Zero-Emission Catenary Hybrid Truck Market Study

March 8, 2012

Prepared for:

AQMD

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The information contained in this report was prepared on behalf of the South Coast Air Quality Management District by the consulting firm of Gladstein, Neandross & Associates (Santa Monica, CA and New York City). The opinions expressed herein are those of the authors and do not necessarily reflect the policies and views of the South Coast Air Quality Management District.

Acknowledgements

The development of this report for the South Coast Air Quality Management District was performed under the leadership of the South Coast Air Quality Management District staff, including:

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About the Authors

Gladstein, Neandross & Associates (GNA) has extensive experience in the alternative fuels industry and has assisted with the successful development and implementation of several of the nation's largest port fleet modernization programs, including the Clean Trucks Program at Ports of Los Angeles and Long Beach (i.e. the San Pedro Bay Ports), Port Authority of New York and New Jersey's Truck Replacement Program, and the New York City Department of Transportation Hunt's Point Clean Trucks Program. GNA spearheaded the implementation of the nation's largest LNG port drayage truck project, the first CNG drayage truck operation in the country, and led the development and deployment of the world's first natural gas powered yard hostlers in a marine container port operation.

GNA provides technical consulting services in a range of cutting-edge alternative fuel vehicle and refueling infrastructure technologies for the on-road and off-road markets, including: natural gas (CNG and LNG), hydrogen, electricity, propane, and renewable fuels such as bio-methane. GNA has two decades of experience with the development and implementation of alternative fuel vehicles and refueling infrastructure projects in the regional trucking, port drayage, refuse, municipal, local pick-up and delivery, yard hostler, and long-haul trucking sectors. The firm provides consulting services to the nation's largest heavy-duty fleet operators; OEMs; technology, infrastructure and fuel providers; and leading public agencies working to lower life-cycle costs and environmental impacts through the increased use of alternative fuel and advanced transportation technologies. The company is widely recognized for leading role the development of several planned regional corridors of natural gas infrastructure. The Interstate Clean Transportation Corridor (ICTC) was conceived by GNA in 1996 and is now the most successful planned LNG fueling corridor in North America, spanning the major highways that connect California, Nevada and Utah. Similarly, GNA is working on the implementation of the Texas Clean Transportation Triangle (TCTT), a corridor effort to connect the Dallas/Fort Worth, Houston, and San Antonio metropolitan regions; and the firm recently developed a blueprint for a similar corridor effort – the Pennsylvania Clean Transportation Corridor (PCTC). GNA also maintains significant experience and knowledge in the use of natural gas in a variety of off-road high-horsepower applications such as marine, locomotives, natural gas and oil drilling operations, mining, and other mobile and stationary industrial uses.

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Executive Summary

Despite major advances in air pollutant emissions performance, heavy duty diesel trucks operating in dense urban areas continue to face pressure to achieve lower emission operation. In areas with historically poor air quality like the South Coast Air Basin, zero-emission requirements are being considered and may become standard. The South Coast Air Quality Management District (SCAQMD), California Air Resources Board (CARB) and Southern California Association of Governments (SCAG) — the agencies responsible for preparing the State Implementation Plan required under the federal Clean Air Act — have stated that to attain federal air quality standards the region will need to transition to broad use of zero and near zero emission energy sources in cars trucks and other equipment.[1] Zero emission standards and technologies are also being proposed in the 2012 Regional Transportation Plan. The draft plan would affect the development of major freeways in Southern California including the I-710 and CA-60 by adding zero-emission truck lanes to these key transportation corridors. The current near-dock rail yard development project known as the Southern California International Gateway (SCIG) has received significant public comment concerning air quality impacts from the project and may ultimately result in the inclusion of a requirement to use zero emission trucks and other equipment. The planned expansion of the existing near-dock rail yard known as the Intermodal Container Transfer Facility (ICTF) is expected to face pressures similar to the SCIG to employ zero emission technologies.

Rising diesel fuel prices and increasing fuel economy standards will also place additional pressures on heavy duty truck manufacturers and their customers to consider alternatives to traditional diesel technologies. Truck manufacturers are actively pursuing drive train hybridization as a key technology pathway to simultaneously reduce fuel consumption and emissions. Based on developments in hybridization for a variety of heavy duty markets, this report explores the potential market for a Zero Emission Truck & Electric Catenary Highway (ZETECH) technology approach – a robust hybrid-electric truck platform with the ability to access overhead catenary power sources.

Catenary-powered hybrid trucks with internal combustion engines can simultaneously address emissions and fuel economy issues while providing operational flexibility at a similar or lower cost of ownership as other zero-emission technologies. Further, the path to catenary hybrid vehicles (CHV) is based on existing and well understood technologies that can be integrated today without the need for dramatic improvements in performance, cost, reliability, or durability.

A potential local market size of up to 46,000 trucks exists in the South Coast Air Basin, based on near-dock drayage trucks and trucks operating on the I-710 freeway. The I-710 is a major truck corridor scheduled to be expanded to include a four-lane roadway dedicated to truck traffic and incorporating zero-emission transportation infrastructure. Additional markets for the truck platform (with or without the catenary interface) include applications where low noise and/or lower emission operation is desirable, particularly in EU countries; and fleets affected by emissions regulations like current California

[1] Southern California Association of Governments, South Coast Air Quality Management District, and California Air Resources Board, *Powering the Future - A Vision for Clean Energy, Clear Skies, and a Growing Economy in Southern California* (2011). http://www.aqmd.gov/pubinfo/Publications/PoweringTheFuture/powering_the_future.htm

fleet rules where a zero or ultralow emission truck would provide additional compliance flexibility. The total number of heavy duty trucks subject to California fleet rules is estimated to exceed 500,000.

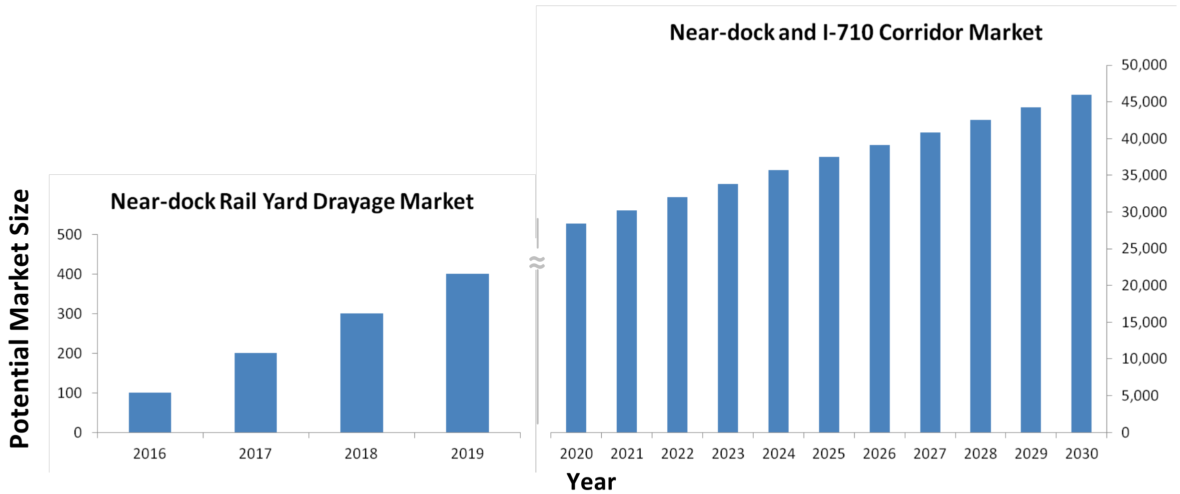

Figure ES-1. Projected potential market size for catenary-hybrid drayage trucks in the South Coast Air Basin

Compelling features of catenary hybrids include:

- Flexible truck platform that will allow for zero-emission operations in key regions of interest while still providing the standard operating range of local and regional haul goods movement trucks.
- Based on existing hybrid technologies and demonstrated system components, making the deployment of a catenary system for near-dock rail yards feasible in the 2016-2020 time frame
- Unlimited zero-emission range when connected to a catenary system.
- Extensible system that can grow from near-dock facilities to the I-710 corridor and eventually comprise a zero emission electric container movement system sought by the ports.
- Ability to use natural gas in extended off-catenary operation, completely eliminating diesel emissions.
- Potential local market size of up to 46,000 trucks. Additional markets for the truck platform (with or without the catenary interface) include:
    - Applications where low noise operation is desirable, particularly in EU countries
    - Fleets affected by emissions regulations like current California fleet rules where a zero or ultralow emission truck would provide additional compliance flexibility
- Similar or lower cost of ownership relative to other zero-emission technologies.

Introduction

The goods movement sector in Southern California is estimated to cause billions of dollars in health related costs each year[2], impacting the health of more than 16.8 million people. A significant portion of this goods movement activity is related to the movement of shipping containers, known as drayage, to and from the Port of Long Beach and Port of Los Angeles (collectively known as the San Pedro Bay Ports). Since 2005, the San Pedro Bay (SPB) Ports and the South Coast Air Quality Management District (SCAQMD) have implemented several emission reduction programs that reduced drayage truck-related NOx emissions by more than 43% and PM emissions by more than 66% in 2010[3]. The drayage fleet now serving the ports includes over 10,000 trucks meeting the U.S. EPA 2007 emission standard and includes over 860 LNG trucks[4]; the largest LNG truck fleet in the United States. Much of the impetus for these emission reduction programs stemmed from the recognition that port commerce would not be allowed to grow without first addressing the significant impact that goods movement has on the health and air quality of the local communities and the region. While the ports have made tremendous progress in the reduction of port-related emissions, local communities are still highly sensitive to any increases in cargo volumes and the associated increase in emissions. Port activity is concentrated in these communities and air pollutant levels tend to be much higher than other communities in the region. In fact, communities adjacent to the ports, rail yards, and freeways suffer disproportionately large effects from the diesel emissions associated with goods movement throughout Southern California. While the worldwide decline in economic activity since 2007 has reduced the volume of goods moved in Southern California, and reduced associated emissions, it is clear that cargo volumes will increase as the economic climate improves. The challenge then, is to accommodate increases in cargo volumes while continuing to reduce the emissions historically associated with goods movement. Because goods movement activities occur in every community in Southern California, emission reduction strategies are being pursued throughout the region on both local and regional levels.

Near-dock rail facilities

It is against this backdrop that Union Pacific (UP) railroad and Burlington Northern Santa Fe (BNSF) railroad are both pursuing infrastructure projects that would significantly increase their capacity to transport cargo between the ports and near-dock rail yards. UP currently operates the Intermodal Container Transfer Facility (ICTF), located approximately four miles from the ports, at the end of the CA-47/103 Terminal Island Freeway (see Figure 1). This facility handles approximately 750,000 containers, or "lifts", each year. UP is actively working to expand the facility to 1.6 million lifts per year. Meanwhile, BNSF is pursuing the development of the Southern California International Gateway (SCIG). When complete, the SCIG will handle approximately 1 million lifts per year. Together, the expansion of the ICTF and development of the SCIG will increase the total number of lifts handled by these near-dock rail facilities from 750,000 to 2.6 million, annually.

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[2] *Goods Movement Emission Reduction Plan- Appendix A: Quantification of the Health Impacts and Economic Valuation of Air Pollution from Ports and Goods Movement in California*, California Air Resources Board, 2006

[3] *San Pedro Bay Ports Clean Air Action Plan 2010 Update*, Port of Long Beach and Port of Los Angeles, October 2010

[4] *Clean Truck Program Gate Move Data Analysis for the month of August 2011*, Port of Los Angeles, August 2011

Figure 1. Near-dock rail yards are located at the end of the Terminal Island Freeway

Environmental Leadership at the San Pedro Bay Ports

With the release of their Clean Air Action Plan (CAAP) in 2006, the Port of Long Beach and Port of Los Angeles established their position as environmental leaders amongst U.S. ports. The CAAP was designed to address all aspects of port-related emissions and resulted several emission reduction efforts, including the highly successful Clean Trucks Program (CTP). By January 1, 2012, nearly every drayage truck at the SPB Ports will meet 2007 emission standards, reducing carcinogenic diesel particulate matter emissions and other air toxics by up to 90%. The CTP also successfully resulted in the deployment of over 800 natural gas trucks and the commercialization of new natural gas product offerings from four major truck manufacturers. Similar clean truck programs have been adopted by many ports around the U.S. In addition, the transformative effect the CTP had on the heavy-duty natural gas truck market has allowed fleets to use natural gas in many additional trucking applications.

Both the ICTF and the future site of the SCIG are located adjacent to sensitive community facilities including schools, senior centers, and athletic fields (see Figure 2). Further, every container transferred to these facilities from the ports must be hauled by a drayage truck, resulting in 2,000 daily truck trips along CA-47/103 and other local roadways. When the SCIG is fully operational and ICTF expansion is complete (estimated 2016), the number of daily truck trips is estimate to increase to 7,000. Many of these additional truck trips along the CA-47/103 will result from diversion of trucks currently travelling on the I-710 between the ports and the BNSF Hobart yard in Commerce, CA. Such diversion of truck traffic may benefit the region by reducing fuel consumption and related air toxics emissions but concentrates truck activity in already heavily impacted communities along the CA 47/103. While the expansion of the near-dock rail facilities may provide economic and environmental benefits to the region, local community groups and officials have pledged to oppose the projects if they do not employ zero-emission technologies to transport cargo to and from the facilities.

Figure 2. Near-dock rail yards are located adjacent to many sensitive community facilities

Regional drayage operations and impacts

Impacts from port operations extend beyond the local communities adjacent to the ports. The I-710 freeway, extending north from the ports for approximately 22 miles, passes through more than a dozen cities and is one of the principal routes for drayage trucks serving the ports (Figure 3). It is estimated that 48,000 daily oneway truck trips on the I-710 freeway result from port-related cargo movement, and this number is anticipated to grow to nearly 100,000 daily trips over the next two decades[5]. Because of the congestion and safety impacts associated with such a large volume of truck trips, the Los Angeles County Metropolitan Transportation Authority (METRO) and six project participants are conducting an Environmental Impact Statement/Environmental Impact Report (EIS/EIR) to consider a variety of alternatives to the transportation of port cargo along the I-710 freeway. Alternatives considered in the study will include dedicated truck lanes and fixed guideway systems for low or zero-emission cargo movement. Given the significant impact that port-related truck trips have on the region, a zero-emission cargo movement system that can serve near-dock rail yards but also be expanded to a regional level should be of significant interest. Pursuing the demonstration and deployment of a zero-emission cargo movement system along the CA-47/103 freeway would be a unique opportunity to establish a system that can serve the near-term needs of residents near the ports and integrate seamlessly into the larger, longer-term I-710 and CA-60 freeway projects. Such a project would also be consistent with the SPB Ports' position amongst U.S. ports as environmental leaders and their long term goal to establish a ***regional*** zero emission container movement system.

[5] *Regional Transportation Plan, Southern California Association of Governments, 2012*

Figure 3. I-710 Corridor Project EIS/EIR study area (source: METRO)

An Environmental Justice Issue

The Gateway Cities are home to more than 800,000 residents, many of whom live only a short distance from major freeways. These residents live closest to the I-710 and CA 47/103 freeways and are exposed to disproportionately high levels of air toxics from diesel trucks.

At the same time, Gateway Cities residents are more likely to be low income or minority households. In fact, residents in the Gateway Cities communities have a median income 17% lower than the Los Angeles-Long Beach-Riverside metro area median income and 11% more of Gateway Cities households are minority households (US Census 2010).

Cities in the I-710 Corridor EIS/EIR study area

- ✓ Long Beach
- ✓ Wilmington
- ✓ Signal Hill
- ✓ Carson
- ✓ Lakewood
- ✓ Compton
- ✓ Paramount
- ✓ Bellflower
- ✓ Lynwood
- ✓ Downey
- ✓ South Gate
- ✓ Cudahy
- ✓ Bell Gardens
- ✓ Bell
- ✓ Huntington Park
- ✓ Maywood
- ✓ Commerce
- ✓ Vernon
- ✓ East Los Angeles

Background

It is likely that some type of zero-emission container movement system will be necessary if the ICTF and SCIG projects are to successfully complete their environmental impact review processes and move forward. While no solution has yet been accepted or demonstrated in the ports, several systems have been proposed.

Zero-emission options for port drayage

In June, 2009 the SPB Ports released a Request for Concepts and Solutions[6] (RFCS) that would provide zero-emission movement of containers between the ports and near-dock rails facilities. Responses to the RFCS can generally be classified into two groups, 1) dedicated guideway systems and 2) zero-emission trucks. Technologies in the dedicated guideway group include magnetic levitation trains (Maglev) and linear synchronous motors. Only one zero-emission truck option was submitted, based on a dual-mode hybrid electric system. However, the zero-emission truck group could be considered to include pure battery-electric trucks (BETs), fuel cell hybrid trucks (FCHTs), and plug-in hybrid electric trucks (PHETs).

Fixed guideway systems

Fixed guideway systems involve the use of a dedicated track, along which containers are transported. In Maglev systems, the container is carried by a special platform that levitates above the track using opposing magnetic forces. Because the platform is not in physical contact with the track, friction is eliminated and the energy needed to propel the container is reduced. The container is propelled forward by alternating magnetic fields, providing for relatively efficient propulsion compared to a typical diesel engine. Linear synchronous motor systems are similar to Maglev, in that they are propelled by alternating magnetic fields. However, these systems do not levitate the container platform as Maglev systems do. Instead, linear synchronous motor systems use some sort of physical support, typically steel rails and wheels. While this increases frictional loss, the track is less complex and less costly to build compared to Maglev systems. In both Maglev and linear synchronous motor systems the propulsion system is electric and can meet the California Air Resources Board's (CARB) definition of zero-emissions[7].

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[6] *Zero Emission Container Movement System - Request for Concepts and Solutions*, Port of Long Beach, 2009. Available at http://www.polb.com/environment/transplan/zecms/default.asp

[7] Under 13 CCR 1962.1, a zero-emission vehicle must emit zero criteria pollutants under all conceivable operating conditions. CARB does not consider the emissions associated with the production of fuel or electricity when certifying a zero-emission vehicle. Electricity generated to power vehicles based on electric propulsion produces substantially lower NOx emissions, and no diesel particulate matter emissions, than would occur using combustion based propulsion.

Figure 4. Conceptual rendering of a Maglev container movement system (source: General Atomics)

Zero-emission trucks

Several truck technologies have been identified that could provide zero-emission drayage operations at near-dock rail facilities, including battery-electric trucks and several electric-hybrid designs (see Figure 5 through Figure 7).

Figure 5. Fuel cell hybrid truck (source: Vision Motors)

Figure 6. Battery electric truck (source: Balqon)

A pure battery-electric truck stores all of its energy in a large battery pack that could be recharged over several hours. If the required operating range is sufficiently short, the required battery pack size would be reduced and much shorter charging times could be realized and possibly enable opportunity charging.

Figure 7. Catenary hybrid diesel bus (King County METRO)

Hybrid systems combine a generator or engine with a reduced-capacity battery pack to provide low or zero emission operation. To achieve zero emission operation, hybrids must derive their energy either from a fuel cell or from the electrical grid. Both fuel cell hybrid and diesel hybrid systems have been used in transit bus applications to achieve zero tailpipe emission operations. Fuel cell hybrids do so by storing hydrogen onboard the vehicle and converting the hydrogen to electricity using a proton exchange membrane (PEM) fuel cell. Emissions from a PEM fuel cell contain no criteria pollutants and the system is therefore considered zero-emission. Hybrids using diesel or natural gas achieve zero emissions when operating from the battery pack or from a catenary (or wayside) power system. The catenary system is used commonly in trolley systems, including transit buses, to provide zero-emission operation in dense urban settings. When not connected to the catenary system, a hybrid truck would have a limited amount of zero-emission operating range, based on the on-board battery capacity, before the engine or generator engaged.

Advantages of zero-emission trucks

The primary requirement for any of the above technologies is the capability to provide zero-emission drayage of containers between the near-dock rail yards and the ports. Additionally, the system will be required to interface with existing terminal operations, either by using existing infrastructure or developing new infrastructure that does not interfere with gate access and terminal/rail yard operations. However, the ports recognize that only a portion of the cargo flowing through the ports is transferred through near-dock rail yards. Indeed, more than 90% of containers currently entering Southern California through the ports travel to locations other than near-dock rail yards (see Figure 8). Therefore, a system that can be work on a regional level is of significant interest.

"Demonstration and commercialization of zero emission trucks is the #1 priority as it relates to implementing zero emission technologies for short-haul drayage."

-Port of Long Beach and Port of Los Angeles

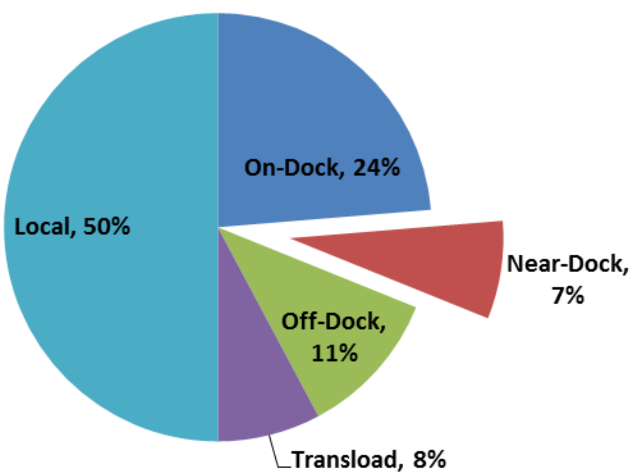

Figure 8. Container mode splits at the SPB Ports in 2008

In their recent roadmap for zero emission technologies[8], the Port of Long Beach and Port of Los Angeles compared zero-emission trucks and fixed guideway systems using seven criteria. Figure 9 summarizes their findings, identifying zero-emission trucks as more compatible with existing drayage operations, more scalable, and less costly than fixed guideway systems. *Ultimately, the ports stated that "demonstration and commercialization of zero emission trucks is the #1 priority as it relates to implementing zero emission technologies for short-haul drayage."*[9]

[8] *Roadmap for Moving Forward with Zero Emission Technologies as the Ports of Long Beach and Los Angeles*, Port of Long Beach and Port of Los Angeles, 2011

[9] *Ibid at 8*

Evaluation Criterion	Electric Trucks	Fixed Guideway
Emissions and Health Risk Reduction	Excellent	Excellent
Constructability	Excellent	Poor
Technology Readiness	Satisfactory	Poor
Operations Compatibility	Good	Unacceptable
Regional Scalability	Satisfactory	Unacceptable
Cost and Economic Sustainability	Good	Unacceptable
Timeline for Implementation	Satisfactory	Poor

Excellent Good Satisfactory Poor Unacceptable

Figure 9. Ports' assessment of zero emission options for short-haul drayage[10]

Comparison of capital costs for fixed-guideway systems and zero-emission trucks

While fixed guideway systems are theoretically capable of providing a zero-emission cargo movement solution, they do so at a significantly higher cost than zero-emission trucks. In support of their I-710 EIS/EIR, METRO estimated capital costs for a fixed guideway system between the ports and intermodal rail facilities, a distance of four miles, at between $4.6 billion and $6.6 billion ($1.1 billion-$1.6 billion per mile). Additionally, first-year operating costs are estimated at $172million to $241 million[11]. Much of the cost related to the fixed guideway system was assumed by METRO to be related to track and container handling stations required to interface the system with existing docks and infrastructure. Containers would be loaded and unloaded from special stations located within port terminals and rail yards. While this approach may be technologically achievable, it imposes requirements on the terminals and rail yards to reorganize their facilities layouts to accommodate the additional buildings and infrastructure. The ability of each terminal and rail yard to accommodate such reorganization of their operations will vary due to space constraints and existing infrastructure; as will the costs and impacts on operational efficiencies.

> *"…capital costs for a fixed guideway system serving the near-dock rail facilities are up to 19 times higher than for a system based on zero-emission trucks using wayside power."*

In stark contrast, a zero-emission truck fleet is assumed to use existing roadways and infrastructure, requiring much less capital investment. While METRO did not include a capital cost estimate for a near-

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[10] *Ibid at 8*

[11] *Alternative Goods Movement Technology Analysis, Initial Feasibility Study Report*, Los Angeles County Metropolitan Transportation Authority

dock system, one could conservatively estimate an average vehicle capital cost of $260 million[12]. In addition, the cost of a catenary (or other wayside power) system, or hydrogen fueling infrastructure must be included. Unfortunately, the METRO report does not provide cost estimates for wayside power infrastructure and did not consider fuel cell trucks. However, cost estimates for transit bus systems (employing catenary power) are approximately $1.3 million per mile[13] and a major catenary truck component manufacturer has estimated costs for a suitable system at $5-6 million per mile. This implies that the cost of the catenary infrastructure would range from $5-$24 million and is small relative to the cost of the vehicles in a zero-emission truck system. *In total, the estimated first capital costs for a fixed guideway system serving the near-dock rail facilities are up to 19 times higher than for a system based on zero-emission trucks using wayside power.*

Over the life of the system, maintenance costs will be a significant part of the total cost. To compare the annual maintenance costs for a fixed guideway system described in the METRO analysis, maintenance costs for three other zero-emission truck options were estimated. Maintenance and replacement costs were included in the estimated total system costs using data present later in this report (see Cost of Ownership - Table 2). Diesel trucks serve as a baseline for comparison and are estimated to cost $775 million over 20 years. It should be noted that much of the maintenance and replacement costs for the zero-emission trucks would be borne by fleet operators, rather than being concentrated with the system operator as in fixed guideway systems, and would be offset by replacing diesel trucks. Table 1 summarizes the costs of the various zero-emission container movement systems. Total 20-year costs for fixed guideway systems are estimated to be as much as 14 times higher than the lowest cost option (catenary hybrids). Fuel cell infrastructure costs are still highly speculative given that no fueling location in the world currently dispenses hydrogen at the rate (6,000 kg/day) that would be required by an FCHV based system. However, the location of a hydrogen pipeline in the port region makes the estimated costs plausible as the pipeline eliminates the need for capital investment in hydrogen production facilities.

[12] Assumes 1,000 trucks needed to provide 2.6 million cargo trips per year, following completion of the SCIG and the ICTF expansion. Truck capital cost of $260,000 based on average of pre-commercialization estimates for various zero-emission truck technologies.

[13] *Electric Trolleybuses for the LACMTA's Bus System*, Arieli Associates, 2006 accessed at www.metro.net/project_studies/atvc/atvc_research/

Table 1. Estimated infrastructure and maintenance costs for several near-dock, zero-emission container movement systems

	NG Catenary Hybrid Truck	Fuel Cell Hybrid Truck	Battery Electric Truck	Fixed Guideway
Infrastructure Required	Catenary lines and associated electrical infrastructure	Hydrogen fueling stations	Charging equipment	Track, container handling stations, associated electrical infrastructure
Infrastructure Cost	$5-$24 million	$17 million	$35-$40 million	$4,600-$6,600 million
Vehicle Costs (fleet of 1,000 trucks)	$282 million	$231 million	$265 million	Included in infrastructure costs
Total Infrastructure Cost	**$287-$306 million**	**$248 million**	**$300-$305 million**	**$4,600-$6,600 million**
Annual Non-vehicle Infrastructure O&M Costs	$0.05-$0.2 million*	Included in infrastructure costs	$2 million**	$172-$241 million
Annual Vehicle O&M Costs	$23 million	$36 million	$34 million	Included in infrastructure O&M costs
Total Annual O&M Cost	**$23 million**	**$36 million**	**$36 million**	**$172-$241 million**
20-year Total Cost	**$0.8 billion**	**$1.0 billion**	**$1.0 billion**	**$8.0-$11.4 billion**
Cost Differential Relative to Standard Diesel Trucks	**$0.0-$0.1 billion**	**$0.2 billion**	**$0.2 billion**	**$7.2-$10.6 billion**
Notes	Infrastructure cost based on estimates of $1.3-$6 million per mile. Higher costs include various security and control systems. *Infrastructure maintenance costs estimated at 1% of system cost annually[14].	Costs based on NREL pipeline delivery model[15]. Estimated $7.75/ annual kg dispensed. No pipeline infrastructure costs included.	Infrastructure costs based on charging and electrical infrastructure costs to support 1,000 trucks[16]. **Infrastructure maintenance costs unknown, but estimated based on a ten year replacement rate for vehicle chargers.	Infrastructure costs include container handling facilities located at 17 port terminals and the near-dock rail yard.

Wayside Power Options

Wayside power systems allow a vehicle to receive energy en-route. In the case of trucks the route is the roadway between the origin and destination. One could also include queue lanes or loading/unloading areas in the route, allowing for opportunity charging of the truck at the beginning and end of the route. One key feature of wayside power is that the truck remains in service and conducting normal business while receiving power. Fueling stations and charging stations that require the vehicle to stop or detour from its route are not considered wayside power.

[14] Based on confidential conversations with catenary system builder.

[15] *Hydrogen Pathways: Cost, Well-to-Wheels Energy Use, and Emissions for the Current Technology Status of Seven Hydrogen Production, Delivery, and Distribution Scenarios*, NREL, 2009

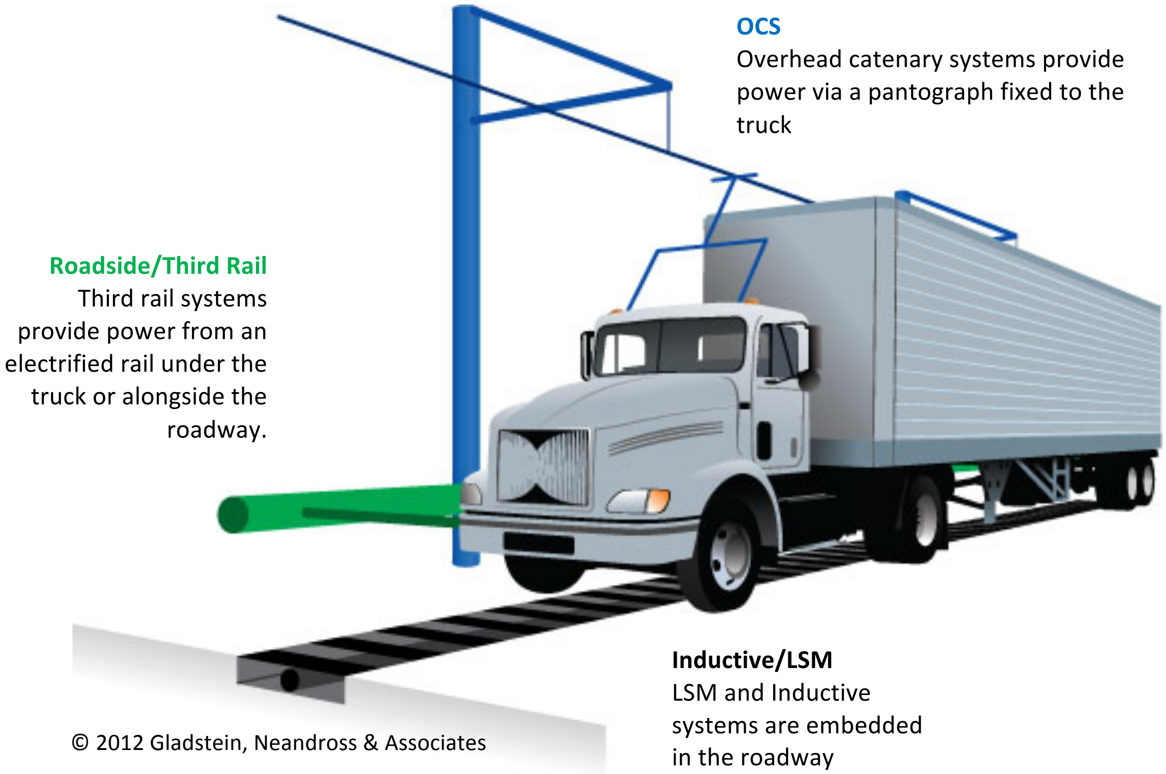
[16] *Technology Status Report - Zero Emission Drayage Trucks*, TIAX LLC, 2011.

Three wayside power systems that have been proposed for zero-emission trucks are:

1. Conductive systems including overhead, roadside, and "third rail" configurations;
2. Inductive or contactless systems; and,
3. Magnetic reaction systems such as linear synchronous motors.

Each system has advantages and disadvantages making a particular system more or less suited to a given application. In the case of drayage trucks serving the ports and the South Coast Air Basin, conductive systems are ultimately more practical. While inductive and LSM systems have the advantage of low visual impact and lend themselves to vehicle automation, the control of these systems in an open road environment with thousands of trucks mixing with existing traffic would be extremely complex. Further, the very low ground clearance required by these systems, on the order of two inches or less, creates risks to the system from standard road debris. Barring damage from road debris, contactless systems also benefit from lower system maintenance as there are no wearing contact interfaces. However, the lower system maintenance costs are offset by accelerated road wear due to the trucks consistently travelling along the same track in the road. Third rail and roadside systems are similar to overhead catenary systems (OCS) in many ways, but require significant safety barriers between the electrical contacts and pedestrians or motorists. Without confining conductive roadside or third rail systems to a dedicated roadway, it would be very difficult to ensure public safety from shock hazards. The primary disadvantage of overhead catenary systems is the visual impact from the overhead wires. However, the proposed locations for OCS are freeways and industrial settings where such concerns should be minimal.

The ease and efficiency with which each system can be integrated into existing roadways or added to new infrastructure also varies significantly amongst the various wayside power options. In general, wayside power options that integrate into the roadbed are apt to be more disruptive to the use of existing roadways during their construction. The construction of such systems would be expected to result in the extended closure of one or more lanes while the system is integrated into the roadway. In contrast, overhead and roadside systems can be constructed during offpeak hours; allowing the roadway to be closed only for a limited period of time each day and reopening to normal traffic during business hours. In new construction enviroments such as the proposed I-710 truck corridor, each system could be integrated into the design and construction of the roadway and the closure of existing lanes is not a concern. The choice of wayside power for new construction is far more likely to be driven by cost, maintenance, and safety considerations as well as the integration of the new system with existing wayside power systems (e.g. connecting the CA-47/103 with the I-710). All wayside power options shares some common construction challenges. Such challenges include 1)location of additional electrical infrastructure such as transmission lines and transformers, 2)interconnecting electrical systems for roadways travelling through more than one utility provider's service area (e.g. Edison and LA Department of Water and Power) and, 3)the ability of the system to accommodate bridges and grade crossings. The solution to some of these issues may be found in the hybrid truck's ability to seamlessly operate on or off the wayside power system, allowing the truck to span gaps in the wayside power system that may be necessary to address the challenges described above. Given the relative strengths and weaknesses of each wayside power option, cateneary systems are expected to be the preferred choice for both existing and new roadways.



Criteria	OCS	Roadside	Third Rail	Inductive	LSM
Road wear	✓	✓	•	•	×
Road debris impact	✓	✓	×	×	×
Visual aesthetics	×	•	•	✓	✓
Safety barrier requirements	•	×	×	✓	✓
Control complexity	✓	•	•	×	×
System wear	•	•	•	✓	✓
Vehicle automation	•	•	•	•	✓
Integration with existing road infrastructure	✓	✓	×	×	×

✓ Better • Average × Worse

Overview of a proposed catenary-accessible, hybrid electric truck platform

The catenary system of overhead wires to provide electricity for heavy duty vehicles has been in use for well over 100 years. Today, catenary systems can be found in applications including urban light rail, city buses, and mining equipment (Figure 12). Looking forward, Siemens Mobility Systems is currently demonstrating their eHighway system, a catenary based system for zero-emission trucks. This long history of catenary systems in heavy duty applications means that the technology and experience already exists to implement a zero-emission drayage truck system based on catenary power. However, it is only recently that hybrid/electric drive technology has matured to the point that a cost-effective hybrid system could be developed that allows for zero-emission operation on and off the catenary line.

In the proposed system discussed in the remainder of this market study, a diesel or natural gas hybrid truck is envisioned that can operate solely on electrical power from the catenary lines. Additionally, an onboard battery will allow the truck to operate in electric mode for a limited distance after disconnecting from the catenary system. A battery-electric range of less than ten miles is estimated to be sufficient to allow for zero-emission operation in the ports and near-dock rail yards and would eliminate the need to install catenary equipment inside of congested rail and port facilities. It is highly desirable to avoid the need for installation of additional equipment or infrastructure at the endpoints of a truck route for two reasons. First, many terminals and rail yards are highly space constrained and may not be able to accommodate additional infrastructure. Second, many truck routes begin or end at numerous warehouses located throughout Southern California. The installation of additional infrastructure at so many locations would likely prove cost prohibitive. A ten mile battery-electric range would likely allow trucks operating in environmentally sensitive neighborhoods, like the Gateway Cities, to exit nearby freeways and enter a zero emission mode of operation as the trucks service warehouses located in these communities. When travelling longer distances, the trucks would revert to a low-emission hybrid-electric mode, while retaining the operating range of typical drayage trucks (i.e. Ventura, San Diego, and Eastern Riverside counties). The hybrid-electric mode also provides the truck with a fall-back mode of operation near the ports in the case of electrical disruptions or system maintenance issues on the catenary system. This approach allows CHVs to serve the same locations currently served by diesel trucks, while confining infrastructure changes to public roadways.

Figure 10. Catenary truck concept drawing (source: Siemens Mobility)

An additional advantage of this Zero Emission Truck & Electric Catenary Highway (ZETECH) architecture is that the trucks can be built and deployed while the catenary infrastructure is being developed. In the early stages of deployment, these trucks would function as advanced hybrid-electric trucks. As catenary infrastructure is deployed, the trucks would provide zero-emission operation near the catenary system. As shown in Figure 11, the near-term goal would be to deploy catenary systems along CA-47/103 to address the needs of the communities around the near-dock rail yards. The system could then serve as the beginning of a long-term, zero-emission truck corridor along the I-710 and CA-60 freeways as proposed in the Southern California Association of Governments (SCAG) Regional Transportation Plan[17]. Finally, the system would be extensible to a regional level, allowing individual communities to deploy catenary systems in locations impacted by port-related goods movement such as the local roads leading to and from rail yards in San Bernardino, Commerce, Vernon and other industrialized areas saturated with warehousing and distribution facilities. The ability of the trucks to span gaps in the catenary infrastructure using battery or hybrid modes would allow each segment of the catenary system to be developed under independent timeframes.

[17] Ibid at 5

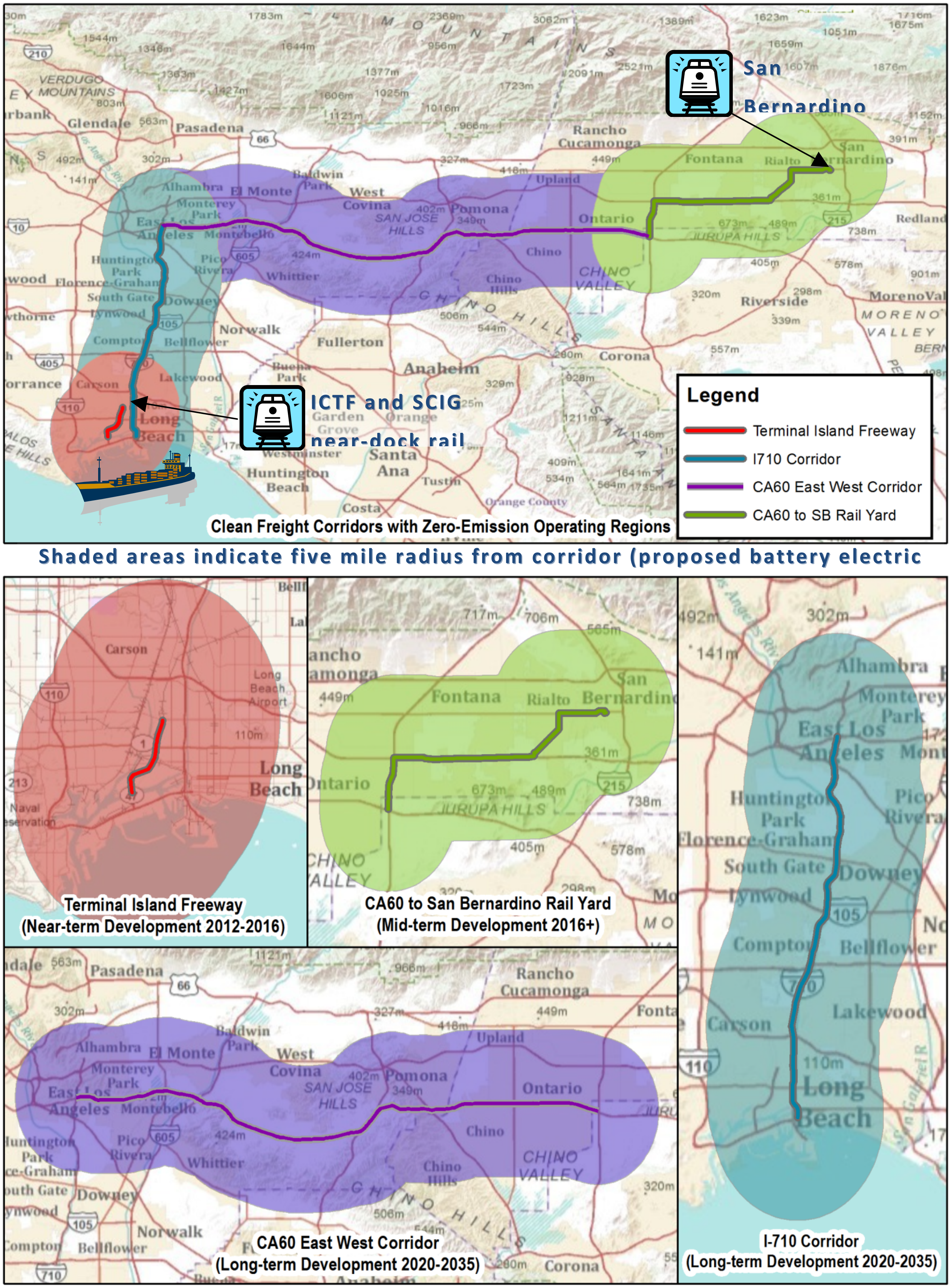


Figure 11. Key Southern California freight corridors

Source: Hitachi Construction Machinery

Source: King County Metro Transit

Source: Los Angeles METRO

Catenary powered vehicles are used in a wide variety of heavy-duty applications

Figure 12. Examples of catenary applications

Market Demand

Drayage services to near-dock rail facilities are only one potential market for a catenary-accessible hybrid truck of the type described in this paper. Expanded catenary systems would allow zero-emission trucks to operate along the major drayage transportation corridors such as the 710, 110, 60, and 10 freeways. Further, a hybrid truck platform with limited all-electric range would be of interest to companies whose current delivery schedules are restricted by noise ordinances and/or emissions limits in many cities, both in the U.S. and internationally. Finally, hybrid trucks are currently available as standard product offerings while next generation hybrids are actively being pursued by every major heavy-duty truck manufacturer under their DOE Supertruck[18] projects. Several component suppliers also offer systems and components with the right architecture for a catenary-accessible hybrid truck, providing truck manufacturers with a robust product base from which to develop CHVs suited to goods

[18] Supertruck is a Department of Energy program with the goal of developing a Class 8 truck that can achieve over 50% fuel efficiency.

movement. *The development of a catenary-accessible truck platform is an evolutionary development that does not require revolutionary technology advances*.

Near-dock rail yard market

The existing near-dock rail yard, the ICTF, currently handles approximately 750,000 lifts or 10% of the containers flowing through the ports annually. To support this level of activity requires a minimum of 300 drayage trucks[19], principally serving only the ICTF. While some motor carriers focus solely on transportation of cargo to and from the ICTF, the current drayage market contains numerous carriers that include the ICTF in some portion of their overall work. Therefore, while 300 dedicated trucks may be sufficient to handle current container flows, the reality is that many more trucks current service the ICTF.

Without the implementation of market drivers that motivate fleets to invest in new technologies to service the ICTF or SCIG, it is reasonable to assume that the near-dock rail yards will continue to be served by a mix of frequent and infrequent callers using diesel trucks. However, as previously discussed, the expansion to the ICTF and the development of the SCIG are likely to encounter pressure to utilize zero emission cargo movement systems. Enacting a requirement to use zero emission trucks or applying financial disincentives to traditional diesel trucks would create the market drivers needed to motivate new investment in trucks serving the near-dock rail yards. In such a scenario, the fleet of drayage trucks serving the rail yards would consolidate to minimize disincentive impacts or new investment costs, and ultimately be composed only of trucks whose primary work is to transfer cargo between the ports and the near-dock rail yards. While future increases in diesel fuel costs may ultimately drive drayage fleets to alternative fuel options, it is assumed that drayage fleets will not adopt zero emission truck technologies without compelling regulations or incentives. Therefore, any market for zero-emission drayage trucks serving near-dock rail yards will be a consolidated fleet of trucks principally dedicated to serving the rail yards. This fleet will also be primarily, if not entirely, composed of zero-emission trucks because it is unlikely that any market for zero-emission trucks would initially form in the absence of a compelling regulation or financial incentive.

Based on the assumptions described above, the potential market for zero-emission trucks serving the fully expanded ICTF and the SCIG, handling 2.6 million lifts per year, is approximately 1,000 trucks[19]. The SCIG is not scheduled to begin operations until 2016 or later and it is entirely feasible to develop a commercial CHV in this time frame. Considering the recent and significant investments in EPA 2007-compliant trucks made by the drayage industry, it is likely that some phase in of a zero-emission truck requirement would take place. This suggests that the 1,000-truck market potential would develop over several years, beginning in 2016.

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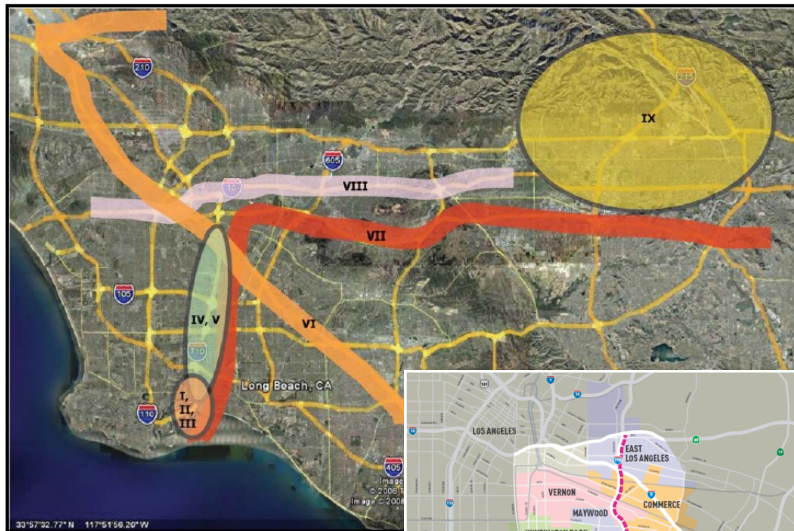
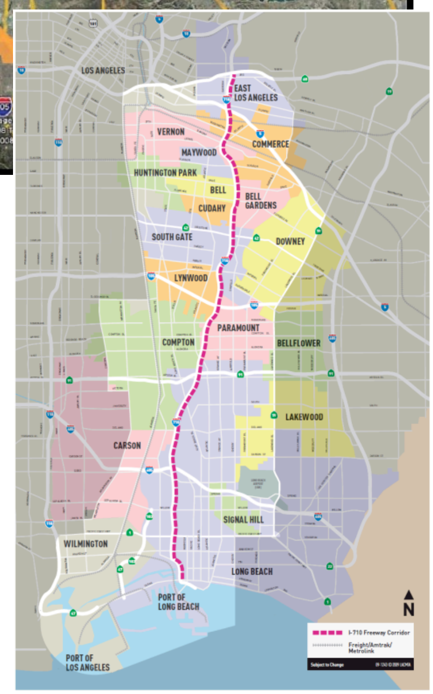
[19] Assumes a single drayage truck dedicated to near-dock service would complete 3 to 4 roundtrips per 8-hour shift and that the drayage trucks would be operated for two shifts per day (360 work days per year).

I-710 Corridor market

An estimated 40,000 to 50,000 truck trips per day on the I-710 are related to port cargo activities. Less than half of these trips can be accounted for by the 9,500 trucks actively serving the port terminals[20]. This implies that in addition to the 9,500 trucks comprising the registered port fleet, a second sizable fleet of trucks transport port cargo between warehouses, truck terminals, and customers. While no exact count of the size of this additional fleet is available, it would be reasonable to assume that the fleet is at least equal in size to the fleet of drayage trucks registered with the ports. In total, a fleet of at least 19,000 trucks are estimated to operate on the I-710 today.

As the I-710 expansion project moves forward, decisions will be made about the best technologies to reduce truck related emissions and traffic congestion from the corridor. In 2004, the local communities along the I-710 identified their preferred strategy, an expansion of the I-710 including the addition of a four lane dedicated roadway for trucks[21]. Since that time, much work has been done to evaluate the feasibility of zero emission trucks on the proposed dedicated roadway. The concept of zero emission trucks has gathered significant support by some I-710 project committee members[22] and the concept looks very promising for inclusion in the ultimate project recommendation, due in 2012. Whether the recommendation would specify catenary systems, other wayside power options, or opportunity charging, the truck platform considered in this market study would be easily adapted to suit the selected zero emission system.





A catenary system in the port can be expanded to the I-710 and the larger region, forming the backbone of an Electric Container Mover System for Southern California

The zero emission system selected by the I-710 project committee could be strongly influenced by a working system serving the near-dock rail yards at the ports. The benefits of using the same system for the CA-47/103 and the I-710 are significant.

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[20] *POLB Truck Move Data Analysis*, Port of Long Beach, August 17, 2011 and *Clean Truck Program Gate Move Data Analysis for the month of September 2011*, Port of Los Angeles, October 2011

[21] *I-710 Oversight Policy Committee Adopted Locally Preferred Strategy*, I-710 Oversight Policy Committee, 2005

[22] *Summary of the June, 2011 meeting of the Transportation Subject Working Group for the I-710 Corridor Project*, accessed at http://www.metro.net/projects_studies/I710/images/TSWG_meeting_2011_0314.pdf

The Environmental Impact Report for the I-710 corridor project is scheduled for completion in early 2013. Given the scope and complexity of implementing the expansion, it is likely that the corridor would not be ready for use by zero emission trucks before the 2020-2030 timeframe. However, CHVs would be able to use any portion of the catenary system as it becomes available rather than requiring completion of the entire corridor. Such an approach is consistent with the phased demonstration and deployment approach identified in the SCAG Regional Transportation Plan, with full scale deployments and commercialization efforts beginning in 2016 and continuing through 2035[23]. Accounting for projected port growth[24], a potential market of approximately 45,000 trucks is estimated to develop during the 2020-2030 timeframe.

Inner-city delivery and regional goods movement markets

Operation of a truck in electric-only mode not only eliminates tailpipe emissions, it also dramatically reduces noise. This ability to provide low noise operation should be of significant value to many companies that are currently prohibited from delivering goods to urban areas in the late evening and early morning hours due to local noise ordinances. Typically, trucks are restricted from delivery activities between 10 p.m. and 6 a.m., although the exact times vary by community. This forces companies to deliver goods during periods of higher traffic congestion, increasing delivery times, fuel use, and emissions. While standard diesel engines are not the only noise source associated with delivery activities, they are certainly a significant contributor and difficult to reduce below required thresholds[25]. A hybrid-electric truck that can operate in electric-only mode while in noise-sensitive regions could comply with noise restrictions and significantly improve freight logistics for many delivery fleets.

The size of the market that could benefit from a truck capable of limited, electric-only range is not precisely known. However, the strongest near-term demand is likely to be in the European Union (EU) with potential additional applications in the U.S. The EU has established a Coordinated Action addressing city logistics and associated noise impacts, attesting to the growing concerns regarding truck noise in inner city environments. While concerns regarding truck noise do not seem to be as significant in the U.S., fleets are eager to reduce operating costs and could achieve these reductions with the type of hybrid platform described in this study. In discussions with a major U.S. delivery fleet manager, there was significant interest in a hybrid truck that could provide continuous performance equivalent to a 12-liter class engine.

The importance of this market is significant. While the port fleet has the potential to be a key market, particularly for catenary-equipped trucks, the market will largely be driven by regulation or other market forcing measures. In contrast, the inner-city delivery markets and non-drayage markets would be viable based on the regulatory environment that already exists in many U.S. and European cities.

Other port markets

Since the inauguration of their Clean Air Action Plan (CAAP) in 2005, the San Pedro Bay Ports policy decisions regarding Clean Trucks have affected ports and the port truck market throughout the U.S. The

[23] Ibid at 5

[24] Projected growth of 242% container throughput by 2030. *Southern California Intermodal Gateway Draft Environmental Impact Report*, Table 1.5, Port of Los Angeles, 2011

[25] *Innovative Approaches in City Logistics - Inner-city Night Delivery*, NICHES (EC Coordinated Action)

ports of New York and New Jersey, Houston, Charleston, Seattle, Oakland, Vancouver, and others have all initiated programs with objectives similar to the Clean Trucks Program portion of the CAAP; i.e. the reduction of pollution from port trucks. Further, the requirements of the CAAP have resulted in the development of multiple natural gas truck offerings by three major truck OEMs. Prior to the CAAP, no truck OEM offered natural gas trucks suitable for drayage service. Daimler Trucks recently completed the delivery of its 1,000th natural gas truck over the last three years and counts both drayage and non-drayage fleets as customers of those trucks. The transformative impacts of the CAAP demonstrate that policy is an important and effective tool toward the development of clean, advanced technology.

The pending decision regarding the SCIG project provides the Ports with the opportunity to maintain their leadership role and would likely have similar results to the CAAP; pushing the development of compliant trucks and spurring similar actions by other ports over the next several years. As previously mentioned the San Pedro Bay Ports handle approximately 40% of all containerized goods entering the U.S. and utilize a fleet of roughly 9,500 drayage trucks. Using these figures as a guide, approximately 14,000 additional drayage trucks operate at other U.S. ports. Some fraction of these trucks perform near-dock or off-dock drayage to rail yards and could be subject to rules similar to those that could be included for the SCIG project. While the degree of near-dock and off-dock cargo handling varies by port, using the SBP Ports as a guide[26] suggests a future market of 2,600 drayage trucks in near-dock and off-dock operations at other ports.

Market Summary

Drayage trucks serving the SCIG and ICTF will present a strong market for approximately 1,000 catenary hybrid-electric trucks, beginning in 2016. The expansion of the I-710 corridor will continue to expand this market to nearly 46,000 trucks, beginning in 2020 (see Figure 13). In addition to these specific market opportunities, the development of a Class 8 hybrid-electric platform with limited battery-electric range has further market applications in both the U.S. and E.U. While the exact size of this market is difficult to predict due to its scope, the general trend of hybridization for improved fuel economy and the related benefits to noise and emissions suggest that a fully capable, Class 8 hybrid platform would be of significant interest to the broader market.

[26] Approximately 19% of cargo at the San Pedro Bay Ports is destined for near-dock or off-dock rail yards per *Southern California Intermodal Gateway Draft Environmental Impact Report*, pg. 1-23, Port of Los Angeles, 2011

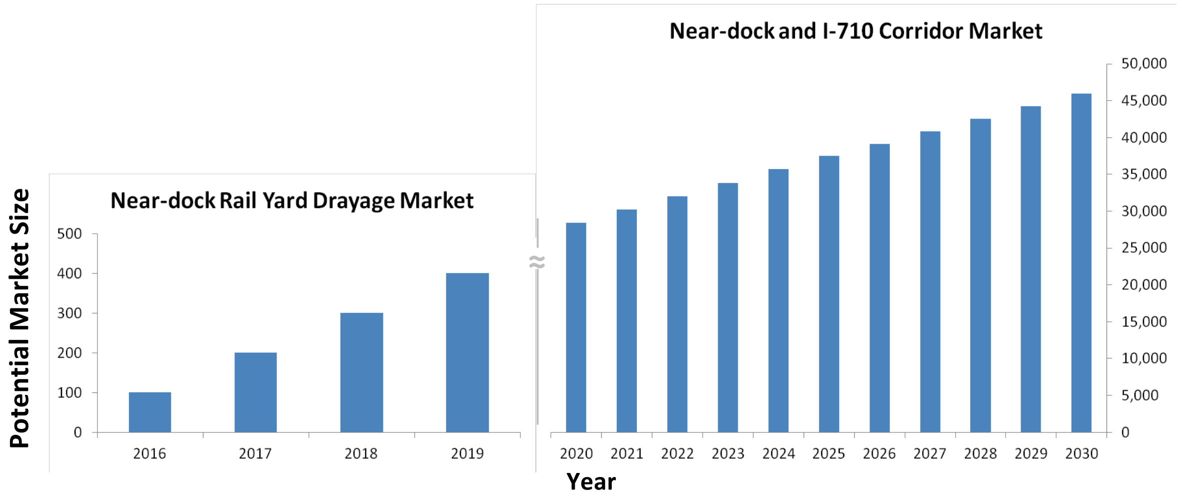

Figure 13. Projected potential market size for catenary-hybrid drayage trucks in the South Coast Air Basin

Cost of Ownership

Slim profit margins in local and regional delivery markets compel trucking companies to seek out the lowest cost truck technologies that will reliably meet their needs. Currently, diesel trucks dominate these markets, although natural gas has made significant inroads in many markets over the last several years due to increasingly stricter emissions requirements, increasing diesel fuel costs, and financial incentives. The U.S. Energy Information Administration (EIA) Annual Energy Outlook projects continuing increases in diesel fuel prices while CARB fleet rules and emissions mitigation measures like those which could be included in project approvals such as the SCIG EIR will continue to exert downward pressure on truck emissions in California. Given the history of emissions programs migrating from California to the rest of the country, the dual pressures of increasing fuel prices and decreasing emissions are likely to be felt in many markets across the U.S. Additionally, new federal fuel efficiency requirements for trucks will drive manufacturers to use advanced (and costlier) technologies in typical diesel trucks. In this context, it is important to consider the cost of ownership for zero-emission alternatives to diesel trucks. Figure 14 below, summarizes a comparison of the 8-year cost of ownership for several heavy duty truck technologies that are zero-emission capable. Typical diesel truck costs are provided as a baseline to compare against diesel catenary hybrid vehicles, natural gas CHVs, fuel cell hybrid vehicles (FCHV), and battery-electric vehicles (BEV) in near-dock and regional haul applications. Each alternative technology can provide zero emission performance. In the case of catenary hybrids, zero emission operation is possible within approximately five miles of the catenary system and is noted as area-specific zero emission operation. For near-dock drayage applications, a five to ten mile range would be sufficient to consistently maintain zero emission operation. Note that the cost of ownership analysis assumes that CHVs in regional operation would be powered primarily by their internal combustion engine. This is a worst case assumption where no catenary infrastructure is available beyond the Terminal Island freeway.

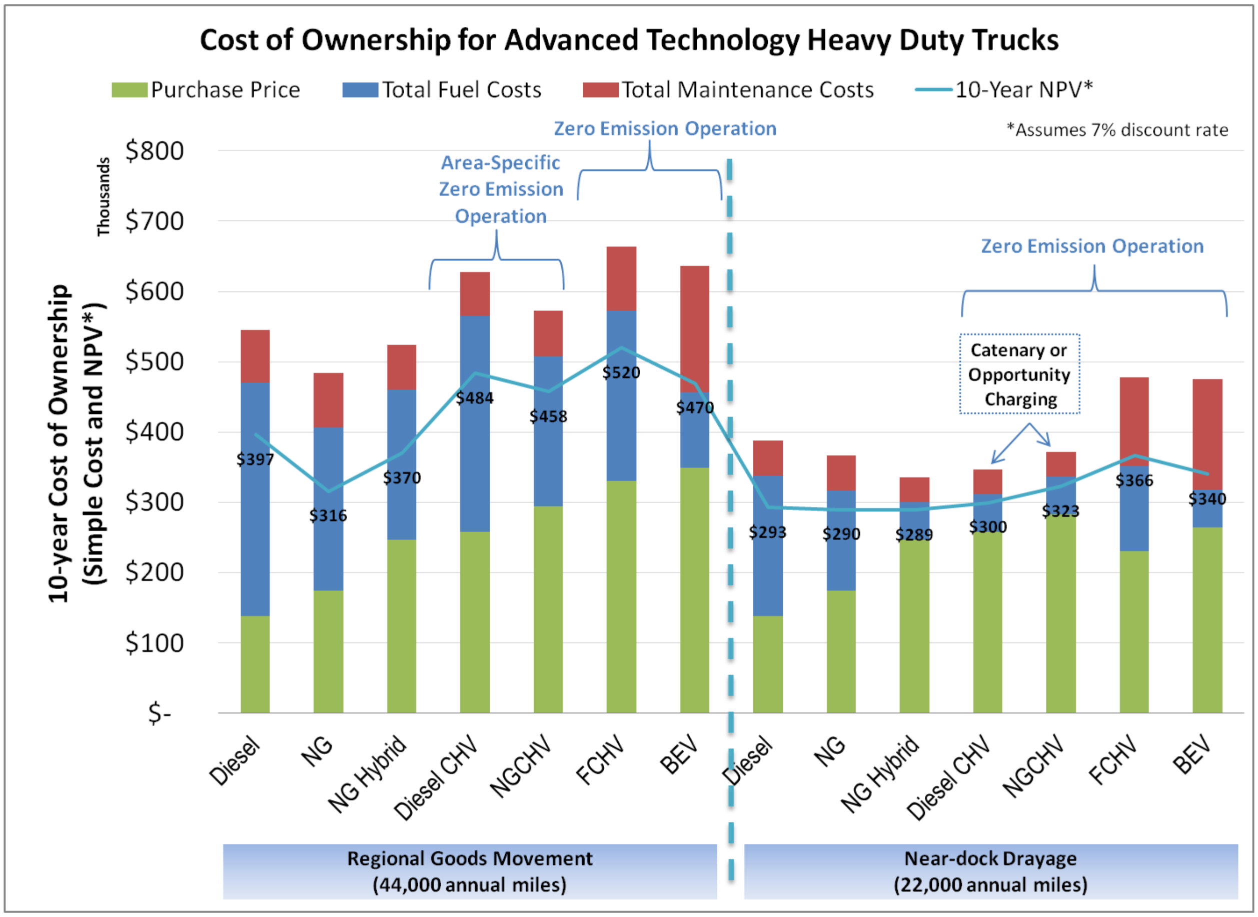

Figure 14. 8-year cost of ownership for advanced technology heavy duty trucks

As shown in Figure 14 and detailed in Table 2, natural gas CHVs are cost competitive with traditional diesel trucks in regional haul applications. The NGCHV achieves this cost competitiveness through significant reductions in fuel costs and modest reductions in maintenance costs relative to the baseline diesel truck. In near-dock applications, where baseline fuel costs are significantly lower, CHVs are the lowest cost zero emission option. BEVs are cost competitive in this analysis, but rely strongly on the availability of electricity at rates that are not significantly inflated by high electricity demand charges commonly encountered by BEV owners. Battery electric vehicle costs are increased due to battery stack replacement costs of approximately $70,000 midway through the truck's ten year life[27] while FCHVs incur additional costs from frequent fuel cell stack replacements every two years, at a cost of $20,000[27].

[27] Ibid at 16

Table 2. Total cost of ownership data for advanced technology heavy duty trucks

	Regional Drayage						
	Diesel	NG	NG Hybrid	Diesel CHV	NGCHV	FCHV	BEV
Vehicle Price	$ 115,000	$145,000	$205,000	$ 215,000	$ 245,000	$275,000	$290,000
FET	$ 13,800	$17,400	$24,600	$ 25,800	$29,400	$33,000	$34,800
Sales Tax	$ 9,488	$11,963	$16,913	$ 17,738	$20,213	$22,688	$23,925
Purchase Price	$ 138,288	$174,363	$246,513	$ 258,538	$ 294,613	$330,688	$348,725
Total Maintenance Costs	$ 75,276	$77,087	$64,514	$ 62,704	$64,514	$91,186	$180,184
Total Fuel Costs	$ 332,200	$232,800	$213,400	$ 306,646	$ 213,400	$242,291	$107,556
Total Cost of Ownership	**$ 545,764**	**$484,249**	**$524,427**	**$ 627,887**	**$ 572,527**	**$664,164**	**$636,464**
5-Year NPV	**$ 285,384**	**$252,164**	**$312,160**	**$ 383,157**	**$ 381,834**	**$431,941**	**$429,168**
7-Year NPV	**$ 334,475**	**$280,210**	**$337,869**	**$ 427,655**	**$ 415,316**	**$466,093**	**$446,967**
10-Year NPV	**$ 396,712**	**$315,768**	**$370,463**	**$ 484,068**	**$ 457,764**	**$520,269**	**$469,533**
Fuel Economy (miles/unit fuel)	6	5.5	6	6.5	6	4.54	0.45
Fuel Price-10 year Avg (DGE, lbs H2, or kW-hr)	$4.53/ DGE	$2.91/ DGE	$2.91/ DGE	$4.53/ DGE	$2.91/ DGE	$2.50/ lb H_2	$0.11/ kW-hr
Maintenance Cost ($/mi)	$0.17	$ 0.18	$ 0.15	$0.14	$0.15	$ 0.21	$ 0.41
Annual Mileage	44,000	44,000	44,000	44,000	44,000	44,000	44,000
Vehicle Life (years)	10	10	10	10	10	10	10

	Near-dock Drayage						
	Diesel	NG	NG Hybrid	Diesel CHV	NGCHV	FCHV	BEV
Vehicle Price	$ 115,000	$145,000	$205,000	$215,000	$ 235,000	$ 192,000	$ 220,000
FET	$ 13,800	$17,400	$24,600	$25,800	$ 28,200	$ 23,040	$ 26,400
Sales Tax	$9,488	$11,963	$16,913	$17,738	$ 19,388	$ 15,840	$ 18,150
Purchase Price	$ 138,288	$174,363	$246,513	$258,538	$ 282,588	$ 230,880	$ 264,550
Total Maintenance Costs	$ 49,912	$50,628	$35,680	$34,942	$ 35,680	$ 126,176	$ 156,371
Total Fuel Costs	$ 199,320	$142,267	$53,778	$53,778	$ 53,778	$ 121,145	$ 53,778
Total Cost of Ownership	**$ 387,520**	**$367,257**	**$335,970**	**$347,257**	**$ 372,045**	**$ 478,201**	**$ 474,699**
5-Year NPV	**$ 224,745**	**$236,872**	**$264,665**	**$275,621**	**$ 298,380**	**$ 302,814**	**$ 320,768**
7-Year NPV	**$ 254,772**	**$260,111**	**$275,443**	**$286,309**	**$ 309,158**	**$ 333,018**	**$ 329,219**
10-Year NPV	**$ 292,839**	**$289,574**	**$289,106**	**$299,860**	**$ 322,821**	**$ 366,398**	**$ 339,933**
Fuel Economy (miles/unit fuel)	5	4.5	0.45	0.45	0.45	4.54	0.45
Fuel Price-10 year Avg (DGE, lbs H2, or kW-hr)	$4.53/ DGE	$2.91/ DGE	$0.11/ kW-hr	$0.11/ kW-hr	$0.11/ kW-hr	$2.50/ lb H_2	$0.11/ kW-hr
Maintenance Cost ($/mi)	$0.23	$ 0.23	$ 0.16	$ 0.16	$0.16	$0.57	$0.71
Annual Mileage	22,000	22,000	22,000	22,000	22,000	22,000	22,000
Vehicle Life (years)	10	10	10	10	10	10	10

Manufacturers and vendors in the hybrid truck market

The manufacturer and vendor supply chain for heavy duty hybrid trucks is rapidly developing in both breadth and depth. Most major Class 8 truck manufacturers in the United States are currently engaged in hybrid truck research and development (Figure 15). The U.S. Department of Energy Super Truck program is only one example of active partnerships between truck manufacturers, engine manufacturers, and hybrid component suppliers. Beyond the Super Truck effort, Kenworth, Peterbilt, Freightliner, and International all offer a hybrid-equipped semi-tractor for purchase. While these trucks are limited to light Class 8 applications, the manufacturers have developed and continue to develop experience with hybrid drive trains. Volvo has also recently announced the development of the second generation of their hybrid system. Volvo is unique is the current Class 8 market space as they are the only manufacturer with a vertically integrated supply chain that includes the hybrid system, engine, and truck.

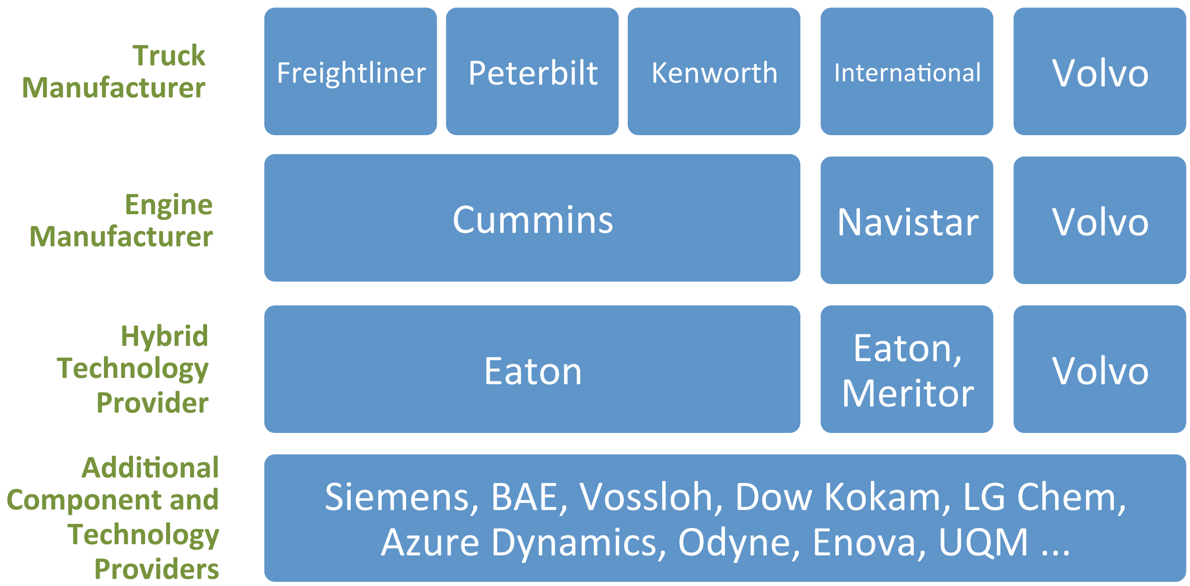

Figure 15. Existing relationships of truck and component manufacturers developing Class 8 hybrids

Of the hybrid systems providers, Eaton has dominated the space and currently offers their system in trucks from four major truck manufacturers. However, outside of the U.S. heavy duty truck market, other hybrid system providers have years of experience in heavy duty hybrid systems. Transit bus applications have been a major contributor to development of hybrid technology in heavy duty vehicles. Manufacturers such as BAE, Siemens, and Vossloh have sold thousands of hybrid systems into the bus market, including trolleybus systems with catenary power sources. These manufacturers have their own supply chains of numerous battery, motor, and power electronics manufacturers.

Siemens has recently demonstrated a working prototype of their catenary hybrid truck technology on a closed test track in Europe, shown in **Error! Reference source not found.**. The success of this system clearly shows that the state of the art in catenary hybrid systems is sufficient to move the technology to real world demonstration and product development programs.

Figure 16. Siemens catenary hybrid truck in operation (source: Siemens Mobility)

Summary

The potential benefits of a catenary-accessible hybrid truck platform, as considered in this market study, are significant. Despite major advances in emissions performance, heavy duty diesel trucks operating in dense urban areas will continue to face pressure to achieve zero emission operations, particularly in areas like the South Coast Air Basin with historically poor air quality. Rising diesel fuel prices will simultaneously place additional pressures on heavy duty truck manufacturers and their customers. Catenary hybrid trucks can simultaneously address both of these issues will providing operational flexibility at a similar or lower cost of ownership as other zero-emission technologies. Further, the path to catenary hybrids is based on existing and well understood technologies that can be integrated today without the need for dramatic improvements in cost, reliability, or durability. Compelling features of catenary hybrids include:

- Flexible truck platform that will allow for zero-emission operations in key regions of interest while still providing the standard operating range of local and regional haul goods movement trucks.
- Based on existing hybrid technologies and demonstrated system components, making the deployment of a catenary system for near-dock rail yards feasible in the 2016-2020 time frame.

- Unlimited zero-emission range when connected to a catenary system.
- Extensible system that can grow from near-dock facilities to the I-710 corridor and eventually comprise a zero emission electric container movement system sought by the ports.
- Ability to use natural gas in extended off-catenary operation, completely eliminating diesel emissions.
- Potential local market size of up to 46,000 trucks. Additional markets for the truck platform (with or without the catenary interface) include:
    - Applications where low noise operation is desirable, particularly in EU countries.
    - Fleets affected by emissions regulations like current California fleet rules where a zero or ultralow emission truck would provide additional compliance flexibility.
- Similar or lower cost of ownership relative to other zero-emission technologies.