technology now, and at widespread deployment?**

The most promising long-term technology for container handling is implementing the automation and electrification of cargo handling operations. Based on the two port terminal automation projects in California, implementing terminal automation requires infrastructure investments of from \$ 0.5 to over \$ 1 billion. The electrified equipment and automation software and hardware require additional capital investments which will vary depending on the degree of automation, but could easily double capital equipment costs. However, industry studies (Seaport, 2013) have shown that automation can reduce terminal operating costs, estimated as “per container”, by up to 25 percent, depending on the chosen equipment mix, compared to typical manual operation. This analysis took into account both the capital costs and the operating costs including energy, maintenance, and labor. Automation also benefits container movement efficiency as well as safety, by providing separation of terminal personnel from various equipment activities. One U.S. semi-automated container port saw an initial increase of

20 percent in hourly container moves and was projecting an increase of up to 30 percent under optimal conditions (NJ, 2014).

The most promising technologies for near-term container handling and bulk handling are electrified non-automated and hybrid equipment. Capital costs for electrified equipment vary from a 10 to 20 percent increase over conventional diesel-fueled equipment for higher sales volume equipment and up to 80 to 100 percent increase in cost for the lower sales volume equipment and less developed technologies. However, consideration of total cost of ownership may result in this equipment being a more attractive option.

## **9. What future activities are planned?**

Future activities include:

- Identifying funding options of both purchase and demonstration of electric, fuel cell, and hybrid CHE at ports and intermodal rail yards,
- Funding and monitoring emissions, performance, and operating cost comparisons of clean diesel-fueled CHE and electric, fuel cell, and hybrid CHE, and
- Incentivizing larger fleet demonstration of zero emission CHE that have successfully completed limited demonstration.

## **10. What is staff's recommendation?**

Staff recommends supporting and incentivizing the installation of the necessary terminal infrastructure as well as the development of reliable electrical supply infrastructure necessary for the automation and electrification of container terminal cargo handling operations. Staff recommends that the infrastructure evaluation include hydrogen supply and fuel cell power generation for either prime or back-up. Staff further recommends supporting incentivizes for both the demonstration and purchase of electric and hybrid (including diesel-electric, natural gas or propane-electric, and fuel cell-electric) container and bulk handling equipment. Demonstrations should include in-use performance and emissions testing to quantify the emission benefits of the different technologies in comparison with clean diesel-fueled equipment.

## I. INTRODUCTION AND PURPOSE OF ASSESSMENT

Because of its geographical location and major ports and railways, California is a global gateway for freight transport. Some of the largest ports in the world are located in California, and with increases in trade and general freight activity, ports, intermodal rail yards, and warehouse distribution centers stand to experience major growth over the next two decades. These facilities are often located in or near densely populated areas and neighborhoods, exposing residents to unhealthy levels of pollutants. In 1998, ARB identified the particulate matter in diesel exhaust, diesel PM, as a Toxic Air Contaminant (TAC), a classification reserved for the most dangerous airborne compounds. The Board subsequently adopted the *Diesel Risk Reduction Plan (DRRP)*, a strategy to reduce these emissions by 85 percent, by 2020 (ARB, 1998).

In 2006, prior to the Air Resources Board (ARB) implementation of the Regulation for Mobile Cargo Handling Equipment at Ports and Rail Yards (CHE Regulation), ARB staff estimated that diesel-fueled cargo handling equipment (CHE) engines operating at ports and intermodal rail yards resulted in approximately 0.54 tons per day (tpd) of diesel PM and 13.4 tpd of NO<sub>x</sub> emissions statewide. The 2006 Diesel Particulate Matter Exposure Assessment Study for the Port of Los Angeles (POLA) and Port of Long Beach (POLB) (ARB, 2006) identified CHE as the third largest source of diesel PM at these two ports.

Consequently, ARB adopted the CHE Regulation in 2005 as part of the DRRP (ARB, 2005a). ARB's implementation of the CHE Regulation, which requires Best Available Control Technology (BACT) for both new and existing diesel-fueled CHE at California ports and intermodal rail yards, has reduced CHE emissions significantly. From 2006 to 2014, CHE diesel PM emissions at California ports and intermodal rail yards were reduced by 85 percent and NO<sub>x</sub> emissions by 68 percent. These reductions were achieved as a result of intensive capital investments in clean diesel-fueled equipment by terminal and rail operators.

CHE is also used at other locations throughout California, primarily warehouse distribution centers. Equipment at non-port, non-intermodal rail yard locations is not subject to the CHE Regulation. However, much of the equipment used at warehouse distribution centers operates indoors, which precludes the use of diesel for this equipment. The equipment used indoors is primarily electric, fuel cell electric, with some propane-fueled. Outdoor equipment at these facilities may be either propane or diesel-fueled.

While significant diesel PM and NO<sub>x</sub> emission reductions have been achieved for CHE at California ports and intermodal rail yard, many areas within California have air quality pollution that exceeds the National Ambient Air Quality Standards. The federal Clean Air Act (Act) establishes planning requirements for areas that exceed the health-based National Ambient Air Quality Standards. Areas are designated as nonattainment based on monitored exceedances of these standards. These nonattainment areas must develop an emission inventory as the basis of a State Implementation Plan (SIP) that

demonstrates how they will attain the standards by specified dates. Additionally, while clean diesel-fueled equipment drastically cuts the criteria pollutant emissions, GHG emissions are not mitigated by this equipment. The purpose of this technology assessment is to help inform and support ARB planning and regulatory efforts, including:

- California's integrated freight planning,
- State Implementation Plan (SIP) development,
- Funding Plans,
- Governor's ZEV Action Plan, and
- California's coordinated goals for GHG and petroleum use reduction.

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## II. OVERVIEW OF MOBILE CARGO HANDLING EQUIPMENT

### A. Types of Equipment and Uses

Mobile cargo handling equipment (CHE) includes mobile equipment at ports, rail yards, and warehouse distribution centers used to either handle freight or perform other on-site activities such as maintenance or repair activities. CHE is as diverse a group of equipment as the cargo that it handles and the tasks it performs. Cargo that arrives and/or departs by ship, truck, or train, can include liquid, bulk (break bulk and dry bulk), and containers. Liquid cargo, such as petroleum products and chemicals, are often transported via pipelines, and therefore, do not usually have mobile CHE associated with their operation. Break bulk cargo, such as lumber, steel, machinery, palletized material, and dry bulk cargo, such as cement, scrap metal, salt, sugar, sulfur, and petroleum coke, are handled using loaders, dozers, cranes, forklifts, and sweepers. Container cargo, which is the most common type of cargo at ports and intermodal rail yards, are handled using yard trucks, rubber-tired gantry (RTG) cranes, rail-mounted gantry cranes (RMGs), top picks, side picks, forklifts, and straddle carriers. There are about 4,600 mobile CHE at California's ports and intermodal rail yards. An equipment-specific inventory of the CHE at California's warehouse distribution centers has not been developed at this time. Below is a description of the most common equipment types.

#### *Container Handling Equipment*

##### Yard Truck

The most common type of cargo handling equipment at ports and intermodal rail yards is a yard truck. Yard trucks are also known as yard goats, utility tractor rigs (UTRs), hustlers, yard hostlers, and yard tractors. Yard trucks are very similar to heavy-duty on-road truck tractors, but historically, the majority has been equipped with off-road engines.

Yard trucks are designed for moving cargo containers. They are used at container ports and intermodal rail yards as well as distribution centers and other intermodal facilities. Containers are loaded onto the yard trucks by other container handling equipment, such as rubber-tired gantry cranes, top picks, or side picks, and they are unloaded the same way. In addition to loading and unloading operations, yard trucks are used to move containers around a facility (yard) for stacking and storing purposes.

The CHE regulation requires yard trucks at California's ports and intermodal rail yards be powered by engines certified to meet United States Environmental Protection Agency (U.S. EPA) model year 2007 or newer on-road or Tier 4f off-road engine emissions standards.



**Yard Truck**

While most yard trucks are diesel-fueled, there is limited availability of those powered by liquefied petroleum gas (LPG), compressed natural gas (CNG), and liquefied natural gas (LNG). A 2012 emissions inventory showed that 18 percent of the yard trucks at POLA are propane-fueled and 2 percent are natural gas-fueled.

Yard trucks have a horsepower range of about 150 hp to 250 hp, with most being around 175 hp to 200 hp. There are approximately 2,500 yard trucks at California's ports and intermodal rail yards.

### Top Handler

Another very common type of container handling equipment is the top handler. Also known as top picks, top handlers are large truck-like vehicles with an overhead boom which locks onto the top of containers in a single stack. They are used within a terminal to stack containers for temporary storage and load containers onto and off of yard trucks. Top handlers are capable of lifting loaded cargo containers weighing as much as 45,000 pounds. Top handlers have a horsepower range of about 250 hp to 400 hp, with most being between 250 hp and 350 hp.



**Top Handler**

### Side Handler

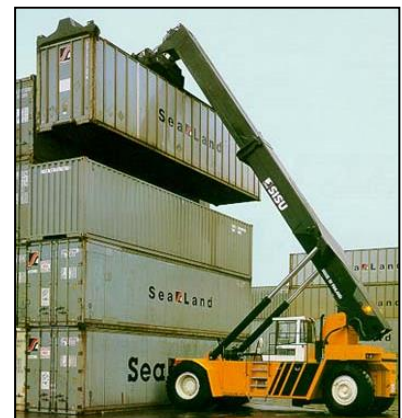
Like the top handler, side handlers (or side picks) are used to lift and stack cargo containers. They look very similar to a top pick, but instead of grabbing the containers from the top, their boom arm extends the width of a container to lift it from the front face (or side). Side handlers are most often used to lift empty containers; however, some are manufactured to lift loaded containers. Side handlers have a horsepower range of about 120 hp to 400 hp, with most being between 160 hp and 250 hp.



**Side Handler**

### Reach Stacker

Another member of the cargo container handling family is the reach stacker. Similar to a top pick, the reach stacker has a telescopic boom (usually attached behind the cab) that moves upward and outward in order to reach over two or more stacks of containers. Reach stackers lock onto the top of the containers in a similar fashion to top handlers. However, they are not nearly as common as top handlers and side handlers because their duties can similarly be performed by rubber-tired gantry cranes. They are most often found at port



**Reach Stacker**

container terminals, but rarely at intermodal rail yards. Reach stackers have a horsepower range of about 250 hp to 400 hp, with most being between 230 hp and 300 hp.

### Gantry Crane

Rubber-tired gantry cranes (RTGs) and rail-mounted gantry cranes (RMGs) are very large cargo container handlers that have a lifting mechanism mounted on a cross-beam supported on vertical legs which run on either rubber tires or rails. While the propulsion of the crane is very slow (about three miles per hour), the lifting mechanism can move quickly, and is therefore able to load and unload containers from yard trucks or from stacks at a very fast pace.



**RTG Crane**

RTGs and RMGs have a horsepower range of about 200 hp to 1,000 hp, with most being between around 300 hp to 1,000 hp. There are approximately 350 RTG cranes at California's ports and intermodal rail yards.

### Shuttle and Straddle Carriers

Shuttle and straddle carriers are large cargo container handlers that have a lifting mechanism mounted on a cross-beam supported on vertical legs which run on rubber tires. The propulsion of the crane is slow (less than 20 miles per hour). These carriers are similar to but smaller and more mobile than RTGs. As with RTGs and RMGs, the lifting mechanism can move quickly, and is therefore able to load and unload containers from yard trucks or from stacks at a very fast pace. Shuttle carriers can pick containers up off of the ground, move them to another location, and either deposit on the ground or stack one-on-one or two high. Straddle carriers are similar to shuttle carriers but can stack containers up to three and four high.



**Straddle Carrier**

The majority of shuttle and straddle carrier engines have horsepower ratings on the order of 200 to 400 hp with a lift capacity range of approximately 40 to 60 tons.

### Automated Guided Vehicle

Automated Guided Vehicles (AGVs) utilize a variety of guidance technologies (guide wire, laser positioning, embedded magnets, etc.) to deliver freight from Point A to Point B without hands-on human control. AGVs can be employed at a broad range of freight handling facilities. AGVs used for freight transport are battery electric vehicles that

typically either have freight handling capabilities similar to small forklifts or which perform duties similar to yard trucks. Yard truck equivalent operation generally involves having shipping containers loaded onto the AGVs by ship-to-shore cranes and unloaded by RTGs or RMGs. AGVs transporting containers from dock-side to a container stack area move at slow speeds of less than 15 miles per hour and can transport up to 60 tons. Smaller AGVs, capable of moving loads of a ton or less, can be used at warehouse distribution centers.



**AGV**

### Forklift

Used at both container facilities and bulk cargo facilities, forklifts are industrial trucks used to hoist and transport materials by means of one or more steel forks inserted under (or in the case of steel coils, in the middle of) the load. Forklifts are extremely diverse in both their size and custom cargo handling abilities. While they are designed to move and/or lift empty cargo containers or stacked or palletized cargo, they can also be designed to move or rotate (flip) truck chassis.

Forklifts can be powered by either electric motors (battery or fuel cell providing the electricity) or internal combustion engines, such as compression ignition (i.e., diesel or natural gas) or spark ignition (i.e., gasoline or propane) engines. Compression ignition forklifts are usually designed for higher lift capacity than their electric or spark ignited counterparts, and are therefore more likely to be used in port or rail cargo handling operations.



**Forklift**

The cargo handling forklifts used at ports and intermodal rail yards have a horsepower range of about 45 hp to 280 hp. There are approximately 800 forklifts at California's ports and intermodal rail yards.

There are additional types of lifts operating at California's warehouse distribution centers. These include stackers, aerial lifts, and man lifts. This equipment is mainly powered by electricity (battery or fuel cell) or propane to maintain indoor air quality. These are described in the Warehouse Distribution Center Equipment section below.

### *Bulk Cargo Handling Equipment*

### Loader

One of the most common dry bulk handling equipment is the loader, which is any type of off-road tractor, with either tracks or rubber tires, that uses a bucket on the end of movable arms to lift and move material. There are many



**Loader**



different types of loaders, including but not limited to, front end, skid steer, backhoe, rubber tired, and wheeled. Loaders used in cargo handling operations range from 36 hp (for small, skid steer loaders) to over 1,000 hp (for large, rubber-tired loaders), with most being between 200 hp and 750 hp.

### Dozer

The term dozer refers to an off-road tractor, either tracked or wheeled, equipped with a blade. Dozers at ports and intermodal rail yards are most often used in dry bulk or break bulk cargo handling operations. They range in size from 77 hp to 900 hp, with most being between 300 hp to 400 hp. Both loaders and dozers are among the approximately 225 bulk cargo handling equipment at California's ports and intermodal rail yards.



Dozer

### *Warehouse/Distribution Center Equipment*

Forklifts can be categorized by the type of tires used on the equipment, either cushion or pneumatic. These are discussed below.

### Cushion-Tired Forklifts

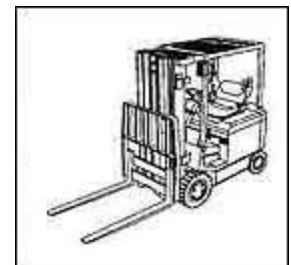
Cushion tires are made of smooth, solid rubber. This type of forklift generally has a small turning radius and, as such, provides better operating characteristics for small spaces and tight aisles (Forkliftcenter, 2013a). Cushion-tired forklifts have lift capacities up to 60,000 pounds.



Cushion-tired

### Pneumatic-Tired Forklifts

Pneumatic tires are similar to a truck tire, made of treaded rubber and filled with compressed air. Pneumatic tires add to the useful life of the equipment by providing additional protection to the equipment (Forkliftcenter, 2013a). Pneumatic-tired forklifts have lift capacities up to 50,000 pounds.



Pneumatic-tired

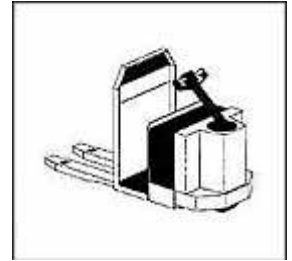
### Electric Forklifts

Electric forklifts can be either cushion-tired or pneumatic-tired. Electric forklifts have no tailpipe emissions and are an excellent fit for indoor warehouse distribution center operations. The dry environment found indoors is also essential for peak electric forklift performance (Forkliftcenter, 2013b). Electric forklifts can be powered by either batteries or fuel cells. Electric forklifts can have lift capacities of up to 40,000 pounds,

however lower lift capacities of up to 12,000 pounds are more commonly used. Electric forklifts represented 60 percent of forklift sales in the U.S. in 2013 (MarketWatch, 2014).

Walkie Stacker

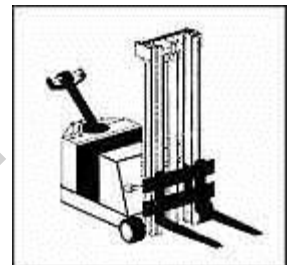
Walkie stackers are lifts that an employee pushes or pulls to transport pallets to areas in the warehouse distribution center where forklifts are not necessary. Walkie stackers are also equipped with masts for lifting pallets to height. Walkie stackers are primarily an indoor application due to their small wheels and low clearance capabilities (Hyster, 2014). Walkie stackers have a lift capacity of up to 4,000 pounds.



**Walkie Stacker**

Aerial Lifts

Aerial lifts are equipment which utilize a vehicle-mounted device, either telescoping or articulated, used to position personnel (OSHA, 2011). Aerial lifts include extendable boom platforms, aerial ladders, and vertical towers. Aerial lifts have a lift capacity of up to 1,000 pounds.



**Aerial lift**

*New Equipment Capital Costs*

Order of magnitude capital costs for commercially available new CHE are summarized in Table II-1 below. These costs were estimated based on staff communications with equipment manufacturer representatives and searching internet sources. These costs range from approximately \$100,000, for smaller equipment, up to \$6M for the rail mounted gantry cranes. Ship-to-shore cranes, which are electric powered, cost on the order of \$10 to \$12M.

**Table II-1: Average New Equipment Costs**

Equipment Category	Equipment Type	Average New Cost (in thousands \$)
Yard Trucks	Yard Truck – Tier 4f	\$125
	Yard Truck - LNG	\$155
Basic Container Handling	Top Handler - Diesel	\$520 - \$600
	Side Handle - Diesel	\$315 - \$600
	Forklift - Diesel	\$40 - \$250

Equipment Category	Equipment Type	Average New Cost (in thousands \$)
Warehouse Distribution Center Lifts	Class I: Electric Motor Rider Trucks	\$22 - \$57
	Class II: Electric Motor Narrow Aisle Trucks	\$23 - \$51
	Class III: Electric Motor Hand Trucks or Hand/Rider Trucks	\$4 - \$27
	Class IV: Propane Internal Combustion Engine Trucks (Solid/Cushion Tires)	\$24 - \$78
	Class V: Propane Internal Combustion Engine Trucks (Pneumatic Tires)	\$24 - \$407
Bulk Cargo Handling	Dozer - Diesel	Small – \$110 (up to 80 hp) Medium - \$400 (up to 200 hp) Large - \$1,400 (up to 600 hp)
	Excavator - Diesel	Small - \$205 (up to 90 hp) Medium - \$270 (up to 190 hp) Large - \$750 (up to 470 hp)
	Loader - Diesel	Sm Wheel - \$130 (up to 100 hp) Small - \$180 (up to 140 hp) Medium - \$450 (up to 300 hp) Large - \$1,550 (up to 700 hp)
Cranes	RTG Crane - Diesel	\$1,300
	RTG Crane – Automated Electric	\$2,500
	RMG Crane - Electric	\$4,000 - \$6,000
	Straddle Carrier - Diesel	\$1,100

Initial equipment capital cost is only one segment of the total cost of equipment ownership. The total cost of ownership also includes energy or fuel costs, fueling or charging infrastructure, maintenance, and labor. Technologies with high initial capital costs yet reduced operational costs may result in a lower total cost of ownership, with acceptable payback periods. Data on the total cost of ownership comparisons with conventional equipment is provided for the zero and near-zero emission technologies in the technology discussion sections.

## B. Emissions Inventory

As shown in Table II-2, there are over 4,600 pieces of CHE operating at ports and intermodal rail yards in California. While emissions from CHE at ports and intermodal rail yard are a small component of the statewide freight emissions, their proximity to populated areas and the associated potential risk exposure provide incentive for introducing zero and near-zero emission technologies in this sector. Additionally, since

the total equipment population is small and the fleets are captive, this sector provides opportunity for developing technologies requiring unique infrastructure.

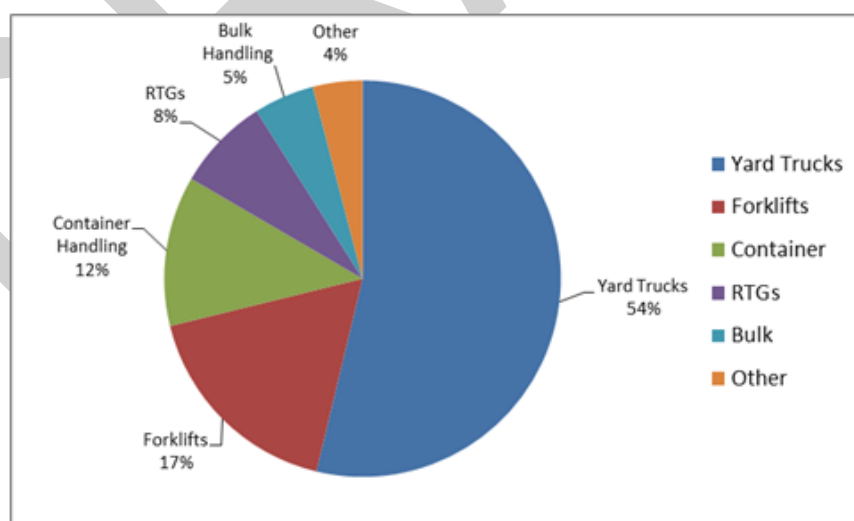
Inventory information for CHE at warehouse distribution centers has not yet been developed. One of the primary CHE data gaps is the need for an emissions and equipment-specific inventory for CHE operating at California’s warehouse distribution centers. Warehouse distribution center CHE inventory development is necessary to determine the need for and possible benefits from emissions reduction strategies at these facilities.

**Table II-2: Estimated Statewide 2013 Cargo Handling Equipment Emissions at California Ports and Intermodal Rail Yards**

Equipment Types	Numbers of Equipment	2013 Pollutant Emissions (tons per day)	
		PM	NO <sub>x</sub>
Yard Trucks	2497	0.04	1.26
Forklifts	809	0.01	0.30
Container Handling Equipment	569	0.02	1.56
RTGs	354	0.01	0.66
Bulk Handling Equipment	229	0.01	0.62
Other	188	0.01	0.26
<b>Totals</b>	<b>4646</b>	<b>0.10</b>	<b>4.66</b>

Figure II-1 shows the distribution by equipment type of the statewide population of CHE.

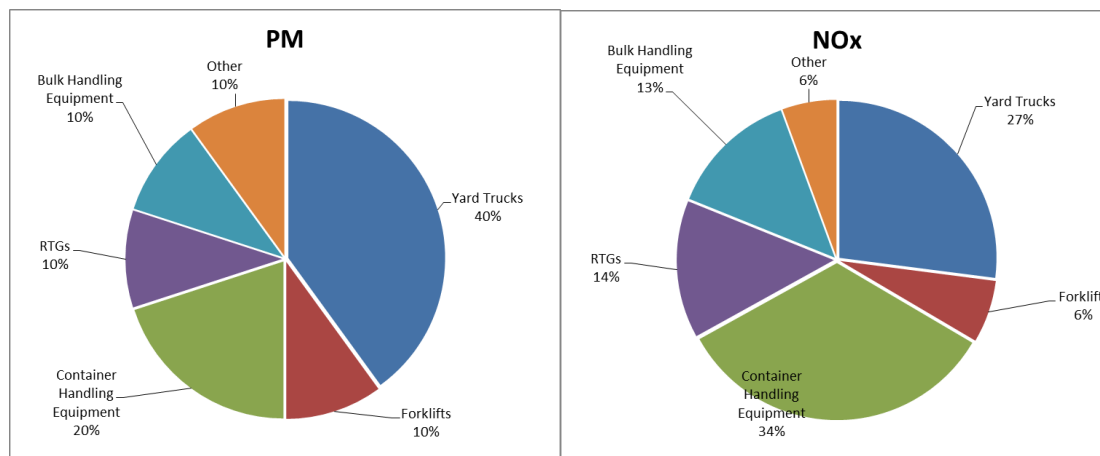
**Figure II-1: 2013 Statewide Population Distribution of Cargo Handling Equipment at Ports and Intermodal Rail Yards**



As shown in Figure II-1 above, the majority, or 54 percent, of CHE at ports and intermodal rail yards is yard trucks. However, less than half of the diesel PM and NO<sub>x</sub> emissions (see Figure II-2 below) are attributable to yard trucks, with approximately

40 percent of the diesel PM emissions and 27 percent of the NO<sub>x</sub> emissions. These lower emissions contribution are due to the owner/operator compliance with the stringent CHE regulation's yard truck emissions performance requirements.

**Figure II-2: 2013 Statewide Diesel PM and NO<sub>x</sub> Distribution of Cargo Handling Equipment at Ports and Intermodal Rail Yards**



CHE at California ports and intermodal rail yards is relatively long-lived equipment, as shown in Table II-3 below. Average equipment ages range from 7 to 22 years. Additionally, all types of equipment, with the exception of yard trucks, have lives longer than 10 years. Average hours of operation are also shown in this table. In addition, the table shows that over 80 percent of CHE at California's ports and intermodal rail yards was in compliance with ARB's CHE regulation by December, 2013.

**Table II-3: Port and Rail Cargo Handling Equipment Demographics by Type**

Equipment Type	Numbers of Pieces of Equipment (2013)	Average Annual Activity (Hours)	Percent On-road Engines/Percent Off-road Engines	Percent Compliance With CHE Regulation (Dec 2013)	Average Age of Equipment (Years)
Yard trucks	2497	2830	90/10	86%	7
Forklifts	809	720	0/100		20.5
Top picks, etc.	569	1860	0/100		11
RTGs	354	2220	0/100		12
Bulk handling	229	970	0/100		22
Other	188	800	50/50		22
Total	4646				

### C. Ports and Intermodal Rail Yards

California is a global gateway for the United States by virtue of its strategic location on the Pacific Rim, its border with Mexico, and its major ports and railways. Some of the largest ports in the world are located in California, and with the increases in trade and general freight activity, both the ports and intermodal rail yards stand to experience major growth over the next two decades.

Currently, the State has 16 primary ports that participate in waterborne commerce: Antioch, Benicia, Crockett, Humboldt Bay, Hueneme, Long Beach, Los Angeles, Oakland, Pittsburg, Port Chicago, Redwood City, Richmond, Sacramento, San Diego, San Francisco, and Stockton. While most of the ports fall under a port authority, the smaller ports, such as Antioch, Benicia, and Crockett, generally have docks or terminals controlled by the terminal owner(s) or operator(s). Figure II-3 shows the current primary ports in California and their approximate locations.

**Figure II-3: California's Ports**



Two major railroad companies, BNSF and UP, operate 14 intermodal rail yards in California. The intermodal rail yards generally handle container cargo to and from trains, trucks, and in the case of the rail yards being located at the ports, to and from ships. Figure II-4 shows the intermodal rail yards operated by BNSF and UP in California and their approximate locations.

**Figure II-4: California's Intermodal Rail Yards**



#### **D. Warehouse Distribution Centers**

Warehouse distribution centers are facilities that serve as a distribution point for the transfer of dry and refrigerated goods to other distribution points or to commercial establishments. Facilities include cold storage warehouses, freight transfer facilities, and inter-modal facilities such as ports and rail yards. Diesel-fueled equipment at these operations are primarily trucks, refrigerated trailers and shipping containers, and yard trucks. CHE used indoors at these centers is generally either electric-powered, propane-fueled, or hydrogen fuel cell electric powered. One of the primary CHE data gaps is the need for an emissions and equipment-specific inventory for CHE operating at California's warehouse distribution centers. A statewide inventory of CHE at warehouse distributions centers must be developed to quantify the numbers and types of equipment in-use at these facilities. Warehouse distribution center CHE inventory development is essential to evaluating the need for and possible benefits from emissions reduction strategies at these facilities. This section provides an overview of the types of equipment and operations at California's warehouse distribution centers.

There are many warehouse distribution centers located throughout California. Often these facilities are located near other freight transportation facilities such as ports, intermodal rail yards, and airports. Additionally these facilities are located near population centers where there is a demand for goods. Figure II-5 below illustrates the locations of distribution centers in Kern County and the central location compared to the various California population centers. Mega distribution centers emerged in 1998 as an effort to gain a competitive advantage by concentrating product at locations that can serve multiple regional markets. This coincided with the advent of the "big-box store" (Symbotic, 2014). California mega distribution centers include facilities at Mira Loma and the Moreno Valley in Southern California.

**Figure II-5: Kern County Distribution Centers**



Source: Kern Council of Governments, 2014

Warehouses at mega distribution centers employ automated equipment to store and retrieve product. The Skechers North American Distribution Center located in Moreno Valley is one example. Five Skechers distribution centers in the Ontario, California area were consolidated into this one mega distribution center. Consolidation has eliminated the truck trips between the five distribution centers. The building housing the Skechers automated facility is approximately 1.8 million square feet and includes many energy efficiency features, including:

- 280,000 square feet of solar panels,
- Wind-sourced air vent system,
- Energy-efficient heating and cooling systems, and
- Cool roof and pavement technologies.

The facility uses an automated storage and retrieval system which has the capacity to ship more than 100 million pairs of shoes annually. The facility, with more than 11 miles of conveyors, relies primarily on the automated conveyor system to move product throughout the facility. However, Skechers also operates a number of different types of forklifts inside the distribution center. Those forklifts include battery electric and propane powered lifts.

## **E. Regulatory Status**

This section provides a regulatory context for the technology assessment by briefly discussing significant ARB regulations that apply to cargo handling equipment.



The ARB regulations, to which CHE is subject, are dependent on the fuel used and where the equipment is operated. These are described below.

Diesel-fueled CHE at California ports and intermodal rail yards are subject to the ARB Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards (section 2479 of title 13, California Code of Regulations (CCR) article 8, chapter 9) (CHE regulation) (ARB, 2005a) (ARB, 2011a).

Diesel-fueled CHE not operating at California ports and intermodal rail yards is subject to the ARB Regulation for In-Use Off-Road Diesel-Fueled Fleets (sections 2449, 2449.1, 2449.2, and 2449.3 of title 13 CCR, article 4.8, chapter 9) (Off-Road regulation) (ARB, 2011b).

Propane and gasoline fueled CHE is subject to ARB's Off-Road Large Spark Ignition Engine Regulation (sections 2430, 2431 2433 2434, and 2438 of title 13 CCR, article 4.5, Chapter 9) (LSI regulation) (ARB, 2008a).

### *CHE Regulation*

The CHE regulation was adopted in 2005 to reduce the diesel PM health risk to communities adjacent to California's ports and intermodal rail yards. It requires that all diesel-fueled equipment be upgraded to reduce diesel PM levels equivalent to that achievable using a diesel particulate filter (DPF). This level of control is being achieved by retiring, replacing, or retrofitting all in-use equipment per a compliance schedule and requiring any new CHE to meet current engine emissions standards and be equipped with a DPF if they do not meet Tier 4 off-road engine emissions standards. The rule is even more stringent for yard trucks, which are required to be equipped with either 2007 or newer on-road engines or off-road engines meeting the Tier 4 final off-road engine emissions standards.

As of December 2013, more than 80 percent of the approximately 4,600 CHE engines at California ports and rail yards have been brought into compliance with the CHE regulation. Compared to 2006 emission levels, 2013 diesel PM emissions are estimated to have been reduced by about 85 percent, NO<sub>x</sub> by 68 percent. With the completion of the compliance schedules by 2017, the reductions are estimated to be over 90 percent diesel PM and 73 percent NO<sub>x</sub>.

### *Off-Road Regulation*

The In-Use Off-Road Diesel-Fueled Fleets Regulation (Off-Road regulation) was adopted by the Board in 2007, last amended in 2010, and received U.S. EPA authorization to enforce in 2013. This regulation is applicable to all self propelled off-road diesel-fueled vehicles with engines rated at 25 hp or greater operated in California. Personal use vehicles, vehicles used solely for agriculture, and vehicles subject to the CHE regulation's performance requirements are exempt from the Off-Road regulation.

#### The Off-Road Regulation:

- Imposes limits on idling, requires a written idling policy, and requires a disclosure when selling vehicles,
- Requires all vehicles to be reported to ARB (using the Diesel Off-Road Online Reporting System, (DOORS)) and labeled with Equipment Identification Numbers (EINs),
- Restricts the adding of older vehicles to fleets starting January 1, 2014, and
- Requires fleets to reduce their emissions by retiring, replacing, or repowering older engines, or installing Verified Diesel Emissions Control Strategies (i.e., VDECS or exhaust retrofits).

The requirements and compliance dates of the Off-Road regulation vary by fleet size. Fleet size is determined based on the total off-road horsepower under common ownership or control in the fleet.

#### *LSI Regulations*

ARB first adopted Large Spark-Ignition (LSI) engine regulations in 1998, which required new LSI engines to meet more stringent NOx and hydrocarbon emissions standards over time, and in 2006, which established verification procedures for LSI retrofit emissions control systems. ARB also adopted the LSI Engine Fleet Requirements Regulation (LSI Fleet Regulation) in 2006, which was amended in 2010 and received U.S. EPA authorization in 2012, to require emissions reductions from existing LSI fleets. The LSI Fleet Regulation also establishes fleet average emission level (FAEL) requirements for medium and large fleets that become more stringent over time. The LSI Fleet Regulation addresses 25 horsepower or greater (greater than 19 kilowatts) engines fueled by gasoline, CNG, or LPG that have a displacement of greater than 1 liter, and are used in forklifts, and the following non-forklift equipment: sweepers/scrubbers, industrial tow tractors, and airport ground support equipment. Fleets with a total of four or more forklifts or four or more pieces of non-forklift LSI equipment, must comply with the LSI Fleet Regulation.

### III. ASSESSMENT OF POTENTIAL TECHNOLOGIES

The types of CHE currently operating at California's ports, intermodal rail yards, and warehouse distribution centers are varied. Most CHE at ports and rail yards has traditionally been powered by diesel-fueled compression ignition engines, but the use of alternative fueled and electric equipment is increasing. The 2012 emissions inventories for POLA and POLB showed that 71 percent of forklifts at POLA and 51 percent at POLB are propane-fueled. Additionally at POLA, 18 percent of the yard trucks are propane-fueled and 2 percent are natural gas-fueled. Cranes are the primary type of all-electric CHE at ports and intermodal rail yards, including RTGs, RMGs, and automated stacking cranes. Additionally the large ship-to-shore cranes used to unload containers from the ships are all-electric.

Warehouse distribution centers require the use of low-emission equipment to maintain adequate indoor air quality. Consequently, electric, propane, and hydrogen fuel cell electric powered equipment, such as lifts, jacks, and sweepers are currently in use at these facilities. Electric and propane-fueled lifts are the most commonly used energy sources used indoors at manufacturing facilities and warehouses distribution centers. Diesel CHE at these facilities is limited to diesel-fueled yard trucks, primarily to move trailers to and from loading bays.

Each type of CHE has a unique engine duty cycle, but there are performance characteristics universal to CHE due to the nature of the activities associated with these industries. These operational characteristics include:

- Durability and reliability comparable with other diesel-fueled equipment,
- Being able to operate for a full 8 to 12 hour shift without down time,
- Quick shift-to-shift turn around with short refueling/recharging/battery exchange capabilities, and
- Equipment operator acceptance.

ARB staff has prepared assessments of the following technologies or efficiency strategies and their applicability to CHE. Those technologies/strategies include:

- Hybrid (electric and hydraulic),
- All-electric (battery and grid source),
- Alternative fuels (H<sub>2</sub>, natural gas (CNG/LNG)),
- Magnetic levitation,
- Lower emission diesel engines (Tier 5),
- Automated container handling operations, and
- Maintenance/reduced engine emissions deterioration.

We will discuss each of these technologies/strategies in the following pages.

## A. Hybrid Technologies

Hybrid equipment, which uses two or more energy sources to provide motive power for the equipment, is a pathway to zero emission technology as it advances the development of its battery and fuel cell components. Equipment manufacturers are developing hybrid equipment for a wide spectrum of CHE, including yard trucks, dozers, loaders, and excavators. The following sections give a brief overview of hybrid technology and then discuss specific applications to CHE.

Opportunities to increase fuel efficiency through hybrid technology, and thus reduce emissions, vary with design but may include:

- Reducing engine size,
- Operating at optimum engine speeds, power output, and temperature,
- Converting kinetic energy normally lost during braking and idle into stored energy,
- Increasing energy storage capability,
- Using stored energy during low power periods, and
- Using batteries recharged from grid source.

### *Technology Description*

Hybrid technologies utilize two or more energy sources to provide motive force for the equipment. These energy sources can operate either in parallel or in series.

With a parallel configuration, both energy sources can provide motive energy to the wheels, either separately, or at the same time. If one energy source is an internal combustion engine, a parallel configuration allows the engine to be directly connected to the transmission and eliminates the need to convert mechanical power to electrical energy and then back to mechanical power. This eliminates the energy losses in these conversions. If the other energy source is a battery, the battery is connected to an electric motor which converts electric energy to kinetic energy to provide motive force (UCS, 2010).

In a series configuration, one energy source feeds energy into another energy source which then provides the motive power to the wheels. One example is an internal combustion engine which runs a generator which charges a battery that provides the motive power to the wheels via an electric motor. The engine can be sized to meet average power demands rather than peak demands but the battery system must be sized to meet the peak power demands. Additionally, since the engine is not required to respond to the various power demands, it can be operated at the most efficient steady-state operating conditions (UCS, 2010). Historically, railroad locomotives are the most common series hybrid application. A locomotive has a diesel engine that drives a generator which produces electricity to provide motive power to the wheels via an electric motor. The series hybrid configuration is used in many types of hybrid heavy equipment such as gantry cranes, bulk equipment, and some hybrid yard trucks currently in development.

Technologies used by hybrids to increase efficiency include regenerative braking, electric motor drive/assist, and automatic start/shutoff. Regenerative braking uses the kinetic energy from the wheels to turn a motor that functions as a generator, producing electricity that can be stored for future use. The resistance of the motor also slows the vehicle, supplementing the braking system and reducing brake wear. Thus, kinetic energy that is normally lost during coasting or braking is converted into electricity. Electric motor drive/assist provides additional power from the battery when needed. This allows the use of smaller, more fuel-efficient engines. The battery also provides the motive force during low speed operation when the engine is least efficient. Automatic start/shutoff reduces energy usage from idling by automatically shutting the engine off when the vehicle comes to a stop and restarts it when the accelerator is pressed. Both series and parallel systems use regenerative braking to recharge the battery, which allows the use of a smaller battery and automatic start/shutoff. However electric motor drive/assist requires a parallel system (DOE, 2013a).

The energy sources being used in off-road hybrid equipment are generally either diesel-electric or diesel-hydraulic combinations. However, additionally, fuel cell-electric hybrids are currently in development. We discuss each of these below along with a variation of the diesel-electric.

#### Diesel-electric hybrids

The diesel-electric hybrid uses a diesel engine teamed with an electric motor to produce the energy required to power the vehicle. The diesel engine can either run a generator to produce electricity to feed the electric motor or, in parallel systems, also provide motive power directly. The electric motor is powered via the alternator or generator as well as an energy storage device such a battery bank or super capacitor (described below). This dual-powered system can provide more power at low engine speeds and has greater efficiency than a single-power source diesel-fueled equipment. The diesel engine can be smaller and more efficient (DF, 2011).

Super capacitors are an energy storage device that works well under conditions where frequent charge and discharge cycles at high current and short duration are needed. Super capacitors store energy as a static charge and not as the result of an electrochemical reaction such as in a battery (BU, 2010). A super capacitor consists of two conductive plates charged at different voltages. The imbalance creates a flow of charge when the plates are connected (Blueshift, 2013).

Super capacitors have existed since 1957, but there were no commercial applications at the time. It was not until the 1990's that advances in materials and manufacturing techniques improved super capacitor performance at a lower cost (BU, 2010). Current super capacitors can be charged in a matter of seconds, have a significantly higher number of cycle lives than batteries, and have a service life of 10 to 15 years (BU, 2010).

Super capacitors are used in several types of hybrid CHE including a RTG crane and bulk handling equipment. The super capacitors are used to store energy normally lost from

braking, such as lowering a container or slowing/stopping a rotating bucket arm. The stored energy is then used as power-assist to the engine when needed (Siemens, 2011) (Komatsu, 2012).

#### Diesel-electric plug-in hybrids

The diesel-electric plug-in hybrid is a diesel-electric hybrid that allows the battery to be recharged using an outside power source in addition to charging with the diesel engine. Plug-in hybrid equipment generally has larger batteries than other types of hybrid technologies in order to store energy from the outside source, generally the electric grid. This allows the battery to potentially serve as the predominant source of power for the equipment and operate a large percentage of the time on electric-only (DOE, 2013b).

#### Diesel-hydraulic hybrids

The diesel-hydraulic hybrid uses a diesel engine, hydraulic pump, hydraulic motor, and low and high pressure tanks. Both tanks contain hydraulic fluid and nitrogen gas. The hydraulic pump, powered by either the diesel engine or, during braking, by the kinetic energy of the wheels, moves the hydraulic fluid from the low pressure reservoir into the high-pressure tank or accumulator. When the accelerator is pressed, the hydraulic fluid is released from the high pressure accumulator through the hydraulic motor which drives the wheels. The hydraulic fluid collects in the low pressure reservoir, which can then be pumped back into the high pressure accumulator. When fluid in the high pressure accumulator is insufficient to drive the hydraulic motor, the diesel engine is started to pump the fluid from the low pressure reservoir through the hydraulic motor, with any excess fluid returning to the accumulator. As with other types of hybrids, hydraulic-hybrids can be configured as either parallel or series hybrids depending on whether the engine is able to directly provide power to the wheels or not.

#### Fuel cell-electric hybrids

The fuel cell-electric hybrid uses a fuel cell power system to produce electricity for motive power. Depending on whether the system is a parallel or series hybrid, the electricity can be used either to directly power a motor, with excess going to energy storage, or to charge an energy storage device, such as a battery or super capacity, which then provides the power.

### *System/Network Suitability and Operational/Infrastructure Needs*

Hybrid technology provides the most benefits when equipment operations require bursts of energy alternating with idle or low power requirement periods and the need to absorb energy. Consequently, this technology is ideal for cranes which raise and lower containers, yard trucks that stop and start often, as well as bulk equipment which operates shovels, buckets, or lifts. An advantage of hybrid equipment is that infrastructure needs are generally the same as for diesel-fueled equipment with the exception of plug-in equipment which requires charging infrastructure.

*Technology Readiness*

Table III-1 below provides a summary of both the commercially available and developing hybrid equipment that could be used in the CHE sector. The table includes container handling equipment, both yard truck and non-yard truck, and bulk handling equipment. The development status of each of these equipment types is discussed below.

**Table III-1 Summary of Commercially Available and Developing Hybrid Equipment for Use as Cargo Handling Equipment**

Equipment Type	Power Type	Number of Models	Status	
			Commercially Available	Under Development
<b>Yard Truck</b>				
Yard Truck	Diesel-Electric Plugin	2	-	2
	Diesel-Electric	1	-	1
	Fuel cell electric	1	-	1
<b>Non-Yard Truck CHE</b>				
<b>Container Handlers</b>				
RTG Crane	Diesel-Electric	4	4	0
	Diesel-Electric Retrofit	6	6	-
	Fuel Cell Electric	1	-	1
AGV	Diesel-Electric	1	1	-
Carriers: Sprinter/ Box / Straddle / Shuttle	Diesel-Electric	10	10	-
	Diesel-Electric Retrofit	2	2	-
Reach Stacker	Diesel-Electric	1	1	-

Equipment Type	Power Type	Number of Models	Status	
			Commercially Available	Under Development
Bulk Handling Equipment				
Dozer	Diesel-Electric	1	1	-
Excavator	Diesel-Electric	2	1	1
	Diesel-Hydraulic	1	-	1
Loader/Material Handler	Diesel-Electric	2	2	-

### Yard Trucks

While yard trucks would appear to be an excellent application for hybrid technology due to their frequent stops, development of a hybrid yard truck has not progressed beyond demonstrations. At least three different demonstrations have occurred at port terminals, with mixed results.

The most successful demonstration was the 2009 three-week demonstration of the Capacity Pluggable Hybrid Electric Terminal Truck (PHETT™) in operation at the Port of Los Angeles (TIAX, 2010). This model was a plug-in series diesel-electric hybrid with a 40 hp interim Tier 4 (Tier 4i) diesel-fueled genset with a 225 hp, 3 phase AC traction motor and lead acid batteries. The PHETT™ performed favorably in comparison to a diesel-fueled on-road engine yard truck when operated in ship loading/unloading service. However, the emissions comparison was disappointing. The PHETT™ demonstrated about 18 percent higher NO<sub>x</sub> emissions on a grams per hour basis than the diesel-fueled on-road engine yard truck although it did produce a 6 percent reduction in diesel PM. A possible contributor to this disappointing NO<sub>x</sub> comparison is the difference in emission standards to which the diesel engines in the two vehicles were certified. The conventional diesel-fueled yard truck was powered by an on-road engine which was certified to a more stringent NO<sub>x</sub> standard than the PHETT™'s off-road Tier 4i diesel-fueled genset. Yard trucks at California ports and intermodal rail yards are required to operate with on-road engines until engines certified to final Tier 4 (Tier 4f) off-road engine emissions standards are available. Consequently, if a Tier 4f genset had been used in the hybrid instead of the less stringent Tier 4i, the results would be expected to have been better due to the Tier 4f's 40 percent lower NO<sub>x</sub> standard and 90 percent lower PM standard as compared to Tier 4i standards for the 40 hp genset.

The U.S. Hybrid diesel-electric hybrid yard truck has undergone demonstrations at both POLB in 2010 and Port of New York (NY) in 2011 through 2012 (CALSTART, 2011) (CALSTART, 2013). The POLB operators had favorable experience with this hybrid, however the NY operators experienced performance problems and more mechanical



issues than with conventional diesel. The POLB demonstration occurred first and some modifications to the yard truck were made in response to that demonstration. While emissions testing was completed during the POLB demonstration, a design issue clouded the results. Emissions testing was planned for the NY demonstration, but was not completed. The POLB demonstration estimated fuel savings at 14 to 20 percent (accounting for the design issue through analysis), significantly higher than the 8 percent fuel saving experienced in the 14-month NY demonstration.

There are two additional hybrid yard trucks currently under development which have not completed demonstrations. These are a diesel-electric plug-in being developed by Balqon in conjunction with Polar Power and a hydrogen fuel cell electric yard truck, the Zero TT, by Vision Industries, who is also partnering with Balqon. The Zero TT is designed to move the heavy containerized cargo inside a port facility or central distribution center. The Zero TT is designed to operate for two eight-hour shifts before refueling the hydrogen tanks. Lithium-ion batteries are used as the power supply and the hydrogen fuel cells recharge the batteries on-the-fly (Reuters, 2015). Vision Industries announced in September 2014 that the company has voluntarily filed for Chapter 11 bankruptcy protection. They intend to continue to operate and work on ongoing government supported programs and research projects while undergoing reorganization (Vision, 2014).

### Cranes and Carriers

Cranes and container carriers are ideal applications for hybrid technology, as exemplified by the mature development of the technology in these applications. Lifting and lowering containers allow for both the supplementation of energy needs by the additional power source and the storing of regenerative energy from braking the container lowering.

Diesel-electric hybrid RTG crane systems are able to reduce the diesel engine size to approximately a third of the horsepower needed for a conventional diesel-fueled RTG crane. The diesel-fueled genset can be sized for average load rather than peak load since it is combined with a battery system. The battery provides the additional power for the peak loads during container lifting. An energy management system allows the battery to store energy from the genset when it produces excess as well as the regenerative energy generated from lowering containers.

In 2005, a prototype hybrid power system by Siemens was retrofitted into an RTG crane in Spain and demonstrated a 50 percent reduction in fuel use (GCC, 2008). In 2007, Railpower completed preliminary testing of their ECO Crane at a Canadian port with a report of a 74 percent fuel savings (GCC, 2007). Other manufacturers report similar fuel savings. There are at least five manufacturers who offer hybrid versions of these cranes, including modules to retrofit existing diesel-fueled cranes. The retrofit modules replace the conventional diesel-fueled power system in an existing crane with a modular hybrid power system. There is also an ARB verified retrofit system which adds a flywheel to the crane to capture the energy from the lowering of containers. The flywheel then provides this energy for the lifting of containers. However, because this system leaves the original

diesel engine in place, which was sized for peak loads, it does not obtain the fuel savings achieved with systems which replace this engine with a much smaller engine.

A fuel cell hybrid RTG crane is under development by Hydrogenics using a battery-fuel-cell hybrid system to lift the containers and regenerative braking to control container descent (Fuel Cell Today, 2013).

An AGV that performs duties similar to a yard truck, such as transporting containers from dock-side to a container stack area, is available in a diesel-electric hybrid. This hybrid includes an ultra, or super, capacitor for energy storage which is estimated to provide 45 percent of the operational power requirements (VDL, 2014).

Shuttle and straddle carriers combine container lifting and lowering with container yard transport. Using these carriers allow the ship-to-shore crane to set the containers on the dock in short stacks when unloading a ship rather than setting them one-by-one on yard trucks. There are a number of both hybrid models and hybrid retrofit options available for shuttle and straddle carriers. Hybrid models have been commercially available since approximately 2008.

#### Reach Stacker

A diesel-electric hybrid reach stacker, made by Konecranes, began a year of field testing of their new hybrid reach stacker in 2013 at the Swedish Port of Helsingborg. The year-long demonstration was successfully completed in 2014. The reach stacker is a diesel-electric series driveline with an electrified hydraulic lifting system and super capacitor for short term energy storage. It demonstrated fuel savings of between 30 and 50 percent compared to a conventional diesel-fueled reach stacker. This model is commercially available (Konecranes, 2013) (Konecranes, 2015).

#### Bulk Handling Equipment

Several models of hybrid bulk handling equipment have recently been introduced, as shown in Table III-1 above. These include a diesel-electric hybrid dozer, three hybrid excavators (two diesel-electric and one diesel-hydraulic), and two diesel-electric hybrid loaders. At least two of the diesel-electric equipment use diesel-electric drive, but include hydraulic systems for non-motive operations. These equipment models are being developed for the construction and mining industries where they are primarily being used.

A 2010-2011 ARB Air Quality Improvement Program (AQIP) project, the Hybrid Off-Road Equipment Pilot Project, provided funding to compare fuel efficiency and emissions of a hybrid dozer, the Caterpillar D7E, and one of the excavators, the Kamatsu HB215-LC-1, to conventional diesel equipment. The project also provided incentive funding, on the order of 10 to 15 percent of the capital cost, towards the purchase of this equipment. A total of 16 pieces of equipment were purchased through the incentive funding, primarily for construction applications. The demonstrations showed that the fuel consumption and emissions benefits/disbenefits of the hybrid equipment were highly dependent on the type

of work the equipment was involved in. While these were only two of the multiple hybrid equipment available, these data suggest that the next generation of hybrid construction equipment will need additional technological advances to ensure it achieves substantial greenhouse gas benefits while also delivering NO<sub>x</sub> emission reductions across all duty cycles.

### *Costs*

For the hybrid CHE equipment currently available (discussed above), with established higher volume markets, capital equipment costs are generally 10 to 20 percent higher than conventional diesel-fueled equipment (CALSTART, 2011). However, reduced fuel costs, due to efficiency improvements, and extended brake life, for systems with regenerative braking (DoE, 2014), could quickly pay back this nominal price premium.

Hybrid equipment fuel efficiency improvements rely on matching the technology with operational characteristics. Hybrid systems that are designed to operate the diesel engine at the most efficient operating conditions and use regenerative braking to recuperate energy losses provide the most efficiency benefits (Katrasnik, 2010). As discussed above, hybrid yard trucks have demonstrated efficiency improvements of 8 to 20 percent whereas hybrid RTG crane fuel savings have been shown to be as much as 50 to 74 percent.

### *Estimate of Emissions Reductions With Technology*

As with other hybrid systems, emissions reductions are dependent on the hybrid system and the engine duty cycle. Reductions in CO<sub>2</sub> emissions will be consistent with the fuel efficiency improvements discussed for each equipment type. NO<sub>x</sub> benefits have varied with the hybrid system and the application. Hybrid cranes have demonstrated the best NO<sub>x</sub> reductions whereas the bulk handling equipment NO<sub>x</sub> reductions have been more mixed. PM reductions have been more consistent, with up to 60 percent reductions demonstrated, although it is becoming more difficult to quantify those reductions due to the low baseline PM emissions with DPF-equipped diesel engines.

The operational benefits associated with hybrid technologies include reduced engine noise and the ability to work full shifts with quick shift-to-shift turn around.

### *Next Steps/Staff Recommendations*

Staff recommends additional demonstrations of hybrid CHE bulk equipment with emission and performance data collection to determine if they can meet the operating conditions at ports and intermodal rail yards. In addition, once the hybrid equipment viability and benefits have been demonstrated, staff recommends that incentives be provided to promote large fleet demonstrations of hybrid CHE at ports and intermodal rail yards to demonstrate durability and reliability. Hybrids can be used as a transitional technology to achieve additional emissions reductions from non-container movement port operations through a combination of incentives and regulatory approaches.

## B. Electric Power Technologies

Electric power technologies have the commonality that all use electricity as the energy source for motive power. Generally, CHE using this energy source is equipped with an electric motor which converts the electricity to kinetic energy for motive power. The differences in these technologies are generally the electricity source. The energy sources (either the electric grid or batteries) and potential use of these power options to CHE are discussed below.

### 1) Electric-grid Powered

There are a number of electric-grid powered technologies being implemented or considered at California's ports and intermodal rail yards. Implementation of electric-grid powered technology involves using the existing California power grid to provide electricity to operate the equipment. Existing applications include auxiliary power for ocean-going vessels (shore-power), catenary (overhead) and in-ground power systems, ship-to-shore cranes, electrified RTG and RMG cranes, and electric-vehicle charging. Electric-vehicle charging is associated with battery-technology.

#### *Technology Description*

The implementation of ARB's Air Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels (OGV) at Berth in a California Port (ARB, 2008b) has spurred the development of shore-power projects at California's ports. The installation of the infrastructure needed for the OGV shore-power program may provide opportunities for CHE owners/operators to use electric CHE. The continued growth of the use of shore-power at port terminals provides infrastructure to help support electric CHE including cranes and yard trucks. Details about the status of shore-power implementation at California's ports, the infrastructure needs associated with shore-power, the costs associated with shore-power, and the emissions reductions associated with shore-power are provided in the Ocean-Going Vessel Technical Assessment document.

Grid-powered technologies will reduce emissions of greenhouses gases and criteria pollutants at the point of application, but greenhouse gas and criteria pollutant emissions associated with power plants may increase unless renewable sources provide the required power.

The advantages of implementing grid-powered CHE include reduced emissions and reduced health risk exposures to communities located near ports and intermodal rail yards. The disadvantages of grid-powered CHE include the engineering challenges posed by installing the system and the high capital costs. Engineering challenges include planning, designing, and installation of the infrastructure necessary to optimize the functionality of CHE using grid-based electricity and the variety of electrical requirements (AAPA, 2007). Additionally, the ability of the grid to accommodate the increase in demand may also be a challenge.

### *Operational/Infrastructure Needs*

Grid-powered CHE requires connections to the electric grid, generally via either a busbar or power cable. Consequently required infrastructure could include trenching for the cable or in the installation of busbar. RMGs will require rail installation. This limits the type of equipment this specific technology is applicable to. Cranes that move in restricted paths are ideal as grid-source equipment.

Electric RTGs typically require electrical service ranging from 4,160 to 13,800 volts depending on use and specifications. These cranes may operate for several thousand hours each year, consuming approximately 400,000 kWhs of electricity annually. Electrical infrastructure that may be needed can include:

- High voltage source and switchgear infrastructure,
- Electrical power from substation to crane switchgear infrastructure, and
- Cabling from switchgear infrastructure to the crane vaults/pits.

Newer or recently upgraded ports may have sufficient electrical capacity in place and may not require additional infrastructure, while older facilities may need to make an initial investment (EPRI, 2010).

### *Technology Readiness*

Grid-powered CHE, principally cranes, are a commercially available, mature technology, for container handling. Table III-2 below provides a summary of the number of manufacturers who provide commercially available grid sourced all-electric equipment used in the CHE sector. The table shows that container handling gantry and ship-to-shore cranes are the primary CHE using grid sourced power.

**Table III-2: Summary of Commercially Available and Developing Grid-Powered All-Electric Equipment for Use as Cargo Handling Equipment**

Equipment Type	Power Type	Number of Manufacturers	Status	
			Commercially Available	Under Development
RTG Crane	Grid Electric	5	5	-
	Grid Electric Retrofit	5	5	-
RMG Crane	Grid Electric	5	5	-
	Grid Electric Retrofit	2	2	-
Ship-to-Shore Crane	Grid Electric	5	5	-
	Grid Electric Retrofit	2	2	-

(Port area, 2014a) (Port area, 2014b) (Port area, 2014c)

Grid-powered CHE for most bulk material handling operations is generally not available due to the non-linear operations associated with bulk handling. Bulk handling CHE does not operate on consistently level surfaces or within prescribed pathways. Those two characteristics make the installation of a fixed, electric infrastructure challenging. However, there are some bulk material handling operations at terminals or manufacturing facilities which employ electrified conveyor belt CHE or electrified stationary bucket CHE for material handling.

### Rubber-tired and Rail-mounted Gantry Cranes

RTGs and RMGs are used to unload containers from yard trucks or AGVs, organize them in container stacks, and then load them onto either rail or drayage trucks for delivery to other locations. RTGs and RMGs have historically been powered by diesel engines. These have either been gensets or pumps depending on whether the lifting mechanism is either electrically operated or hydraulic. However, electric cable reel or busbar RTGs and RMGs are a mature technology used at the automated foreign ports with the first delivered in 2002. This technology is starting to be employed by U.S. port terminal and intermodal rail yard owners/operators to reduce equipment operating costs and environmental impacts. An additional benefit from grid powered gantry cranes is the ability to use regenerative braking when lowering containers to capture energy that is normally dissipated. This is estimated to reduce power demands by about 35 percent (GPA, 2012).

### Ship-to-Shore Cranes

Ship-to-shore cranes are dockside gantry cranes used to load and unload containers from container ships. Ship-to-shore cranes can be powered two ways; by a diesel-fueled generator on the top of the crane or by electric power from the dock. Ship-to-shore cranes powered by electric shore-power are the most common. Of the more than 150 cranes at the ports of Los Angeles and Long Beach, all are electric-powered from the dock (POLA, 2014a) (LBBJ, 2012).

#### Cost

As mentioned above, grid-powered ship-to-shore cranes are already commonly in use in California. Capital costs for electric ship-to-shore cranes are comparable to diesel models. And while new ship-to-shore cranes can be purchased for approximately \$10-12 million, diesel equipment can be retrofitted for approximately \$350,000 per crane (EPRI, 2009).

Capital equipment costs for grid-powered RTGs and RMGs are marginally higher than diesel models, on the order of 10 percent. These costs may equalize as the technology becomes more widely used. Retrofit of a diesel RTG to electric costs approximately \$250,000 (EPRI, 2010).

Infrastructure costs will vary depending on the existing port or rail configuration. Newer or recently upgraded ports may have sufficient electrical capacity in place for grid powered RTGs or RMGs and may not require additional infrastructure expenditures, while older facilities may need to make an initial investment. Electrical infrastructure that may be needed can include:

- High voltage source and switchgear infrastructure,
- Electrical power from substation to crane switchgear infrastructure, and
- Cabling from switchgear infrastructure to the crane vaults/pits (EPRI, 2010).

The costs of developing the infrastructure required by grid-powered RMGs at intermodal rail yards would be similar to the infrastructure needed to power the RMGs at an automated terminal. Those costs are discussed later in this document. Other infrastructure investments could include trenching for the cable or in the installation of busbar. As an example of the associated costs, the Port of Savannah will be installing busbars (or conductor rails) for an additional 20 electric RTGs at the cost of \$11.5 million (American Shipper, 2015). RMGs require rail installation; however this is necessary for either diesel or electric equipment.

ARB staff estimated the costs of replacing current RMG and yard truck technology at intermodal rail yards with all-electric RMGs and battery yard trucks to be \$5 million per RMG and \$210,000 per yard truck (ARB, 2011c).

Grid-powered gantry cranes provide significant operating cost benefits with reduced energy use and reduced maintenance. Grid-powered gantry cranes are estimated to reduce annual energy costs by approximately 60 percent when compared to diesel-fueled gantry cranes (EPRI, 2010). Maintenance costs for grid-powered gantry cranes are also typically lower than for diesel since they do not require frequent oil changes or engine tuning nor do they experience diesel engine-related failures or require engine replacements. Consequently, equipment down time can be correspondingly lower. One port, the Port of Savannah, estimated that 25 percent of its equipment down time was due to diesel-related issues (EPRI, 2010). The use of grid-powered gantry cranes eliminates this source of down time.

#### *Estimate of Emissions Reductions With Technology*

Electrified cranes eliminate dock-side emissions of NO<sub>x</sub>, diesel PM, and GHGs and offer significant savings in fuel costs and equipment maintenance. Annual GHG emissions reductions for electrified ship-to-shore cranes are estimated to be approximately 25 percent as compared to GHG emissions from diesel-powered ship-to-shore cranes (EPRI, 2009). This is based on taking into account the increased GHG at power plants due to the increased energy demand. Similarly, there would be increased criteria pollutants at power plants, though presumably less than those eliminated from the diesel crane.

### *Next Steps/Staff Recommendations*

Staff recommends supporting and incentivizing the transition to fully automated, all-electric CHE at container handling terminals and intermodal rail yards. This should include incentivizing the implementation of the infrastructure necessary to support grid powered CHE. Currently, terminal port landlords are funding the infrastructure development by recouping investment via long-term leases.

#### 2) Battery Technologies

Battery technology is a crucial component to a wider adoption of free-ranging electric vehicles. Batteries are a vehicle power source that has had limited application in light-duty vehicles for almost 150 years. Battery electric vehicles (BEV) utilize power stored as chemical energy in rechargeable batteries (DOE, 2013a). Battery-only electric vehicles get all of their power from battery packs. There is no internal-combustion engine (ICE) associated with the vehicle.

#### *Technology Description*

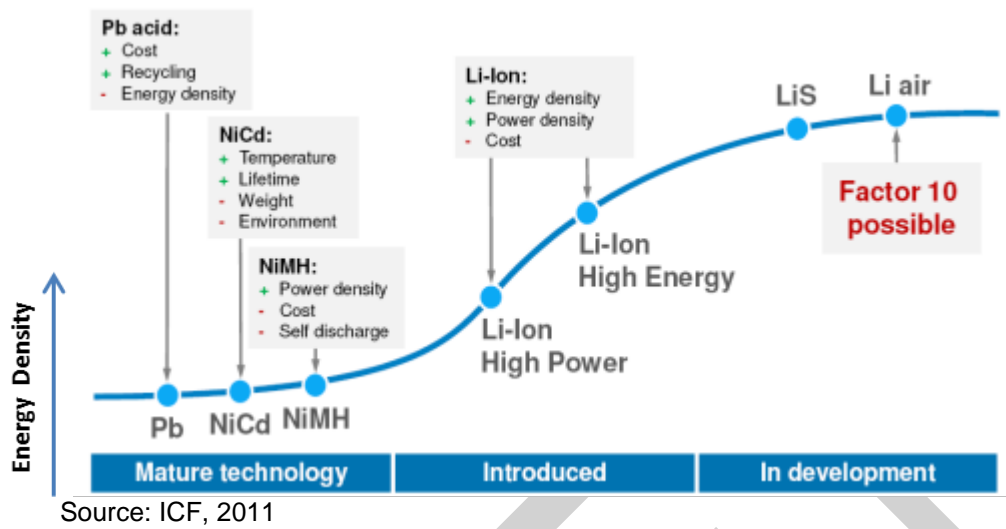
Currently, there are three primary battery types being used for propulsion of BEVs (DOE, 2013b). These are:

- Lithium-ion,
- Nickel metal hydride, and
- Lead acid.

Lead acid and nickel metal hydride batteries are more mature technologies but with lower energy density than lithium-ion batteries. This is shown in Figure III-1 below. However, lithium-ion battery technology is maturing as the primary battery technology currently being used in BEVs.



**Figure III-1 Battery Technology Status**



ARB staff has prepared discussions of the different types of batteries, battery charging technologies and challenges, and battery technology research in the Medium and Heavy-Duty Battery Electric Vehicles Technology Assessment document. The reader can refer to discussions in that document for more information about battery technologies. This section will focus on the specifics associated with the different types of batteries and their applicability to CHE.

As discussed earlier, there is a broad range of equipment types represented within the CHE sector. CHE includes equipment types ranging from heavy-duty bulk handling equipment to light-duty (comparatively speaking) walkie stackers. Generally speaking, the battery technologies associated with medium- and heavy-duty on-road vehicles are applicable to many types of CHE operating at port terminals and intermodal rail yards. At the other end of the spectrum, CHE at warehouse distribution centers can be equipped with lighter-duty battery technologies.

### *Technology Readiness*

Table III-3 below provides a summary of both the commercially available and developing battery-electric equipment that could be used in the CHE sector. The table includes container handling equipment; both yard truck and non-yard truck, and bulk handling equipment. The development status of each of these equipment types are discussed below.

**Table III-3: Summary of Commercially Available and Developing Battery All-Electric Equipment for Use as Cargo Handling Equipment**

Equipment Type	Power Type	Number of Models	Status	
			Commercially Available	Under Development
<b>Yard Truck</b>				
Yard Truck	Battery Electric	4	1	3
<b>Non-Yard Truck CHE</b>				
Container Handlers				
AGV	Battery Electric	1	1	-
Bulk Handling Equipment				
Forklift	Battery Electric	11	11	-
Loader / Material Handler	Battery Electric	10 stationary 1 mobile	11	-
Specialty				
Railcar Mover	Battery Electric	6	6	-

Lead acid batteries are the most mature, most common, and cheapest form of battery technology used in battery electric CHE. Lead acid batteries were used in the earliest versions of battery electric vehicles and the current commercially available battery electric CHE primarily employ lead acid battery technology. Warehouse distribution centers are the CHE application where lead acid batteries continue to be the predominant type of battery used. However, as new battery technologies demonstrate longer run times, it is anticipated that they will replace this older technology.

Lithium-ion battery technology is not yet fully mature, but lithium-ion batteries are the most recent wide-spread battery technology being used to power developmental battery electric CHE. There are a number of prototype CHE vehicles equipped with lithium-ion batteries currently in demonstration projects at California's ports (TAP, 2013).

## Yard Trucks

There are currently four different manufacturers developing battery electric yard trucks for use at California ports, the Balqon XRE20, TransPower ElectTruck, Orange EV T-Series, and Terberg YT 202-EV. The Balqon, TransPower, and Terberg are all new-build OEM production vehicles. The Orange EV has been based on converting diesel yard trucks to all-electric, refurbishing the entire truck in the conversion process. They have recently begun exploring a partnership with Kalmar Ottawa to deliver new-build battery-powered all electric yard trucks (Orange EV, 2015c).

The Balqon, TransPower, and Orange EV vehicles are involved in U.S. demonstrations which are summarized in Table III-4 below. Balqon will be demonstrating a minimum of two, with a possibility of up to six, yard trucks at POLA terminals this year (2015). TransPower has on-going demonstrations at both a distribution center and two port terminals. The response to these demonstrations has been positive. These demonstrations have indicated that per mile power use in port operation is about twice that demonstrated in distribution center operation. Orange EV has made successful demonstrations outside of California, at a freight distribution facility, a manufacturing site, and an intermodal services site, and will begin demonstrations this year at the following California facilities: Ports America, the Union Pacific Intermodal Container Transfer Facility (ICTF), and the POLA Yusen Terminals. These recent demonstrations are showing that battery electric yard trucks can achieve the performance necessary for port and rail application. The longer term demonstrations beginning this year will prove whether this technology is sufficiently reliable and durable for port and rail application.

**Table III-4: Summary of Battery-Electric Yard Truck Demonstration Projects**

<b>Manufacturer</b>	<b>Battery</b>	<b>Demo Start Date and Location</b>	<b>Goals</b>	<b>Demonstration Description</b>
Balqon	Lithium	2015 - POLA: APM Terminal and Evergreen	Demonstrate performance in real world environment	Demonstrate up to six XE-20 electric yard trucks at POLA. Demonstration will initially be with one truck at APM Terminal and one at Evergreen with an additional two trucks delivered to each facility if the first trucks perform as required. Start of demonstration currently awaiting clearance of an administrative hurdle (POLA, 2015).

Manufacturer	Battery	Demo Start Date and Location	Goals	Demonstration Description
TransPower	Lithium (Trans Power, 2014a)	January 2015 – present - Dole Fresh Fruits, San Diego, September 2014 through present – Ikea Center, Tejon, CA. October 2014 through March 2015 - SA Recycling and TTSI, POLB. Scheduled to be used at Eagle Marine Terminal, POLA, for longer term deployment.	Meet or exceed diesel-fueled yard trucks' throughput (TransPower, 2014b)	Ikea demonstration - exceeding power and speed of conventional. IKEA average power use 2.1 kWh per mile (TransPower, 2014b). Dole San Diego and TTSI POLB average power use 4-4.5 kWh per mile. Eagle Marine Terminal POLA demonstration awaiting charging station. California Energy Commission recently awarded funding to TransPower to expand their electric vehicle manufacturing capabilities.
Orange EV	Lithium	2014 14 day demonstrations at a freight distribution, a manufacturing, and an intermodal services site all outside California. 2015 Demonstrations to begin at Ports America, UP-ICTF, YTI	Demonstrate equipment is durable and productive. Included specific test objectives and record keeping for performance analysis.	Lifted and pulled design 81k LB GCWR (Gross Vehicle Weight Rating - total maximum weight of equipped, loaded truck.). Pulled up to 96k LB GVWR. Demonstrated could work up to 24 hours on a single charge with extended battery and up to 16 hours in the heavy-duty intermodal environment. Opportunity charging can extend this. Demonstrated speeds from 15 to 20 miles per hour (Orange EV, 2014).

Manufacturer	Battery	Demo Start Date and Location	Goals	Demonstration Description
TransPower	Lithium	2013 – HEB supermarket-chain distribution center San Antonio, TX	Develop vehicle architecture Durability test Real world test Performance assessments	Two tractors demonstrated ability to work 10-12 hr shift, good acceleration, pulled heaviest containers. Long-term reliability not yet demonstrated. Average energy use 2.2 kWh per mile. Estimated fuel cost reduced to ~1/4 conventional diesel cost (TransPower, 2013).
Balqon	Lithium	2009 POLA	Test reliability and endurance of lithium-ion battery, compare to the lead acid batteries	A yard truck and a drayage truck, with lead acid batteries, were to be retrofitted with lithium-ion batteries. Dynamometer test of retrofitted drayage with unloaded container showed a potential doubling of range compared to lead acid battery. However the yard truck was not tested (TAP, 2014).
Balqon	Lead acid	2008 POLA	Prove performance and commercial feasibility in drayage application	Drayage demonstration that is considered to be applicable to yard truck application.

### Automated Guided Vehicles

There is currently one manufacturer of battery electric AGVs with 20 years of battery electric European port terminal experience. This AGV has demonstrated the ability to operate up to 12 to 15 hours on a charge. Battery recharging (accomplished via battery swapping) requires approximately six hours. In some locations, the battery electric AGVs are operating approximately 6,000 hours per year and running 24 hours per day (Gottwald, 2011).

## Bulk Handling Equipment

Battery powered forklifts, aerial lifts, and sweepers are mature technologies that are in use at distribution centers and manufacturing plants. The indoor use requires low emission technologies. This equipment primarily uses lead acid battery technology which must be recharged after every shift. This is often accomplished through battery swapping which requires the storage and off-shift charging of the swapped-out battery, as well as the capital investment of the additional batteries. While the majority of electric forklifts come in lift capacities of 2,000 to 12,000 pound, at least one manufacturer has models with capacities up to 40,000 pounds. Lift capacities of up to 100,000 pounds are advertised but achieving these capacities greatly increases the capital cost. These very high lift capacity forklifts are not off-the shelf equipment, which contributes to the cost. As battery technology advances and production volumes increase, these costs will drop and the total cost of ownership could provide economic incentives.

At least two manufacturers offer battery electric material handlers, one stationary and the other mobile. This equipment has an articulated swinging arm which directs a bucket for picking up and moving loose material. The stationary handler is grid sourced and the mobile is battery electric. The stationary equipment comes in a number of models handling up to 15 tons. The battery operated model handles up to 2 tons.

## Specialty Equipment - Railcar Mover

Two manufacturers offer battery powered rail car movers. These would primarily be used to reposition railcars in the rail yard or maintenance shop.

### Costs

Although the initial capital costs for battery electric equipment are higher than those for clean diesel, reduced fuel and maintenance costs can provide a return on investment that can be as short as three years for equipment such as battery electric forklifts.

As an emerging technology, battery–electric yard trucks are still approximately twice the cost of clean diesel technology. However, we anticipate these costs to drop significantly as the technology matures into a higher volume sales market. Additionally, cost savings will be realized due to reduced maintenance and lower fuel costs, leading to a lower cost of ownership. The replacement of a diesel engine with a battery system eliminates all of the engine and emission control system maintenance associated with the equipment. The regenerative braking provided by the electrical system also reduces brake wear, lowering brake maintenance costs. Fuels costs are also reduced by the switch from diesel fuel to electrical energy. Orange EV estimates that an owner of 10 electric yard trucks would save up to \$6 million over 10 years due to these reduced fuel and maintenance costs (Orange EV, 2015d).

While battery electric AGVs can be up to several times the cost of yard trucks, this equipment cost includes the price of the guidance system which provides additional

benefits including reduced labor costs and increased worker/equipment safety. Reduced fuel costs also help lower the total cost of ownership for this equipment.

Although battery electric forklifts are 10 to 20 percent higher in capital cost as compared to diesel for lift capacities of up to 6,000 pounds, reduced fuel and maintenance costs can produce a return on investment in less than three years (LiftsRUs, 2014) (EPRI, 2014). Forklifts with higher capacities are not as commonly used as the lower capacity forklifts and can be from 30 to 40 percent more expensive than diesel. However these costs are anticipated to come down with higher production volumes.

#### *Next Steps/Staff Recommendations*

Staff recommends supporting continued demonstrations of battery electric equipment at ports and distribution facilities to develop equipment reliability and durability data. Specifically, larger fleet demonstrations of electric yard trucks for one to two years will provide data necessary to support the reduced total cost of ownership claims of technology manufacturers.

#### C. Lower Emission Alternative Fuels

Two lower emission alternative fuels were considered for the CHE technical assessment, hydrogen and natural gas. While LPG or propane could be considered an alternative fuel, it is conventionally used in CHE at warehouse distribution centers, and so was considered a conventional fuel.

##### 1. Hydrogen Fuel Cell Electric Technology

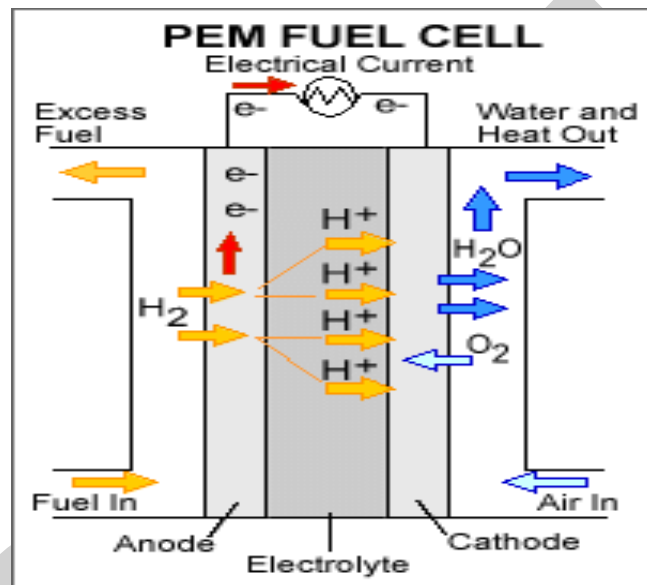
#### *Technology Description*

Fuel cell electric technology is presented in more details in the Medium and Heavy Duty Fuel Cell Electric Vehicles Technology Assessment. One of the common types of fuel cell is the Polymer Electrolyte Membrane (PEM) fuel cell. A brief description of how a PEM fuel cell works is provided below.

A hydrogen fuel cell is a device that uses hydrogen and oxygen to create electricity, emitting only heat and water. Figure III-2 provides a schematic of how a PEM fuel cell works. The PEM fuel cell consists of an electrolyte membrane sandwiched between an anode (negative electrode) and a cathode (positive electrode). Hydrogen fuel is channeled to the anode, where the catalyst separates the hydrogen's negatively charged electrons from the positively charged protons. The membrane allows the positively charged protons to pass through to the cathode, but not the negatively charged electrons. The negatively charged electrons must flow around the membrane through an external circuit. This flow of electrons forms an electrical current. At the cathode the positively charged hydrogen ions (protons) combine with the negatively charged electrons and oxygen to form water and heat.

The amount of power produced by a fuel cell depends on several factors, including fuel cell type, cell size, temperature at which it operates, and pressure at which the gases are supplied to the cell. A single fuel cell produces less than 1.16 volts - barely enough electricity for even the smallest applications. To increase the amount of electricity generated, individual fuel cells are combined in series, into a fuel cell "stack." A typical fuel cell stack may consist of hundreds of fuel cells (DOE, 2014a).

**Figure III-2: Polymer Electrolyte Membrane Fuel Cell**



Source: U.S. Department of Energy

### *Operational/Infrastructure Needs*

Fuel cells can be used as a battery replacement for battery-electric applications. Forklifts have been the primary application for which these battery replacements have occurred in the CHE arena. However, with the growth of CHE battery electric technology, we anticipate that more opportunity for new fuel cell electric applications will open up.

Fuel cell electric technology requires refueling infrastructure to support the operation. This includes fueling space and equipment to support the hydrogen supply option chosen. Options include liquid hydrogen delivery and storage, or on-site hydrogen production through either steam methane reforming (SMR) or electrolysis.

Generally, if hydrogen is being delivered, the material handling facility does not develop its own hydrogen infrastructure. Instead, the hydrogen provider and materials handling facility will develop an operating lease of the hydrogen equipment. The liquid hydrogen handling storage equipment is normally located immediately outside the equipment service center within a fenced enclosure. Liquid hydrogen is transported to and stored on site in a cryogenic storage tank. Hydrogen is withdrawn from the tank as a liquid and then gasified by a vaporizer. Generally, two hydrogen dispensers are located inside the



warehouse. Each dispenser draws fuel from the ground storage cylinders, after which, the compressor automatically replenishes the cylinders as required (Plug Power, 2012).

To avoid hydrogen transportation costs, some companies use onsite hydrogen production through SMR with pressure swing adsorption (PSA) to purify the hydrogen. Onsite hydrogen reforming infrastructure is similar in cost to liquid hydrogen infrastructure so there is little difference in capital investment. The elimination of fuel liquefaction and transportation yields a competitive advantage for onsite hydrogen reformation over liquid distribution (Plug Power, 2012).

There are two primary reactions for the SMR process: the reforming reaction and the water gas shift reaction. In the reforming reaction, natural gas is mixed with steam, heated to over 1,500 degrees Fahrenheit, and reacted in the presence of a nickel catalyst to produce hydrogen and carbon monoxide. The carbon monoxide from the reforming reaction is combined with steam in the water gas shift reactor to produce additional hydrogen (Air Products, 2013).

Electrolysis uses an electric current to split water into hydrogen and oxygen. The electricity required can be generated using any of a number of resources. However, to minimize greenhouse gas emissions, electricity generation using renewable energy technologies, such as wind, solar, geothermal, hydroelectric power, nuclear energy, or natural gas with carbon sequestration are preferred (DOE, 2012).

### *Technology Readiness*

Hydrogen fuel cell electric technology is commercially available and being used in material handling equipment applications as replacement for batteries in high throughput warehouses with multi-shift operations. The research and development of hydrogen fuel cell electric forklifts involves multiple sectors including fuel cell stack manufacturers, fuel cell system integrators, and material handling equipment manufacturers. Manufacturers of fuel cell stacks, such as Ballard, Hydrogenics, and Nuvera Fuel cells are involved in designing, developing, and manufacturing the fuel cell electric products. System integrators, such as Plug Power, work on building the fuel cell technology into power pack units that can be fitted to forklifts, pallet trucks and other similar vehicles. Material handling vehicle manufacturers work along with system integrators in fitting of fuel cell electric systems to their forklift vehicles.

Plug Power is a fuel cell system integrator for battery replacements forklifts in Class I, II, and III. Plug power is also working on extending their fuel cell systems to other applications including ground support equipment, transportation refrigeration units, and range extenders. Their development of hydrogen fuel cell range extenders for FedEx Express electric delivery trucks will help to expand their products into the range extension market for small-to medium-sized electric vehicle fleets including port vehicles.

Hydrogenics, also a fuel cell system provider for forklift applications, has developed an integrated fuel cell system, Celerity, for medium and heavy duty transportations. Celerity

is a compact modular unit that can be installed as a single unit or as multiple units in increments of 60kW for primary power or range extension. The typical applications include utility and ground support vehicles, shuttles, school buses and truck fleets (Class 4-6). Hydrogenics has been awarded two projects by California Energy Commission for its “Medium and Heavy-Duty Vehicle Technology Demonstration” program. For the first project, with the technical support of Siemens, Hydrogenics will integrate its advanced CelerityPlus™ fuel cell drive system into a Class 8 drayage truck. Total Transportation Services, Inc. (TTSI) will demonstrate the Hydrogen fuel cell-powered drayage trucks on the Alameda Corridor as well as in the ports of Long Beach and Los Angeles. For the second project, New Flyer, a heavy-duty buse manufacturer, will integrate Hydrogenics’ CelerityPlus™ fuel cell drive system into its 40-foot battery transit bus platform, Xcelsior, for a 12 month demonstration. These fuel cell-battery hybrid applications could be transferable to a yard truck application. Hydrogenics is also developing a Celerity based RTG crane system using a battery-fuel-cell hybrid system to lift the containers and regenerative braking to control containers descent (Hydrogenics, 2015).

Table III-5 below provides a summary of the commercially available hydrogen fuel cell electric equipment that could be used in the CHE sector. A hydrogen fuel cell electric hybrid yard truck is also mentioned in section III.A. Hybrid Technologies, above.

**Table III-5: Summary of Commercially Available and Developing Hydrogen Fuel Cell Electric Equipment for Use as Cargo Handling Equipment in North America**

Equipment Type	Power Type	Number of Fuel Cell Manufacturers	Status	
			Commercially Available	Under Development
Forklift	Hydrogen Fuel Cell Electric	5	5	-

There are about 8,000 hydrogen fuel cell electric forklifts operating in the U.S. at manufacturing facilities and warehouses distribution centers, with approximately 800 deployed in California, primarily at distribution centers (DOE, 2014b). The most significant advantage of fuel cell electric technologies is no tailpipe emissions of criteria pollutants or toxic air contaminants. Other advantages of fuel cells include longer operating times than batteries, quick refueling time, longer lifetime, and improved facility space utilization. Hydrogen fuel cell electric forklifts provide more than 12 hours of constant power without performance degradation (NREL, 2013a). Battery-powered forklifts experience a power decline as the battery discharges.

Fuel cell electric forklifts can be fueled quickly, in less than 3 minutes by the forklift operator, compared to approximately 15 minutes for each battery swap. Additionally, a battery can require as much as 8 hours for charging and several additional hours of cooling time prior to reuse. Fuel cell electric systems have longer lifetime compared to lead acid batteries. The average fuel cell electric system lifetime is 10 years, with the fuel cell stacks refurbished every 3 years (Ballard, 2014). Lead acid batteries need to be

replaced every 3 years. Deploying fuel cell electric forklifts also saves warehouse space, compared to battery electric forklifts. Battery electric forklifts require additional warehouse space for storing batteries for swapping and charging the battery packs. Hydrogen fuel cell electric forklifts produce zero tailpipe emissions of both GHG and criterial pollutant emissions at their point of use. Lead acid batteries can leak sulfuric acid requiring spill-kits and regular clean-ups to prevent corrosion within the forklifts.

The challenges that fuel cell electric forklifts face are the capital cost of hydrogen fueling infrastructure and the fuel cost. The cost of hydrogen is a significant part of fuel cell electric operating cost for material handling equipment users. Hydrogen cost depends on a variety of production and regional considerations. As discussed above, hydrogen can be produced from natural gas using high-temperature steam (SMR) or by electrolysis. SMR accounts for about 95 percent of the hydrogen used today in the U.S. An efficient means of delivering large quantities of hydrogen fuel over long distances and at low cost does not yet exist. Pipeline transmission, the least expensive delivery method, is currently not available for hydrogen.

### Cost

While the hydrogen fueling infrastructure cost and fuel cost are significantly higher than conventional battery operated forklifts, studies have shown that fuel cells can be the more cost effective option for high volume warehouse distribution center operations. A 2013 study by the National Renewable Energy Laboratory (NREL) found that fuel cell electric lifts are predicated to have a lower cost of ownership compared to traditional battery lifts in both Class I/II and Class III material handling equipment. NREL found that for Class I and II forklifts used in multi-shift operations, fuel cell electric could reduce the overall cost of ownership by 10 percent per year per lift truck. The cost of ownership of Class III can be reduced by 5 percent per year for each lift truck. While fuel cell electric material handling equipment (MHE) have higher costs for hydrogen fuel and hydrogen infrastructure compared to the energy and infrastructure needs for battery MHE, fuel cell electric forklifts can yield significant savings in labor costs and facility space costs. For Class I and II MHE, fuel cell electric lifts can lower annual per-lift truck labor costs from \$4,400 for battery change and charging to only \$800 for hydrogen fueling and can lower annual facility space costs from \$1,900 for battery storage and charging to \$500 for hydrogen fueling (NREL, 2013a).

Currently, hydrogen (including delivery and storage) is priced at \$8.00 - \$9.00 per kilogram (Plug Power, 2012). Depending on the equipment, the manufacturer, unit size and volume of units produced, the commercial price of a hydrogen fuel cell power pack is approximately \$14,000 to \$30,000 per unit. By comparison, a lead acid forklift battery costs between \$2,600 and \$5,500 depending on the forklift class (Ballard, 2014). The total capital cost of a hydrogen fueling station varies with the size and type. A study by NREL summarized the capital cost per capacity (\$/kg-day) associated with three sizes of stations in the updated 2012 Hydrogen Analysis (H2A) Model case studies for onsite SMR and electrolysis stations. As shown in Table III-6 below, the volume-specific capital cost drops substantially with increased usage (NREL, 2013b).

**Table III-6: On-site Hydrogen Production Station  
Capital Cost as a Function of Hydrogen Production**

Capacity Kg/day	Capital costs per capacity (\$/kg/day)	
	SMR	Electrolysis
100	\$11,230	\$10,601
400	\$ 5,182	\$ 5,242
1,000	\$ 4,031	\$ 4,394

(NREL, 2013b)

*Estimate of Emissions Reductions*

Hydrogen fuel cells have zero tailpipe emissions of both GHG and criteria pollutant emissions. However, the pathway of hydrogen from well-to-tank, including feedstock, hydrogen production, hydrogen liquefaction, distribution and storage, and compression contributes GHG emissions. If hydrogen is produced via SMR, onsite at a refueling station, the energy and emissions will consist of those associated with the feedstock, production, and compression, but will not include those associated with the liquefaction and transportation. One well-to-wheel analysis for hydrogen results in 98.3g CO<sub>2</sub>e/MJ of greenhouse gas emissions generated during the production and use of hydrogen in a fuel cell electric vehicle. This pathway assumes North American natural gas as the feedstock (ARB, 2009). In comparison, a similar well-to-wheel analysis for diesel results in 98.03g CO<sub>2</sub>e/MJ of greenhouse gas emissions (ARB, 2012).

*Next Steps/Staff Recommendations*

Staff recommends support and incentive funding for demonstration of fuel cell electric hybrid yard trucks and RTG cranes. Staff also recommends a study of the performance demands of forklifts at ports and rail yards to support the development of fuel cell technology for forklifts at these locations. Additionally, staff recommends the support of technology advancements related to the reduction of costs associated with hydrogen fuel and hydrogen fueling infrastructure.

## 2. Natural Gas Technology

Natural gas, a fossil fuel, is comprised mainly of methane (CH<sub>4</sub>)<sup>1</sup>. In its natural state it is colorless, odorless, non-toxic, with a limited range of flammability. A minute amount of a sulfur compound (mercaptan) is added to the gas to facilitate detection of leaks. There is an abundant supply of natural gas in Northern America and around the world.

### *Technology Description*

As a vehicle fuel, natural gas can be stored in one of two forms, CNG, and LNG. Generally CNG is stored in cylinders under a pressure of 3,000 to 3,600 pounds per square inch. LNG is produced when natural gas is condensed into liquid by cooling it to negative 260 degrees Fahrenheit through a liquefaction process. Because it must be kept at cold temperatures, LNG is stored in a double-walled, vacuum-insulated stainless steel tank. The storage of the fuel as a liquid increases the energy density of the fuel allowing more energy to be stored onboard a vehicle. An LNG fuel system can work well for heavy duty vehicles that require more fuel for longer operating range.

Natural gas engine technology is described in more detail in the Lower NO<sub>x</sub> Heavy-Duty Natural Gas and Other Alternative Fuel Engines Technology Assessment document. A brief description of natural gas engine technology is provided below.

The natural gas engine primarily used in CHE is spark ignited, using stoichiometric combustion with cooled gas exhaust recirculation (EGR) and a three-way catalyst (TWC). The cooled-EGR system takes a measured quantity of exhaust gas and passes it through a cooler to reduce temperatures before mixing it with fuel and the incoming air charge to the cylinder. Stoichiometric combustion in combination with cooled-EGR results in both increased power density and thermal efficiency. It also reduces in-cylinder combustion temperatures and creates an oxygen-free exhaust, which then enables the use of a TWC for NO<sub>x</sub> control. A TWC is a simple, passive device that reduces hydrocarbons (HC), carbon monoxide (CO) and NO<sub>x</sub>. TWC is largely maintenance-free and provides consistent performance across all duty cycles. The current natural gas engines meet current U.S. EPA and ARB emission standards, as well as 2014 U.S. EPA and U.S. Department of Transportation fuel economy and GHG regulations (Cummins Westport, 2014a).

These natural gas engines are most frequently used to power on-road trucks and buses as well as refuse haulers with some applications in sweepers. Consequently, yard truck is the most easily transferable CHE application but other equipment types with similar power requirements and duty cycles are also possible applications. These could include other container handling equipment such as top and side handlers, reach stackers, AGVs, and some shuttle and straddle carriers. Some smaller bulk handling equipment might also be possible applications.

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<sup>1</sup> Section 2292.5 of title 13, CCR, article 3, chapter 5, specifies a minimum CH<sub>4</sub> content of 88 percent by mole for natural gas used as an alternative motor vehicle fuel.

### *Operational/Infrastructure Needs*

Use of natural gas technology requires natural gas fueling infrastructure. CNG is delivered through the pipeline system, while LNG is normally delivered by truck to the fueling station. There are two types of CNG stations: fast-fill and time-fill. The basic fueling system components include dryer, compressor, and dispenser. Other components, such as storage, valves, temperature compensation systems, and multiple single hose fueling posts may be used depending on the CNG station design. LNG requires significant infrastructure investment along the supply chain including liquefaction facilities, LNG distribution trucks, and LNG stations. After the fuel is delivered to the fleet facility, it is stored in cryogenic tanks and pumped into vehicles in much the same way as other liquid fuels. LNG stations are structurally similar to gasoline and diesel fuel stations (DOE, 2014c).

According to the Department of Energy Alternative Fuels and Advance Vehicles Data Center (AFDC) in 2014, there are 752 public CNG stations and 62 public LNG stations in the United States. The world's largest natural gas truck fueling station was open for business on a site adjacent to the Ports of Long Beach and Los Angeles in 2009. This public access station was configured to fuel trucks on a 24/7 basis, features two 25,000-gallon LNG storage tanks, six LNG dispensers, and two CNG dispensers.

### *Technology Readiness*

The Cummins Westport ISL G natural gas engine is currently the most prevalently used on-road natural gas engine for medium duty applications in California. The ISL G engine is used mainly for on-road applications, such as trucks and school buses. The horsepower range for this engine is 250 to 320 hp. Within the CHE sector, yard trucks are the application in which natural gas is primarily being used. Two yard truck manufacturers are supplying yard trucks equipped with the ISL G engines, but only a small number of yard trucks have been sold in the market. Cummins Westport is working on an ISB G engine, which has a lower horsepower range compared to the ISL G engine, and is more applicable for the off-road yard truck application. Per Cummins Westport, ISB G engines will be comparable to the previously available B Gas Plus engine, but with improved performance. The B Gas Plus engine horsepower range is 195 to 230 hp. The ISB G engine is expected to be released in 2016. While the operation parameters for ISB G engine are not fully defined yet, more information on ISB G should be available by mid-2015 (Cummins Westport, 2014b). Table III-7 below summarizes the status of CHE either commercially available or being developed for natural gas fueling.

**Table III-7: Summary of Commercially Available and Developing Natural Gas Equipment for Use as Cargo Handling Equipment**

Equipment Type	Power Type	Number of Models	Status	
			Commercially Available	Under Development
Yard Truck Engine	Natural Gas	2	1	1

The natural gas yard truck has several benefits associated with economics and environment, including lower emissions than gasoline and diesel engines, lower engine noise than diesel engines, and simple after-treatment compared to diesel engines. In addition, most of the natural gas used in California is produced within the U.S.

The disadvantages associated with natural gas technology are primarily attributable to the relative immaturity of the technology for off-road application and the lack of natural gas infrastructure. Additionally, the on-board storage requirements of CNG or LNG are much greater than those for refined petroleum products, which increase vehicle weight and tend to reduce fuel economy. In addition, natural gas leaks would need to be guarded against due to possible explosions or fire, in addition to the climate impacts of methane leaks.

#### Cost

A CNG or LNG-fueled yard truck costs from \$30 to \$40 thousand more than a diesel-fueled yard truck with either an on-road or Tier4f off-road engine. And, while natural gas is less expensive per BTU than diesel, the less optimally sized ISL G engine does not currently provide the fuel economy to take full advantage of the less expensive fuel. The fuel efficiency for the ISL G engine is 10 to 15 percent lower than for a yard truck with a similarly sized diesel engine (Cummins Westport, 2014c). Additionally, since most diesel yard trucks would be equipped with the smaller displacement ISB engine, the fuel efficiency comparison suffers more. The ISB engine size is more compatible with typical yard truck power requirements. However, with the introduction of the ISB G engine in 2016, we would anticipate that this smaller, more optimally sized, natural gas engine will provide improved fuel efficiency as compared to the currently available ISL G engine. This more optimally sized engine could provide additional fuel cost benefits currently not being realized to due to the ISL G engine's higher power rating.

The cost of installing natural gas infrastructure varies depending on size, capacity, the type of natural gas, and the way the natural gas is dispensed (fast fill, or time-fill). According to U.S. Department of Energy, costs for installing a CNG fueling station can range up to \$2 million depending on the size and application. Smaller CNG fueling units average \$10,000, including installation. The capital cost of an LNG fueling site can range from \$1 to \$4 million.

### *Estimate of Emissions Reductions*

The currently available Cummins Westport ISL G natural gas engine was designed for on-road applications. The ARB executive order shows that both PM and NO<sub>x</sub> emissions of the ISL G engine are below the 2010 PM and NO<sub>x</sub> standards. A Cummins' well-to-wheels (WTW) analysis estimated up to a 20 percent WTW GHG emissions benefit for natural gas over diesel fuel (Cummins Westport, 2014d).

### *Next Steps*

Staff recommends supporting the funding of the evaluation and comparison of in-use performance, emissions, and fuel efficiency of a LNG yard truck, equipped with a ISB G engine (when available), with a diesel-fueled yard truck with an on-road engine certified to the 2010 U.S. EPA on-road emission standards. Additionally, staff recommends incentivizing the development of natural gas infrastructure at port and rail terminal facilities. This could potentially be tied in with LNG infrastructure for OGVs.

#### D. Magnetic Levitation Technologies

Magnetic levitation technologies (maglev) are another advanced technology that has possible application as a CHE energy efficiency improvement strategy. This section will provide information on different maglev technologies.

### *Technology Description*

There are three types of maglev technology, electromagnetic suspension (EMS), electrodynamic suspension (EDS), and fixed magnet technology. EMS technology was developed in Germany and uses servo-controlled electromagnets. EDS technology was developed in Japan and uses superconducting magnets. Fixed magnet technology was developed in the United States and uses permanently fixed magnets (LEVX, 2014a).

#### Electromagnetic Suspension (EMS)

In an EMS system, the electromagnets are attached to the undercarriage of the transport system and directed upwards towards the guide way (Presson, 2002). There is one set of magnets to elevate the transport system and another to propel it forward. These magnets are arranged in C-shaped arms that wrap around the track (Schmidt/Carroll, 2014).

#### Electrodynamic Suspension (EDS)

An EDS system uses super-cooled superconductor electromagnets (Presson, 2002). The use of superconductors creates an additional expense, but the super-cool environment reduces resistance in the wiring. The reduced resistance means that a smaller, lighter generator is required than with wiring operating at ambient temperatures (UNC, 2005).



## Fixed Magnet Technology

Fixed magnet technology uses an array of permanently fixed magnets whose magnetic fields create a magnetic repulsion that naturally occurs between like poles of permanent magnets. Propulsion forces are generated using an eddy current drive which involves a vehicle-mounted rotating magnetic disc that interacts with a guideway mounted aluminum linear rail to produce the driving force (IEEE, 2000) (LEVX, 2014b).

The primary advantages maglev technology has over conventional rail include increased energy efficiency due to reduced friction, reduced noise, higher top speeds, and lower maintenance (ODEC, 2004). The primary disadvantage of maglev technology is the significant infrastructure cost (MLM, 2014).

### *System/Network Suitability and Operational/Infrastructure Needs*

Maglev technology is suitable in situations where there is a long term, fixed route application. Moving containers at terminals from storage rows to on-dock rail operations may be one such application.

Required infrastructure is the fixed magnetic track. Permanent magnet technology does not require an energy source for the track.

### *Technology Readiness*

There are several examples of commercial applications of maglev technology in operation. These include a maglev passenger train in Shanghai operating over an approximately 19 mile route from an airport to a subway station (NAMTI, 2005). In Korea, there is a maglev train carrying passengers four miles from the Incheon airport to Yongyu (GT, 2014). In the United States, Magna Force (LEVX) has developed a demonstration track at their Port Angeles, Washington test site (LEVX, 2014b) and the U.S. Department of Transportation partnered with Old Dominion University (ODU) to develop a successful maglev demonstration project at ODU (DOT, 2013).

While the existing commercial maglev systems in operation are primarily for passenger transportation, there are also multiple projects in different stages of planning that would include freight movement. There is a multi-modal transportation project in the Seattle, Washington area for light freight and passengers, (LEVX, 2014c) as well as proposals for dedicated freight transportation systems in both South Carolina and Mexico being developed with the capability of transporting up to 960 TEU's per hour (LEVX, 2014d) (LEVX, 2014e). Additionally, there is an Israeli system to demonstrate passenger transport capabilities (skyTran, 2014).

## Cost

Costs of maglev systems depend on the type of maglev technology used to levitate the train and the location of the project. The permanent magnet method is the least expensive system.

Maglev technologies require the construction of new track infrastructure. Cost for an 850 foot permanent magnet technology test track in Port Angeles, Washington was estimated to be \$5 million per lane-mile (LEVX, 2014f). The maintenance costs of a maglev system are lower than the maintenance costs for a conventional rail system (NHMFL, 2014) (MLM, 2014).

The 20-mile Shanghai passenger maglev train, using EMS technology which requires electrical infrastructure for the electro magnetism, cost approximately \$60 million per mile to construct (NAMTI, 2005). Other estimates for the costs per mile to construct a maglev train system in China are approximately \$40 million per mile for EMS technology (NHMFL, 2014). Another estimate of costs to construct a maglev system is approximately \$85 million per mile for a 100-mile permanent magnet system connecting POLA and POLB with inland distribution hubs. These costs are approaching the per mile cost for urban area freeway construction (LA Times, 2006) (GA, 2014).

### *Estimate of Emissions Reductions with Technology*

The emissions reductions of GHGs and criteria pollutants for a permanent magnet system are estimated to be approximately 95 percent due to reduced friction between the train and the rails and the use of either linear synchronous motors or eddy current drives.

### *Next Steps/Staff Recommendations*

Staff recommends a technical evaluation to quantify the cost/benefit characteristics of the permanent magnet maglev technology in a port or rail application.

#### E. Lower Emission Diesel Engine

The lower emission off-road diesel engine technology, also known as the “Tier 5” engine, would meet more stringent emissions standards than the current U.S. EPA Tier 4f off-road engine standards.

The engineering and technology needed to achieve additional emissions reductions from diesel-fueled on-road engines is in the research stage. ARB is partnering with SouthWest Research Institute to test diesel engine efficiency strategies for on-road engine applications. The strategies that will be tested have not been finalized, but may include:

- Variable valve actuation (VVA),
- Advanced exhaust gas recirculation (EGR),
- Engine friction reduction,
- Alternative combustion cycles, and

- Improved exhaust heat recovery.

ARB staff anticipates the transfer of technology to off-road engines to follow within three to five years of being adopted for on-road applications. A target NO<sub>x</sub> emissions standard of 0.02 grams per brake horsepower-hour is the current goal of the ARB/SouthWest Research Institute joint effort.

Further discussion of this topic is provided in the Lower NO<sub>x</sub> Heavy-Duty Diesel Engines Technology Assessment document.

#### F. Automated Container Handling Operations

Automation of port terminal and intermodal rail yard container handling operations, particularly for containerized freight, is an energy efficiency strategy that has been discussed since containerized shipping was introduced as a shipping efficiency measure in the mid-1950s (WSC, 2014). The advent of technologically advanced CHE and container tracking and movement management software has made the terminal efficiency benefits of terminal automation even greater.

##### *Technology Description*

Terminal automation involves replacing manually-operated diesel-fueled CHE with automatically controlled electric or diesel-electric hybrid CHE using sophisticated software designed to more efficiently move freight from ship to drayage truck pick-up.

More detailed descriptions of specific automated terminals are provided in the Technology Readiness section below.

##### *System/Network Suitability and Operational/Infrastructure Needs*

As discussed above, terminal automation is a viable alternative to the current operations at California's container terminals. There are a number of operational and infrastructure needs that must be addressed for both terminal automation and electrification. These include:

- Electrical infrastructure (i.e., additional substations, switchgear, transformers, and power),
- Concrete foundations and pavement,
- Sensing device matrix embedded in the yard for guiding AGVs,
- Busbars or channels for power reel cables to deliver electricity to electrified cranes,
- Software to coordinate and monitor CHE activity as well as organize and coordinate the location and distribution of good being handled, and
- Underground conduit for telecommunication, fiber optics (POLA, 2013a).

### Technology Readiness

In 1993, the ECT terminal at the Port of Rotterdam utilized AGVs and automated stacking cranes (ASCs) together for the first time. This is considered the birth of terminal automation (ECT, 2014). There are now five semi-automated or fully automated terminals in Europe and six semi-automated or fully automated terminals in Asia and Australia (AECOM, 2012). In addition, there is a fully-automated terminal being planned for the Victoria International Container Terminal at the Port of Melbourne (NASDAQ, 2014). There are currently two semi-automated terminals in the United States, Virginia International Gateway in Portsmouth, Virginia and Global Container Terminal NY/NJ in Bayonne, New Jersey (VIG, 2014) (NJ, 2014).

In California, two Southern California port terminals are in the process of implementing automation. The Long Beach Container Terminal (LBCT) is in the process of becoming a fully automated terminal and TraPac at the Port of Los Angeles is in the process of becoming a semi-automated terminal.

Specific information about the four semi-automated or fully automated terminals in the U.S. is provided in Table III-8 below.

**Table III-8: U.S. Automated Terminals**

Terminal Characteristic	Terminal			
	Virginia International Gateway	Global Container Terminals, NY/NJ	Long Beach Container Terminal	TraPac
Level of Automation	Semi-automated	Semi-automated	Fully automated	Semi-automated
Facility Acreage	230	100	300	100
Annual Container Throughput Capacity	1.1 million TEUs	-	3+ million TEUs	1 million TEUs
Ship-to-shore Cranes	8 electric	6 electric	14 electric	12 electric
Straddle/Shuttle Carriers	27 shuttle (diesel-electric hybrid)	-	-	25-30 straddle (diesel-electric hybrid)
Automated Guided Vehicles (AGVs)	-	-	70	-
Rail-mounted Gantry Cranes (RMGs)	30	20	70	38
On-dock Rail Available?	Yes	-	Yes	Yes

Terminal Characteristic	Terminal			
	Virginia International Gateway	Global Container Terminals, NY/NJ	Long Beach Container Terminal	TraPac
On-dock Rail Cranes	4 RMGs	-	5 RMGs	2-3 double cantilevered electric cranes
Yard Trucks	Used to move containers to on-dock rail	-	Used to move containers to on-dock rail	-
How is drayage truck congestion managed?	-	-	Scheduled truck visits	No truck scheduling
Status	In operation	In operation	Under construction	Under construction

Additional information about the California terminals currently implementing automation, LBCT at POLB and TraPac Terminal at POLA, is provided below.

LBCT (Middle Harbor Project)

The LBCT Middle Harbor Project at POLB includes modernizing and reconfiguring two existing terminals into one fully automated terminal (POLB, 2010). This will become the first fully-automated terminal in the United States. This project took the original terminals down to bare ground, added acreage, and is in the process of installing infrastructure to support a fully-automated/fully-electric terminal. The LBCT Middle Harbor project will increase the total terminal capacity to 3.3 MTEU at a cost of approximately \$1.2 billion for construction. Modernization costs are split between the land owner (City of Long Beach) and tenant (LBCT) with the land owner providing the infrastructure improvements and the tenant providing the equipment. LBCT has entered into a 40 year lease of the property from the City of Long Beach at a cost of \$4.6 billion. It is estimated that, upon completion, the project will have 50 percent lower emissions than the original terminals, in spite of the doubled through-put. This is accomplished by both increasing efficiency with automated container tracking, organization, and scheduled drayage pick-up, and all-electric operation from ship to drayage. The high level of automation and the removal of personnel from high traffic areas will also greatly increase worker safety.

The only diesel-fueled equipment operating at the terminal will be the 2014 model year clean-diesel yard trucks that will transport containers from the drayage pick-up area to the on-dock rail facility. There is an expanded on-dock rail facility which allows a shift of more than 30 percent of the cargo shipments from trucks to rail. Shore power infrastructure is also provided at the dock (Middle Harbor, 2014) (ARB, 2014).

The project includes:

- All-electric AGVs,
- AGV automatic battery swapping and charging infrastructure,
- Automated all-electric RMGs,
- Improved on-dock rail,
- Updated electrical system (including new substations, transformers, conduit, wiring, etc.),
- Installing reinforced concrete foundations for AGV and RMG operations and rail,
- New gates and scheduled container pick-up,
- New transport refrigeration unit or reefer racks with electrical plug-ins, and
- Computerized container tracking (POLB, 2010).

### TraPac

TraPac is in the process of modernizing and semi-automating their container terminal at Berths 136 – 147 at POLA. The renovation will include diesel-electric hybrid automated stacking cranes and semi-automated RMG cranes. The project includes:

- Semi-automated RMGs,
- Terminal access improvements,
- Improving on-dock rail access,
- Updating the electrical system (including new substations, transformers, conduit, wiring, etc.),
- Updating the storm drain system,
- Installing reinforced concrete foundations for rail and buildings,
- New gates and security fencing,
- New reefer racks,
- Prefabricated walkways, and
- Computerized container tracking (POLA, 2013a) (Futureports, 2007).

### Rail Yard Modernization

UP is planning on modernizing their Intermodal Container Transfer Facility (ICTF). The modernization will include replacing 10 diesel-fueled RTGs with 39 electrified wide span gantry (WSG) cranes. Additionally, they plan on eliminating all on-site diesel fueling. The two remaining on-site yard trucks will be powered by either biodiesel, propane, or LNG. ICTF serves both POLA and POLB (ICTF-JPA, 2015).

BNSF is currently working with POLA to develop the Southern California International Gateway (SCIG) project. SCIG will be a new intermodal rail yard utilizing up to 20 electrified RMGs which will employ regenerative braking (POLA 2013b).

## Cost

Based on the two port terminals currently being automated in California, the infrastructure and equipment costs can be from \$ 0.5 to over \$1 billion depending on the size of the terminal and the degree of automation being implemented.

POLA and POLB, as the landowners/landlords, are paying for the infrastructure improvements associated with the terminal upgrades. POLA estimates their infrastructure costs to automate the TraPac terminal to be approximately \$450 million (POLA, 2013a). POLB estimates their infrastructure costs to automate the LBCT Middle Harbor Project to be approximately \$1.2 billion (Seaport, 2013).

The terminals are purchasing the automated equipment and the associated software and computer hardware. The equipment costs associated with that equipment varies with the level of automation being implemented at the terminal. There are a variety of equipment type “mixes” that terminals can use to move containers from ship-to-drayage truck.

The equipment types used in most non-automated terminal operations include RTGs, reach stackers, and yard trucks. The types of equipment used at an automated terminal generally include ASCs, AGVs, and RMGs. A study by the Seaport Group evaluated the terminal operating costs (per container costs) associated with several different equipment “mixes.” They found that an automated equipment mix of ASCs and AGVs results in an estimated cost reduction of approximately 25 percent less per container as compared to a manually-operated equipment mix of RTGs, reach stackers, and yard trucks. The same study found that while manually operated cantilever RMGs and yard trucks are a more efficient combination than the RTGs, reach stackers, and yard trucks, using an automated equipment mix of ASCs and AGVs still reduce per container costs by approximately 13 percent. This study included capitals costs (equipment and computer, assuming 10 percent discount rate), labor, energy, equipment maintenance, and supplies (Seaport, 2013). Reduced labor costs are a significant contributor to the cost reductions associated with automated operation. However negotiations between the International Longshore and Warehouse Union (ILWU) and the terminals will impact the actual labor reductions that occur. Additionally, this should be considered in concert with understanding that the automation of other competing ports could result in loss of business at non-automated California ports which would result in substantial regional job loss (POLA, 2014b).

The above analysis provides a more accurate picture than looking at capital costs alone, such as comparing yard trucks and AGVs. A yard trucks certified to meet the most current U.S. EPA on-road or off-road engine emissions standards (Tier 4f for off-road engines) cost approximately \$125,000. In comparison, an AGV can cost anywhere from 45 percent less to eight times more than a yard truck depending on the propulsion and automation features (INC, 2014). Similarly, automated RMGs can be from one and a half to three times more expensive than a diesel-fueled RTG (Konecranes, 2014b).

Another primary benefit of automation is the increased hourly container throughput. Semi-automated Global Container Terminal, which recently automated its operations, saw

an initial increase of 20 percent in hourly container moves and was projecting an increase of up to 30 percent under optimal conditions (NJ, 2014).

The Seaport Group study also evaluated the impacts of automation on safety. The study found that automated equipment provides for a separation of terminal personnel from the various equipment activities associated with ship-to-drayage truck container movements (Seaport, 2013). Removing terminal personnel from the container movement activities should significantly improve the operational safety. Automation also significantly reduces the chance of human error impacting the container movements. The biggest cost savings associated with automation involves the reduction in labor costs (Seaport, 2013).

#### *Estimation of Emissions Reductions with Technology*

The estimated emissions reductions associated with the automation of cargo handling operations depend on the level of automation and electrification accomplished. There will be zero on-site emissions of GHGs and criteria pollutant emissions at fully electric automated terminals. However there would be increases in GHGs and criteria pollutants for the additional electricity from power generation unless it is produced by renewable sources. Semi-automated terminals will have some diesel PM and NO<sub>x</sub> emissions from diesel-fueled or diesel-hybrid equipment. However, overall there would be a significant reduction in emissions of GHGs and criteria pollutants compared to a traditional container handling system. The magnitude of the reductions would depend on the size of the terminal, the annual container throughputs, and the level of automation implemented.

#### *Next Steps/Staff Recommendations*

Implementing automated electrified technology at California's ports and intermodal rail yards represents the most promising approach for reducing local criteria pollution from CHE to zero or near-zero levels. Staff recommends supporting the transition to automated electrified CHE at container terminals and intermodal rail yards by incentivizing the installation of terminal infrastructure, the development of reliable electrical supply infrastructure, and the purchase of automated equipment.

#### G. Engine Maintenance/Reduced Deterioration

Maintaining engines within OEM-specified operational parameters is an effective emissions and energy efficiency strategy. This strategy does not actually provide additional emissions benefits over new diesel engines, but it does reduce or eliminate the emissions increases associated with engine operation degradation (DoE, 2010).

#### *Technology Description*

Normal engine wear, or engine tampering, can introduce engine misoperation that impacts the emissions of NO<sub>x</sub> and diesel PM (DieselNet, 2007). Engine misoperations that are commonly found include:

- Restricted air flow (dirty air filters, etc.),



- Fouled or leaky injectors,
- Engine valve timing changes,
- Turbocharger damage or worn seals, and
- Aftertreatment control device blockage or damage (McCormick, 2003).

Most of these issues can be addressed through the implementation of a regular maintenance schedule. Regular maintenance can result in an energy efficiency savings of up to 20 percent (DOE, 2010). Actual energy efficiency improvements will depend on the age of the engine and the degree of engine degradation (ESMAP, 2011).

### *System/Network Sustainability and Operational/Infrastructure Needs*

Engine maintenance programs are an integral part of maintaining efficient engine performance. Operational needs for a successful engine maintenance program include:

- Assembling a team focused on implementing a cohesive engine maintenance strategy,
- Developing an engine maintenance audit program, and
- Implementing a strategy for improving engine maintenance practices (DEEP, 2000).

The 2011 amendments to the CHE regulation included requirements for annual opacity monitoring to detect engine misoperation. The maximum opacity limits for certified engines are a function of the PM standard to which the engine was certified. These limit values are based on a correlation of exhaust opacity with diesel PM emissions levels developed by ARB staff for off-road engines. The maximum limit for unregulated engines is set at 55 percent opacity, similar to that for unregulated on-road engines. Engine-out exhaust opacity of retrofitted engines must comply with the opacity limit required for the installed VDECS. This will help prevent VDECS failures. This program is similar to ARB's heavy-duty diesel-fueled vehicle opacity inspection program and requires engines with excessive exhaust opacity be serviced or repaired.

While ARB is waiting for U.S. EPA authority to enforce this requirement, we understand that most California terminals are already implementing this program.

### *Technology Readiness*

The CHE opacity monitoring program has been implemented using existing technology. Opacity reading meters have been used to conduct on-road heavy-duty diesel-fueled vehicle roadside opacity tests since 1988. The technology is proven and readily available.

### *Cost*

The capital costs of implementing an opacity monitoring program include the price of the opacity reading meters (between \$5,500 and \$9,000) and training costs of approximately \$1,800, which includes the costs of the class and labor time. On-going costs include

annual engine exhaust opacity testing and recordkeeping of approximately \$50 per engine tested. As an alternative, an equipment owner/operator can hire a consultant to monitor and record the engine exhaust opacity for approximately \$60 per engine.

#### *Estimate of Emissions Reductions with Technology*

Emissions reductions associated with effective engine maintenance programs depend on the engine technology and the comprehensiveness of the maintenance program improvements. Since the emissions improvements associated with engine maintenance programs reflect a return to OEM recommended emissions levels, there are no measurable emissions savings. However, regular engine maintenance reduces excess emissions and maximizes fuel efficiency (DEEP, 2000).

#### *Next Steps/Staff Recommendations*

Staff recommends identifying approaches to ensure that all CHE owners/operators have comprehensive engine maintenance programs. Additionally, staff recommends conducting a study utilizing the opacity testing data associated with the CHE regulation to quantify the improvements in engine exhaust characteristics associated with improved engine maintenance programs.

#### **IV. SUMMARY OF TECHNOLOGY ASSESSMENT AND NEXT STEPS TO DEPLOYING ADVANCED TECHNOLOGIES**

From 2006 to 2014, CHE diesel PM emissions at California ports and intermodal rail yards have been reduced by 85 percent and NO<sub>x</sub> emissions by 68 percent. These reductions have been achieved as a result of intensive capital investments in clean diesel-fueled equipment by terminal and rail operators. CHE at California ports and rail yards employs the cleanest diesel-fueled technology available due to compliance with the CHE regulation. The ports and rail yards operators were required to comply with the CHE regulation throughout the recent economic recession and are only recently recovering. Consequently, further emission reductions require technologies that provide improved efficiency and economic, as well as air quality, benefits for the freight facilities and the people who work there.

Of all the freight sectors being evaluated for ARB's sustainable freight program, CHE is the one with the highest potential for inclusion of advanced technologies. The total population of equipment is low and CHE fleets are captive. The types of applicable technologies that can be used to power zero and near-zero emissions equipment is available and those technologies are either commercially available or being demonstrated in a variety of CHE.

The implementation of electrified automated systems for container terminals are the most promising for achieving a high-efficiency zero-emission freight system. While the automation of cargo handling operations using electrified equipment is seen as the ultimate goal for container handling terminals, interim benefits could be achieved by the development and deployment of electric and hybrid non-automated equipment including yard trucks and container handler equipment, such as top picks and reach stackers. Hybrid cranes and straddle carriers are in use, but the development of other hybrid container handling equipment is not as mature. These development efforts include the development of both electric and hybrid yard trucks, which have been progressing for over five years with demonstrations of electric models continuing. Recommended next steps would be to support and incentivize both the demonstration and purchase of electric, fuel cell, and hybrid container handling equipment. Additionally, ARB should support and incentivize the installation of the necessary terminal infrastructure as well as the development of reliable electrical supply infrastructure necessary for the automation and electrification of cargo handling operations at container terminals. Fuel cell prime power and backup generation should be evaluated as possible options for these freight facilities.

For bulk handling terminals, the development and implementation of hybrid and electric bulk handling equipment are the most promising. While hybrid vehicles have been fully deployed in the light duty vehicle market, as well as for a number of container applications, such as gantry cranes, hybridization is still an emerging technology in the off-road bulk equipment arena. There are a number of hybrid off-road bulk handling equipment that have become commercially available in the last few years. Operators using these new hybrids, primarily in the construction and mining industries, attest to the

fuel savings provided by the hybrid technology. These fuel savings equate to real GHG emission reductions. However the criteria pollutant reductions, specifically NO<sub>x</sub>, are less certain for these newly developed bulk equipment. Next steps for encouraging the deployment of hybrid technology at bulk handling terminals include support through incentivizing hybrid equipment demonstrations at these facilities. Demonstrations should include in-use performance and emissions testing to quantify the emission benefits of the different technologies in specific applications in comparison to conventional clean diesel technology.

Staff recommends that the cost-effectiveness of using natural gas as a pathway to NO<sub>x</sub> reduction at ports and rail yards be evaluated. Additionally, as battery-electric CHE is developed and demonstrated, a cost/benefit analysis of using fuel cells as the power source should be made for these CHE.

The main challenges to deploying zero and near-zero emission technologies at California ports and intermodal rail yards include assuring adequate investment recovery time associated with actions taken to comply with current CHE regulation, the availability of cost-effective next generation technologies, and adequately demonstrating that alternative technology will provide the same reliability and shift to shift turn around that diesel fueled equipment has provided. The successful deployment of advanced technologies for the CHE sector will depend on:

- The technology providing an economic or competitive advantage over current technologies, as well as the technology demonstrating:
  - Reliability and durability that's comparable with diesel-fueled technology,
  - Ability to operate an entire shift without down time, and
  - Quick shift-to-shift recharge/refuel/battery exchange times.
- The availability of incentive funding and reliable infrastructure to promote the use of these technologies.

CHE is also used at other locations throughout California, primarily warehouse distribution centers. Equipment at non-port, non-intermodal rail yard locations is not subject to the CHE regulation. However, much of the equipment used at warehouse distribution centers operates indoors, which precludes the use of diesel for this equipment. The equipment used indoors are primarily electric, fuel cell electric, with some propane-fueled. Outdoor equipment at these facilities may be either propane or diesel-fueled. Currently, a statewide inventory of CHE at warehouse distributions centers (numbers and types of equipment) does not exist. Developing a warehouse distribution center CHE inventory is essential to evaluating the need for and possible benefits from emissions reduction strategies at these facilities.

In conclusion, staff recommends supporting and incentivizing the installation of the necessary terminal infrastructure as well as the development of reliable electrical supply infrastructure necessary for the automation and electrification of container terminals. Staff further recommends supporting incentivizes for both the demonstration and purchase of electric, fuel cell, and hybrid container and bulk handling equipment. Demonstrations should include in-use performance and durability and emissions testing

to quantify the emission benefits of the different technologies in comparison with clean diesel-fueled equipment.

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## V. REFERENCES (By Section)

### **Executive Summary**

(ARB, 2006) California Air Resources Board, *Diesel Particulate Matter Exposure Assessment Study for the Ports of Los Angeles and Long Beach, Final Report*, April 2006.

<http://www.arb.ca.gov/ports/marinevess/documents/portstudy0406.pdf>

(ARB, 2011) California Air Resources Board, *Amendments to the Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards, Initial Statement of Reasons*, August, 2011.

<http://www.arb.ca.gov/regact/2011/cargo11/cargoisor.pdf>

(Konecranes, 2014a) Port of Helsingborg endorses the world's first hybrid Konecranes reach stacker, <http://www.konecranes.com/resources/media/releases/2014/port-of-helsingborg-endorses-the-worlds-first-hybrid-konecranes-reach-stacker> , Konecranes, May, 2014.

(NJ, 2014) NJ.com, *Global's Automated Terminal Offers a Window Into Shipping's Future*, 2014.

[http://www.nj.com/business/index.ssf/2014/06/globals\\_automated\\_terminal\\_offers\\_a\\_window\\_into\\_the\\_shippings\\_future.html](http://www.nj.com/business/index.ssf/2014/06/globals_automated_terminal_offers_a_window_into_the_shippings_future.html)

(Seaport, 2013) Seaport Group, *Financial Implications of Container Terminal Automation*, August, 2013.

[http://www.seaport.com/files/8413/7643/5363/News\\_Q32013.pdf](http://www.seaport.com/files/8413/7643/5363/News_Q32013.pdf)

### **Section I – Introduction and Purpose of Assessment**

(ARB, 1998) California Air Resources Board, *Report to the Air Resources Board on the Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant; Part A, Exposure Assessment*, As Approved by the Scientific Review Panel on April 22, 1998.

[http://www.arb.ca.gov/toxics/dieseltac/part\\_a.pdf](http://www.arb.ca.gov/toxics/dieseltac/part_a.pdf)

(ARB, 2005a) California Air Resources Board, *Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards*, December, 2005.

<http://www.arb.ca.gov/regact/cargo2005/cargo2005.htm> .

(ARB, 2006) California Air Resources Board, *Diesel Particulate Matter Exposure Assessment Study for the Ports of Los Angeles and Long Beach, Final Report*, April 2006.

<http://www.arb.ca.gov/ports/marinevess/documents/portstudy0406.pdf>

## **Section II – Overview of Cargo Handling Equipment**

(ARB, 2005a) California Air Resources Board, *Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards*, December, 2005.

<http://www.arb.ca.gov/regact/cargo2005/cargo2005.htm> .

(ARB, 2008a) California Air Resources Board, *Regulation for New 2001 and Later Off-road Large Spark-ignition Engines (25 and Greater Horsepower)*, November, 2008.

<http://www.arb.ca.gov/msprog/offroad/lsi/lsictp/lsictp.htm#reg>

(ARB, 2011a) California Air Resources Board, *Amendments to the Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards*, September, 2011.

<http://www.arb.ca.gov/regact/2011/cargo11/cargoisor.pdf>

(ARB, 2011b) California Air Resources Board, *Regulation for In-Use Off-Road Diesel-Fueled Fleets*; December 2011.

<http://www.arb.ca.gov/msprog/ordiesel/reglanguage.htm>

(Forklift Center, 2013a) Forklift Center, *How to Choose Between Solid Rubber, Pneumatic, and Poly Urethane Forklift Tires*, 2013.

<http://www.theforkliftcenter.com/guide/choosing-a-forklift-tire-type.php>

(Forklift Center, 2013b) Forklift Center, *Advantages of Electric Forklifts (with a few drawbacks too)*, 2013.

<http://www.theforkliftcenter.com/guide/advantages-of-electric-forklifts.php>

(Hyster, 2014) Adapталift Hyster, *What is a Walkie-Stacker? Basic Types and Guidelines*, 2014.

<http://www.aalhysterforklifts.com.au/index.php/about/blog-post/what-is-a-walkie-stacker-basic-types-application-guidelines>

(Kern Council of Governments, 2014) Kern Council of Governments, *Kern's Freight and the Regional Transportation Plan*, July 1, 2014.

(MarketWatch, 2014) Market Watch, *Global and China Forklift Industry Report, 2013*, January, 2014.

<http://www.marketwatch.com/story/global-and-china-forklift-industry-report-2013-2014-01-09>

(OSHA, 2011) U.S. Department of Labor, Occupational Safety and Health Administration, *OSHA Fact Sheet – Aerial Lifts*, 2011.

<https://www.osha.gov/Publications/aerial-lifts-factsheet.pdf>

(Symbolic, 2014) *The Evolution of Warehouse Automation*, accessed October 2014

<http://www.symbolic.com/evolution-robotic-warehousing/>

### **Section III – Assessment of Potential Technologies**

(AAPA, 2007), American Association of Port Authorities, *Use of Shore-power for Ocean-going Vessels White Paper*, May 2007.

[http://wpci.iaphworldports.org/data/docs/onshore-power-supply/library/1264151248\\_2007aapauseofshore-sidepowerforocean-goingvessels.pdf](http://wpci.iaphworldports.org/data/docs/onshore-power-supply/library/1264151248_2007aapauseofshore-sidepowerforocean-goingvessels.pdf)

(AECOM, 2012) AECOM, *Port of Los Angeles Automated Container Terminal Survey*, May, 2012.

<http://www.portoflosangeles.org/Board/2012/May%202012/POLA-Automation-Survey-Draft.pdf>

(Air Products, 2013) Air Products, *Steam methane reformer overview*,

<http://www.airproducts.com/~media/Files/PDF/industries/energy-hydrogen-steam-methane-reformer-datasheet.pdf>

(American Shipper, 2015) American Shipper, *Savannah sets new container record in April*, May 18, 2015.

[http://www.americanshipper.com/Main/ASD/Savannah\\_sets\\_new\\_container\\_record\\_in\\_April\\_60308.aspx](http://www.americanshipper.com/Main/ASD/Savannah_sets_new_container_record_in_April_60308.aspx)

(ARB, 2008b) Air Resource Board, *Air Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-going Vessels at Berth in a California Port*, December, 2008.

<http://www.arb.ca.gov/regact/2007/shorepwr07/93118-t17.pdf>

(ARB, 2009) California Air Resources Board, *Detailed California Modified GREET Pathway for Compressed Gaseous Hydrogen from North American Natural Gas*, February, 2009.

[http://www.arb.ca.gov/fuels/lcfs/022709lcfs\\_h2.pdf](http://www.arb.ca.gov/fuels/lcfs/022709lcfs_h2.pdf)

(ARB, 2011c) California Air Resources Board, *Supplement to the June 2010 Staff Report on Proposed Actions to Further Reduce Diesel Particulate Matter at High-Priority California Railyards*, July, 2011.

[http://www.ci.benicia.ca.us/vertical/sites/%7B3436CBED-6A58-4FEF-BFDF-5F9331215932%7D/uploads/NRDC\\_Reference\\_Material\\_Volume\\_2.pdf](http://www.ci.benicia.ca.us/vertical/sites/%7B3436CBED-6A58-4FEF-BFDF-5F9331215932%7D/uploads/NRDC_Reference_Material_Volume_2.pdf)

(ARB, 2012) California Air Resources Board, *LCFS Lookup Tables as of December 2012*, 2012. [http://www.arb.ca.gov/fuels/lcfs/lu\\_tables\\_11282012.pdf](http://www.arb.ca.gov/fuels/lcfs/lu_tables_11282012.pdf)

(ARB, 2014) California Air Resources Board, *Staff notes from Middle Harbor tour*, July 2014.



(Ballard, 2014) Ballard, *Economics of Fuel Cell Solutions for Material Handling*, October 2014,

[http://www.ballard.com/files/PDF/Material\\_Handling/MH\\_EconBenefits\\_FCvelocity\\_041411.pdf](http://www.ballard.com/files/PDF/Material_Handling/MH_EconBenefits_FCvelocity_041411.pdf)

(Blueshift , 2013) Blueshift, *Are Supercapacitors Really the Future of Energy Storage?*, December, 2013.

<http://blueshiftpdx.com/blog/2013/are-supercapacitors-the-future-of-energy-storage>

(BU, 2010) Battery University, *Supercapacitor*, 2010.

[http://batteryuniversity.com/learn/article/whats\\_the\\_role\\_of\\_the\\_supercapacitor](http://batteryuniversity.com/learn/article/whats_the_role_of_the_supercapacitor)

(CALSTART, 2011) CALSTART, *Hybrid Yard Hostler Demonstration and Commercialization Project Final Report*, March, 2011.

<http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2516>

(CALSTART, 2013) CALSTART, *Hybrid Yard Hostler Demonstration Project Final Report*, January, 2013.

[http://www.calstart.org/Libraries/Consulting/Hybrid\\_Yard\\_Hostler\\_Demonstration\\_Project\\_Jan\\_2013.sflb.ashx](http://www.calstart.org/Libraries/Consulting/Hybrid_Yard_Hostler_Demonstration_Project_Jan_2013.sflb.ashx)

(Cummins Westport, 2014a), Cummins Westport Inc., *Technology for emissions control, 2014*.

<http://www.cumminswestport.com/technology>

(Cummins Westport, 2014b) Cummins Westport Inc., Personal communication, August, 2014.

(Cummins Westport, 2014c) Cummins Westport Inc., Personal communication - email, July 18, 2014.

(Cummins Westport, 2014d) Cummins Westport Inc., *ISL G Technology Overview*

<http://greaterindiana.com/downloads/Cummins-Crosspoint-Overview.pdf>

(DEEP, 2000) Diesel Emissions Evaluation Program, *The Relationship Between Diesel Engine Maintenance and Exhaust Emissions*, 2000.

[http://www.camiro.org/DEEP/Project\\_Reports/mtce\\_report.pdf](http://www.camiro.org/DEEP/Project_Reports/mtce_report.pdf)

(DF, 2011) Diesel Forum, *Diesel Electric Hybrid Vehicles*, June, 2011.

<http://www.dieselforum.org/files/dmfile/DieselElectricHybridVehicles.pdf>

(DieselNet, 2007) DieselNet, *Emission Effect of Engine Faults and Service*, 2007.

[https://www.dieselnets.com/tech/emi\\_fault.php](https://www.dieselnets.com/tech/emi_fault.php)

(DOE, 2010) US Department of Energy, Energy Efficiency & Renewable Energy, *Operations and Maintenance Best Practices, A guide to Achieving Operational Efficiency*, August, 2010.

[http://www1.eere.energy.gov/femp/pdfs/omguide\\_complete.pdf](http://www1.eere.energy.gov/femp/pdfs/omguide_complete.pdf)

(DOE, 2012) Hydrogen Production - Current Technology, 2012.

<http://energy.gov/eere/fuelcells/hydrogen-production-current-technology>

(DOE, 2013a) Alternative Fuels Data Center, Department of Energy, *All Electric Vehicles*, June, 2013.

[http://www.afdc.energy.gov/vehicles/electric\\_basics\\_ev.html](http://www.afdc.energy.gov/vehicles/electric_basics_ev.html)

(DOE, 2013b) Alternative Fuels Data Center, Department of Energy, *Batteries for Hybrid and Plug-in Electric Vehicles*, June, 2013.

[http://www.afdc.energy.gov/vehicles/electric\\_batteries.html](http://www.afdc.energy.gov/vehicles/electric_batteries.html)

(DOE, 2014a), US Department of Energy, Office of Energy Efficiency and Renewable Energy, *Maintenance and Safety of Hybrid and Plug-in Electric Vehicles*, December, 2014.

[http://www.afdc.energy.gov/vehicles/electric\\_maintenance.html](http://www.afdc.energy.gov/vehicles/electric_maintenance.html)

(DOE, 2014b), US Department of Energy, Office of Energy Efficiency & Renewable Energy, ASME Fuel cell Science, Engineering, and Technology Conference, *U.S. DOE Perspective for Fuel cell Vehicles and H2 Fueling*, June, 2014.

(DOE, 2014c), US Department of Energy, Office of Energy Efficiency & Renewable Energy

<http://energy.gov/eere/fuelcells/types-fuel-cells>

(DOE, 2014d), US Department of Energy, Office of Energy Efficiency & Renewable Energy, Alternative Fuels Data Center,

[http://www.afdc.energy.gov/fuels/natural\\_gas\\_infrastructure.html](http://www.afdc.energy.gov/fuels/natural_gas_infrastructure.html)

(DOT, 2013) U.S. Department of Transportation, Federal Railroad Administration, *MagneMotion Maglev Demonstration on ODU Guideway*, July, 2013.

<http://faculty.washington.edu/jbs/itrans/ODU%20MM%20demo%20final%20report.pdf>

(ECT, 2014) European Container Terminals, *History*, 2014.

<http://www.ect.nl/en/content/history>

(EPRI, 2009) Electric Power Research Institute, *Electric Ship to Shore Cranes: Costs and Benefits*, December, 2009.

<http://www.epri.com/search/Pages/results.aspx?k=Electric+Ship+to+Shore+Cranes:+Costs+and+Benefits>

(EPRI, 2010) Electric Power Research Institute, *Electric Cable Reel Rubber-tired Gantry Cranes: Costs and Benefits*, March, 2010.

<http://www.epri.com/search/Pages/results.aspx?k=RTG>

(EPRI, 2014) Lift Truck Ownership Cost Comparison,

[http://et.epri.com/Calculators\\_LiftTruckComparison\\_with\\_cap2.html](http://et.epri.com/Calculators_LiftTruckComparison_with_cap2.html)

(ESMAP, 2011) Energy Sector Management Assistance Program, *Best Operational and Maintenance Practices for City Bus Fleets to Maximize Fuel Economy*, December, 2011.

[http://www.esmap.org/sites/esmap.org/files/FINAL\\_EECI-BusGuideNote\\_BN010-11.pdf](http://www.esmap.org/sites/esmap.org/files/FINAL_EECI-BusGuideNote_BN010-11.pdf)

(Fuel Cell Today, 2013) Event Report: Hydrogen + Fuel Cells 2013

<http://www.fuelcelltoday.com/analysis/event-reports/2013/hydrogen-plus-fuel-cells-2013>

(Futurereports, 2007) Futurereports, *TraPAC EIR – Why it's so important*, 2007.

[http://futurereports.org/trapac\\_eir.html](http://futurereports.org/trapac_eir.html)

(GA, 2014) General Atomics, *Electromagnetic Cargo Conveyor (ECCO)*, 2014.

<http://www.ga.com/ecco>

(GCC, 2007) Green Car Congress, *Diesel Hybrid Rubber-Tired Gantry Crane in Service in Canada*, June, 2007.

[http://www.greencarcongress.com/2007/06/diesel\\_hybrid\\_r.html](http://www.greencarcongress.com/2007/06/diesel_hybrid_r.html)

(GCC, 2008) Green Car Congress, *DP World Orders 19 Siemens Diesel-Hybrid Drive Gantry Cranes for Saigon Port*, March, 2008.

<http://www.greencarcongress.com/2008/03/dp-world-orders.html>

(Gottwald, 2011) Gottwald Port Technology, *New Model of Gottwald Battery-driven Container AGV Begins Operation at Hamburg*, June, 2011.

[http://www.porttechnology.org/news/new\\_model\\_of\\_gottwald\\_battery\\_driven\\_container\\_agvs\\_operation\\_hamburg\\_port/#.VCsRfRZp5Ls](http://www.porttechnology.org/news/new_model_of_gottwald_battery_driven_container_agvs_operation_hamburg_port/#.VCsRfRZp5Ls)

(GPA, 2012) Georgia Ports Authority, *GPA Unveils North America's First ERTG*, December 14, 2012.

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

(GT, 2014) Global Times, *South Korea unveils first domestically-developed urban maglev train*, May, 2014.

<http://www.globaltimes.cn/content/860672.shtml>

(Hydrogenics, 2015) Hydrogenics website  
[http://www.hydrogenics.com/about-the-company/news-updates/2015/03/30/hydrogenics-awarded-\\$4.4-million-in-projects-from-the-california-energy-commission](http://www.hydrogenics.com/about-the-company/news-updates/2015/03/30/hydrogenics-awarded-$4.4-million-in-projects-from-the-california-energy-commission)

(ICF, 2011) *Impacts of Electric Vehicles - Deliverable 2, Assessment of electric vehicle and battery technology*, Delft, April 2011.  
[ec.europa.eu/clima/policies/transport/vehicles/docs/d2\\_en.pdf](http://ec.europa.eu/clima/policies/transport/vehicles/docs/d2_en.pdf)

(ICTF-JPA, 2015) Modernization Project – Project Description, June 2015.  
[http://www.ictf-jpa.org/project\\_description.php](http://www.ictf-jpa.org/project_description.php)

(IEEE, 2000) Institute of Electrical and Electronics Engineers, Transactions on Applied Superconductivity, *The Inductrack: A Simpler Approach to Magnetic Levitation*, March, 2000.  
<http://www.askmar.com/Magnets/Inductrack%20Magnetic%20Levitation.pdf>

(INC, 2014) INC.com, *Automated Guided Vehicles: Behind the Swift Business of a Heavy Industry*, March, 2014.  
<http://www.inc.com/christine-lagorio/best-industries/automated-guided-vehicles.html>

(Katrasnik, 2010) Katrasnik, *Fuel Economy of Hybrid Electric Heavy-duty Vehicles*, August, 2010.  
[http://www.researchgate.net/publication/266175609\\_Fuel\\_Economy\\_of\\_Hybrid\\_Electric\\_Heavy-Duty\\_Vehicles](http://www.researchgate.net/publication/266175609_Fuel_Economy_of_Hybrid_Electric_Heavy-Duty_Vehicles)

(Komatsu, 2012) Komatsu, *HB215LC-1 Hybrid: Crawler Excavators*, March, 2012.  
[http://www.komatsueurope.com/komatsu-machine.asp?machine\\_type\\_id=1&prdt\\_id=457](http://www.komatsueurope.com/komatsu-machine.asp?machine_type_id=1&prdt_id=457)

(Konecranes, 2013) *Konecranes presents the world's first hybrid reach stacker*. November, 2013.  
<http://www.konecranes.com/resources/media/releases/2013/konecranes-presents-the-worlds-first-hybrid-reach-stacker>

(Konecranes, 2014b) Konecranes. Personal communication, September, 2014.

(Konecranes, 2015) *Hybrid Reach Stacker Brochure*, June, 2015.  
[http://www.kclifttrucks.com/sites/lifttrucks/files/download/konecranes\\_lift\\_trucks\\_hybrid\\_rst\\_brochure\\_2015\\_en\\_8809085\\_low.pdf](http://www.kclifttrucks.com/sites/lifttrucks/files/download/konecranes_lift_trucks_hybrid_rst_brochure_2015_en_8809085_low.pdf)

(LA TIMES, 2006) Los Angeles Times, *Ports Considering Maglev Trains to Cut Smog*, November, 2006  
<http://articles.latimes.com/2006/nov/28/local/me-maglev28>

(LBBJ, 2012) Long Beach Business Journal, *Long Beach Container Terminal: The Port of the Future Designing the Middle Harbor: Green Thinking From Top to Bottom*, April, 2012.

<http://www.lbbusinessjournal.com/long-beach-business-journal-newswatch/527-long-beach-container-terminal-the-port-of-the-future.html>

(LEVX, 2014a) Magna Force, *Company Profile*, 2014.

[http://www.levx.com/pages\\_about.cfm](http://www.levx.com/pages_about.cfm)

(LEVX, 2014b) Magna Force, *A Case Study in Efficiency*, 2014.

[http://www.levx.com/pages\\_testing\\_m.cfm](http://www.levx.com/pages_testing_m.cfm)

(LEVX, 2014c) Magna Force, *Eastside Rail Corridor, Preserving Freight Service in a Multi-use Environment*, 2014.

(LEVX, 2014d) Magna Force, *Greenville-Spartanburg International Airport and South Carolina Inland Port*, 2014.

(LEVX, 2014e) Magna Force, *Sustainable Transportation Infrastructure for Mexico*, 2014.

(LEVX, 2014f) Magna Force, *Benefits: Cost Reduction*, 2014.

[http://www.levx.com/pages\\_benefits\\_cost.cfm](http://www.levx.com/pages_benefits_cost.cfm)

(LiftsRUs, 2014) Electric Forklift versus Internal Combustion Forklift Comparison Guide

[http://www.liftsrus.com/InfoDocs/Forklift\\_Comparison\\_Guide.html](http://www.liftsrus.com/InfoDocs/Forklift_Comparison_Guide.html)

(McCormick, 2003) McCormick, et al, *Quantifying the Emission Benefits of Opacity Testing and Repair of Heavy-Duty Diesel Vehicles*, 2003.

[http://www.researchgate.net/publication/10861062\\_Quantifying\\_the\\_emission\\_benefits\\_of\\_opacity\\_testing\\_and\\_repair\\_of\\_heavy-duty\\_diesel\\_vehicles](http://www.researchgate.net/publication/10861062_Quantifying_the_emission_benefits_of_opacity_testing_and_repair_of_heavy-duty_diesel_vehicles)

(Middle Harbor, 2014) *Middle Harbor Redevelopment Project*, 2014.

<http://www.middleharbor.com>

(MLM, 2014) Maglev in Minnesota, *Maglev Advantages and Disadvantages*, 2014.

<http://maglevmn.weebly.com/pros-and-cons.html>

(NAMTI, 2005) North American Maglev Transport Institute, *Shanghai's Maglev: Levitating Beyond Transportation Theory*, April, 2005.

<http://namti.org/published-articles/articles/engineering-world-australia/shanghais-maglev-levitating-beyond-transportation-theory>

(NASDAQ, 2014) NASDAQ.com, *Cargotec's Kalmar Wins Significant Order for Melbourne's New Automated Container Terminal*, September, 2014.

<http://www.nasdaq.com/press-release/cargotecs-kalmar-wins-significant-order-for-melbournes-new-automated-container-terminal-20140903-00100>

(NHMFL, 2014) National High Magnetic Field Laboratory, *Maglev Trains*, 2014.

<http://www.magnet.fsu.edu/education/tutorials/museum/maglevtrains.html>

(NJ, 2014) NJ.com, *Global's Automated Terminal Offers a Window Into Shipping's Future*, 2014.

[http://www.nj.com/business/index.ssf/2014/06/globals\\_automated\\_terminal\\_offers\\_a\\_window\\_into\\_the\\_shipping\\_future.html](http://www.nj.com/business/index.ssf/2014/06/globals_automated_terminal_offers_a_window_into_the_shipping_future.html)

(NREL, 2013a) Todd Ramsden, National Renewable Energy Laboratory, *An Evaluation of the Total Cost of Ownership of Fuel Cell-Powered Material Handling Equipment*, April, 2013.

[http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fuel\\_cell\\_mhe\\_cost.pdf](http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fuel_cell_mhe_cost.pdf)

(NREL, 2013b) M. Melaina and M. Penev, National Renewable Energy Laboratory, *Hydrogen Station Cost Estimates, Comparing Hydrogen Station Cost Calculator Results with Other Recent Estimates*, September, 2013.

<http://www.nrel.gov/docs/fy13osti/56412.pdf>

(ODEC, 2004) Online Digital Education Connection, *Maglev Pros and Cons*, 2004.

[http://www.odec.ca/projects/2004/leun4m0/public\\_html/procon.html](http://www.odec.ca/projects/2004/leun4m0/public_html/procon.html)

(Orange EV, 2014) *On a Roll: Successful Electric Truck Demonstrations in LTL Freight Distribution, Intermodal, Manufacturing*, October 22, 2014.

<http://orangeev.com/on-a-roll-successful-electric-truck-demonstrations-in-ltl-freight-distribution-intermodal-manufacturing/>

(Orange EV, 2015a) OrangeEV, *Maintenance Savings*, April, 2015.

(Orange EV, 2015b) OrangeEV, *Pure Electric Terminal Trucks*, April, 2015.

(Orange EV, 2015c) Orange EV and Kalmar Ottawa Team Up on Zero-Emission, Electric Terminal Tractor, March 24, 2015.

<http://orangeev.com/orange-ev-and-kalmar-ottawa-team-up-on-zero-emission-electric-terminal-tractor/>

(Orange EV, 2015d) Orange EV, *Lower Total Cost of Ownership – Orange EV*, May 2015,

<http://orangeev.com/lower-total-cost-of-ownership/>

(Plug Power, 2012) Sharalyn Savin, *New York Energy Highway Request for Information Plug Power*, May, 2012.

<http://www.nyenergyhighway.com/Content/documents/89.pdf>

(POLA, 2013a) Port of Los Angeles, *TraPac Terminal Program, Cost Summary & Status Update*, August, 2013.

[http://www.portoflosangeles.org/Board/2013/September%202013/090513\\_Item\\_4\\_Transmittal\\_5v2.pdf](http://www.portoflosangeles.org/Board/2013/September%202013/090513_Item_4_Transmittal_5v2.pdf)

(POLA, 2013b) *Southern California International Gateway Project Final Environmental Impact Report*, February 2013.

[http://www.portoflosangeles.org/EIR/SCIG/FEIR/feir\\_scig.asp](http://www.portoflosangeles.org/EIR/SCIG/FEIR/feir_scig.asp)

(POLA, 2014a) Port of Los Angeles, *Zero Emission Technologies*, 2014.

<http://www.portoflosangeles.org/environment/zero.asp>

(POLA, 2014b) City of Los Angeles Harbor Department, Department of Planning and Economic Development Division, *Container Terminal Automation*, April, 2014.

[http://portoflosangeles.org/Board/2014/April/041714\\_item5\\_Transmittal\\_6.pdf](http://portoflosangeles.org/Board/2014/April/041714_item5_Transmittal_6.pdf)

(POLA, 2015) Tim DeMoss of POLA, personal communication, May 2015.

(POLB, 2010) Port of Long Beach, *Middle Harbor Redevelopment: Program Overview*, October, 2010.

<http://www.polb.com/civica/filebank/blobdload.asp?BlobID=7853>

(Port area, 2014a) Rubber Tyred Gantry Crane (RTG)

<http://www.portarea.com/en/knowledge/handling-equipment-types/rubber-tyred-gantry-cranes-rtg.html>

(Port area, 2014b) Rail Mounted Gantry Cranes (RMG)

<http://www.portarea.com/en/knowledge/handling-equipment-types/rail-mounted-gantry-cranes-rmg.html>

(Port area, 2014c) Ship To Shore Gantry Cranes (STS)

<http://www.portarea.com/en/knowledge/handling-equipment-types/ship-to-shore-gantry-cranes-sts.html>

(Presson, 2002) Nick Presson, *Magnetic Levitation – Emerging Technologies*. 2002.

<http://www.faculty.rsu.edu/users/c/clayton/www/presson/paper.htm>

(Reuters, 2015) Reuters

<http://www.reuters.com/finance/stocks/companyProfile?rpc=66&symbol=VIICQ.PK>

(Schmidt/Carroll, 2014) Schmidt/Carroll, *Inductrack Magnetic Levitation Trains for More Efficient Travel in the United States*, March, 2014.  
<http://136.142.82.187/eng12/Chair/pdf/4227.pdf>

(Seaport, 2013) Seaport Group, *Financial Implications of Container Terminal Automation*, August, 2013.  
[http://www.seaport.com/files/8413/7643/5363/News\\_Q32013.pdf](http://www.seaport.com/files/8413/7643/5363/News_Q32013.pdf)

(Siemens, 2011) Siemens, *Energy Saver for Container Cranes, 2014*.  
<http://www.siemens.com/sustainability/en/environmental-portfolio/products-solutions/industry-solutions/eco-rtg-for-container-cranes.htm>

(skyTran, 2014) skyTran, *High-speed, Elevated, Mass Transit Gets Real*, June, 2014.  
[http://www.skytran.us/documents/skyTran\\_PressRelease-14-06-23.pdf](http://www.skytran.us/documents/skyTran_PressRelease-14-06-23.pdf)

(TAP, 2013) San Pedro Bay Ports Clean Air Action Plan Technology Advancement Program, *2012 Annual Report*, May, 2013.  
<http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2566>

(TAP, 2014) San Pedro Bay Ports Clean Air Action Plan Technology Advancement Program, *2013 Annual Report*, April, 2014.  
<http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2573>

(TIAX, 2010), TIAX, *Pluggable Hybrid electric Terminal Truck (PHETT™) Demonstration at the Port of Los Angeles Technical Report: Fuel Consumption and Emissions Estimates*, May, 2010.  
<http://www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2517>

(Transpower, 2013) TransPower, *High-Powered Electric Terminal Tractor (HPETT), Final Report, New Technology and Research Development Program, 582-11-13472-2019*, July, 2013.  
[https://www.tceq.texas.gov/assets/public/implementation/air/terp/ntrd/prog\\_rpts/transpower\\_Final.pdf](https://www.tceq.texas.gov/assets/public/implementation/air/terp/ntrd/prog_rpts/transpower_Final.pdf)

(Transpower, 2014a) TransPower, *Quarterly Progress Report, Project 13-3146*, April, 2014.

(Transpower, 2014b) TransPower, *Yard Tractor and Drayage Demo*, September, 2014.

(UCS, 2010) Union of Concerned Scientists, Hybridcenter.org, *Hybrids Under the Hood*, 2010.  
<http://www.hybridcenter.org/hybrid-center-how-hybrid-cars-work-under-the-hood-2.html>

(UNC, 2005) Heim, Long, and Newcomb, *Maglev Trains*. 2005.  
<http://www.unc.edu/~lindseyl/index.htm>



(USEPA, 2009) United States Environmental Protection Agency, *Hydraulic Hybrid Vehicles*, October, 2009.

<http://www.epa.gov/cleandiesel/documents/420f09051.pdf>

(VDL, 2014) *VDL Containersystemen Automatic Guided Vehicle*, 2014.

[http://www.vdlcontainersystemen.com/data/uploads/vdl%20containersystemen/spreader/Brochure/VDL\\_Containersystemen%20AGV\\_2012-10-001.pdf](http://www.vdlcontainersystemen.com/data/uploads/vdl%20containersystemen/spreader/Brochure/VDL_Containersystemen%20AGV_2012-10-001.pdf)

(VIG, 2014) Virginia International Gateway, 2014.

<http://www.portofvirginia.com/facilities/vig/>

(Vision, 2014) *Vision Industries Files for Voluntary Chapter 11 Bankruptcy Protection*, September 25, 2014.

<http://finance.yahoo.com/news/vision-industries-files-voluntary-chapter-210000055.html>

(WSC, 2014) World Shipping Council, *History of Containerization*, 2014.

<http://www.worldshipping.org/about-the-industry/history-of-containerization>

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## Appendix A:

### List of Acronyms and Abbreviations Acronyms and Abbreviations Used in This Document

AC	Alternating Current
Act	Federal Clean Air Act
AFDC	DOE Alternative Fuels and Advanced Vehicles Data Center
AGVs	Automated Guided Vehicles
Ah	Amp-hours
AQIP	Air Quality Improvement Program
ARB	Air Resources Board
ASCs	Automated Stacking Cranes
BACT	Best Available Control Technology
BEV	Battery Electric Vehicle
CCR	California Code of Regulations
CHE Regulation	Cargo Handling Equipment Regulation
CO	Carbon Monoxide
C-Rate	Charge, or Discharge, Times
DC	Direct Current
DOE	U.S. Department of Energy
DPR	Diesel Particulate Filter
DRRP	Diesel Risk Reduction Plan
CNG	Compressed Natural Gas
EDS	Electrodynamic Suspension
EGR	Exhaust Gas Recirculation
EMS	Electromagnetic Suspension
EVB	Electric Vehicle Battery
GHG	Greenhouse Gases
H <sub>2</sub>	Hydrogen
H2A	Hydrogen Analysis Model
HC	Hydrocarbons
HP	Horsepower
ICE	Internal Combustion Engine
ICTF	International Container Transfer Facility
In-Use Off-Road Regulation	Regulation for In-Use Off-Road Diesel-Fueled Fleets
LBCT	Long Beach Container Terminal
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LSI Regulation	Off-Road Large Spark Ignition Engine Regulation
MHE	Material Handling Equipment
NiMH	Nickel Metal Hydride Battery
NMHC	Non-methane Hydrocarbons
Nov	November
NO <sub>x</sub>	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
NY	New York

ODU	Old Dominion University
OOCL	Orient Overseas Container Line
PEV	Plug-in electric Vehicle
PHETT	Capacity Pluggable Hybrid electric Terminal Tractor
PM	Diesel Particulate Matter
POLA	Port of Los Angeles
POLB	Port of Long Beach
RMG	Rail-mounted Gantry Crane
RTG	Rubber-tired Gantry Crane
SCIG	Southern California International Gateway
SIP	State Implementation Plan
SMR	Steam Methane Reforming
TAC	Toxic Air Contaminant
TPD	Tons per Day
TWC	Three-way Catalyst
U.S.	United States
U.S. EPA	U.S. Environmental Protection Agency
UTR	Utility Tractor Rigs
VDECS	Verified Diesel Emissions Control Strategies
VVA	Variable Valve Actuation
\$/kg-day	Dollars Per Kilogram-Day

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