ORNL/TM-2017/77-R1

Transportation Electrification Beyond Light Duty: Technology and Market Assessment

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September 2017

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Energy and Transportation Science Division

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Date Published: September 2017

Prepared by
Energetics Incorporated
Under subcontract to
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ACRONYMS AND ABBREVIATIONS

ACRP	Airport Cooperative Research Program
ANL	Argonne National Laboratory
APTA	American Public Transportation Association
APU	Auxiliary power unit
ARB	California Air Resources Board
BEV	Battery electric vehicle
CHE	Cargo handling equipment
CNG	Compressed natural gas
DOE	Department of Energy
DOT	Department of Transportation
EERE	DOE Office of Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
EV	Electric vehicle
FAA	Federal Aviation Administration
GPU	Ground power unit
GSE	Ground support equipment
GVW	Gross vehicle weight
hp	Horsepower
JEMS	Jobsite Energy Management System
LAX	Los Angeles Airport
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MTDC	Medium Truck Duty Cycle project
NCFO	National Census of Ferry Operators
NEC	Northeast Corridor
NREL	National Renewable Energy Laboratory
NVH	Noise, vibration, and harshness
NYSDOT	New York Department of Transportation
NYSERDA	New York State Energy Research and Development Authority
OEM	Original equipment manufacturer
OGV	Ocean going vessel
ORNL	Oak Ridge National Laboratory
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
PM	Particulate matter
POLB	Port of Long Beach
PTO	Power take off
RORO	Roll-on roll-off
RTG	Rubber tired gantry
SCAG	Southern California Association of Governments
SU	Single unit
TEU	Twenty-foot equivalent unit
TIM	Time in mode
TIP	Truck Industry Profile

VIN	Vehicle identification number
VIUS	Vehicle Inventory and Use Survey

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ACKNOWLEDGEMENTS

The authors are grateful for the support of the Department of Energy (DOE) Vehicle Technologies Office (VTO) and gratefully acknowledge the support and guidance provided by Rachael Nealer, PhD, of VTO. The authors would also like to thank the stakeholders who participated in the Beyond Light Duty: Electrification of Goods and People Movement Workshop and provided their insightful review of the draft of this report.

EXECUTIVE SUMMARY

Commercial fleets form the backbone of the nation's economy, getting people and the things they need to the places they need to go and performing services necessary to keep public and private physical infrastructure in working order. Commercial fleets include a wide range of vehicle and equipment types, typical uses, and sizes, and involve millions of on-road and off-road vehicles. This diversity means there is no single solution for reducing fuel consumption and operating costs.

This document focuses on electrification of government, commercial, and industrial fleets. These fleets have been divided into three market segments based on equipment use: service fleets, goods movement, and people movement. In particular, it addresses highway vehicles not used for personal transport; non-highway modes, including air, rail, and water; and non-road equipment used directly or in support of these uses.

Electrification offers the potential for addressing future transportation energy and emissions challenges in portions of the commercial fleet. Some fleets are already making steps toward electrification, such as those used for airport ground support and local delivery. Other fleets are years or decades away from any significant electrification due to challenging duty cycles, functional requirements, or remote operation. Commercial fleets purchase vehicles as tools to do specific jobs based on business case analysis. Therefore, electrification presents an opportunity for these fleets if the electric drive vehicles can fulfill one of two conditions: 1) satisfactorily perform the intended mission at a total cost of ownership that is equal to or less than conventional vehicles; or 2) provide valuable additional features at an added cost that the market is willing to pay.

Within highway vehicles, there are electric options available for nearly every application, with the exception of long haul trucks. Although long haul tractors are responsible for the largest fraction of highway heavy vehicle fuel consumption, their duty cycle and daily trip distances are poorly suited for electrification. However, several other applications offer particularly promising potential for significant energy and/or environmental benefits from electrification: transit buses, school buses, regional and local delivery trucks, utility service vehicles, and refuse trucks.

There are challenges associated with getting to a favorable operational and business case for commercial fleets. While electrification in the light duty market is making progress, this success does not translate readily to commercial vehicles. Because of the higher, sustained power and daily energy demands, rugged operational environments, and often high lifetime miles or hours for medium and heavy vehicles, light duty technologies cannot simply be scaled up. As a result, electrification of commercial vehicles is at an early stage of development and there are few production vehicle options available. Stakeholders identified several key challenges to expanding in this market:

- Sales volumes are low and resulting costs are high, which is problematic for the business case in getting the payback on investments that most fleets are seeking.

- There are few suppliers of electric drive commercial vehicles and many of these companies are new and relatively small, also resulting in high cost and delivery delays.

- Many fleets are unwilling to consider purchasing equipment from these new and unproven suppliers due to perceived risk.

- Manufacturers have difficulty scaling up to higher volumes because of component supply constraints. As a result, fleets that have successfully completed pilot projects are unable to pursue full-scale deployment or are frustrated by delivery delays. At this time, larger vehicle manufacturers and Tier 1 suppliers for commercial vehicles are not actively participating in the electric drive market to any significant degree.

At the current stage of development, electric drive vehicles (particularly battery electric vehicles) cannot always meet the worst-case duty cycle requirements of commercial applications, limiting use to a subset of the market. The sufficiency of installing charging infrastructure at the fleet location, and its cost, is dependent on fleet operating profiles. System requirements and cost are driven by power and recharge speed demands which, for example, are very different for a transit bus compared to a delivery fleet with frequent and prolonged idling. Where public charging is required to meet operational needs, sufficient infrastructure density is of concern to fleets. Depending upon the location and system requirements, this infrastructure can be costly to construct. The lack of standards for medium and heavy vehicle charging equipment further hinders development of infrastructure.

Electrified work trucks and vocational trucks can be particularly challenging to produce and certify. These vehicles are often produced by upfitting a powertrain and work body to a mass produced chassis. The upfitter then serves as the manufacturer of record and must take responsibility for certification of the vehicle to federal regulations. This process is time consuming and costly and these companies must recoup the cost over their relatively small production volumes. In addition, when the truck original equipment manufacturer (OEM) makes a change to the vehicle, no matter how small, the upfitter must recertify the vehicle. Upfitters expressed the need to collaborate more closely with the OEMs.

There are challenges to developing a robust market for electrified commercial vehicles, but there are also opportunities in this market.

- The performance, availability, and cost of electric drive commercial vehicles could be improved through basic and applied research in energy storage, electric drives, vehicle systems, and related technologies. The challenges presented by medium and heavy vehicle requirements represent important research gaps.

- Laws and incentives could encourage the development and use of electric drive vehicles in the goods and people movement segments and the development of a resilient electric drive vehicle and component industry.

- Current regulations and certification procedures can either help or hinder the development of electric drive commercial vehicle products. Adjustment of these regulations could encourage additional deployment of vehicle options in the short and long term.

- Fleets can support electric drive vehicle deployment by gaining a better understanding of their drive and duty cycles and the necessary capabilities of fleet vehicles to meet these duty cycles. This understanding will help fleets identify where electric drive vehicles can be applied successfully and avoid early failures due to mismatched vehicles and applications. Fleets can also seek out objective third-party information about electric drive vehicles and their current and future availability to gain a better understanding of the market for their long-term vehicle purchase planning.

- Fleet owners could incorporate into decision-making both the economic and non-monetary value of enhanced vehicle operator and commercial customer satisfaction that electrification conveys. Benefits that are non-monetary or difficult to monetize can be significant and may be the primary motivation for electrification.

- Stakeholders identified the need for objective third parties to provide unbiased and reliable information that explains the benefits and challenges of these technologies and their potential in the future.

The commercial vehicle market is a complex system with many inter-related players. Deploying electric-drive vehicles in this market requires addressing all parts of this system, including the manufacturing, purchasing, research, and regulations. Achieving success for electric-drive vehicles in the commercial market will be a long process, but a number of innovative and dedicated people and companies from each of these spheres are actively engaged in addressing these challenges.

1. INTRODUCTION

Electrification of the transportation sector can provide a number of benefits, such as reducing the economic and security costs of petroleum dependence, improving local air quality, and reducing operating costs. There currently are a number of light duty electric vehicle models that are produced by major manufactures at commercial scale and available for purchase in the United States. Meanwhile, the market for electric vehicle technology in heavier vehicles is less mature. This report provides a basic overview of transportation market segments that could potentially be involved in electrification beyond light duty highway vehicles and provides the background necessary to understand the potential for electrification in these markets. This report outlines a framework for selecting specific applications with promising potential for electrification; however, it does not examine these applications in detail. This document contributes to the understanding of the challenges and opportunities for electrification in the service and goods and people movement fleets in order to guide policy makers and researchers in identifying where federal investment in electrification could be most beneficial.

1.1 BACKGROUND

Since the 1970s, the United States has made significant strides in improving the nation's air quality and reducing dependence on petroleum. These accomplishments are due to stringent federal regulations on fuel efficiency and emission of criteria pollutants. In order to meet fuel consumption and air quality goals, Federal and State governments must address all economic sectors: electricity utilities, transportation, industry, commercial and residential, and agriculture.

Today, the United States is the world's largest user of oil and refined petroleum products (CIA, 2014). Much of this demand is created by the transportation sector, which is almost entirely dependent on petroleum products. The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) and its stakeholders have explored the technology, economic, and operational considerations related to PEV application in the transportation sector beyond light duty highway vehicles. These discussions began to identify opportunities, challenges, and research gaps. The University of California, Davis, Institute of Transportation Studies hosted a workshop on April 27, 2016 to identify high-potential electrification market opportunities beyond light duty. This document reviews the workshop's feedback on existing technology and market availability for commercial vehicle electrification. Both quantitative and qualitative analysis techniques are used to consider operational, economic, normative[1], and technical challenges and opportunities.

This report documents the information collected on existing plug-in electric vehicles and serves as the backbone for future research on commercial vehicle electrification. The scope of this study includes highway vehicles and non-highway mobile equipment in areas with the primary objective of providing vocational services and moving goods and people. The scope covers commercial medium and heavy highway vehicles, airport ground support equipment, and cargo

[1] The term normative is used to refer to a broad range of issues that arise from values, beliefs, perspectives, and behaviors. Examples include corporate culture, standard operating procedures, technological bias, driver behavior, valuation of environmental or social impact, etc.

handling equipment in private, utility, and government fleets. Stakeholder input is included anonymously throughout the report.

1.2 SCOPE

This report examines the status and potential for electrification of fleet vehicles and mobile equipment. Where possible, information is provided on fleet size, sales, and available plug-in options. For the purposes of this document, PEVs include battery electric vehicles (BEVs) that operate solely on electricity and plug-in hybrid electric vehicles (PHEV) that also include an internal combustion engine.[2]

This document focuses on electrification of government, commercial, and industrial fleets. These fleets have been divided into three market segments based on equipment use: service fleets, goods movement, and people movement. In particular, it addresses highway vehicles not used for personal transport; non-highway modes, including air, rail, and water; and non-road equipment used directly or in support of these uses. The following sections describe the applications covered by each segment and the types of vehicles and equipment included in each. It also provides an overview of the market; currently available electrified products and their level of development; and a discussion of the known challenges relating to their purchase and use. A complete listing of identified electric products is included in Plug-In Vehicle Products.

This document does not cover light-duty on-highway vehicles in weight classes 1 and 2, as this is a market for which products are available to consumers at commercial production scale. Also, the light duty market differs substantially from the commercial truck market, and vehicle purchasers use very different decision processes to select vehicles and technologies. This report also does not address highway vehicles or non-highway equipment used for recreation, such as all-terrain vehicles, or smaller equipment owned by households, such as lawnmowers. This study does not cover the market for charge sustaining hybrid electric vehicles or fuel cell vehicles, as these technologies are not within the scope of the current project.

Within this document, technologies or vehicles will be referred to as “commercial” or “commercially-available” if the vehicle is being built in series production and intended for retail or fleet sales. For many PEVs, production volumes are very low but can still be considered commercial if they are not custom-built one-off designs.

1.3 SEGMENT OVERVIEWS

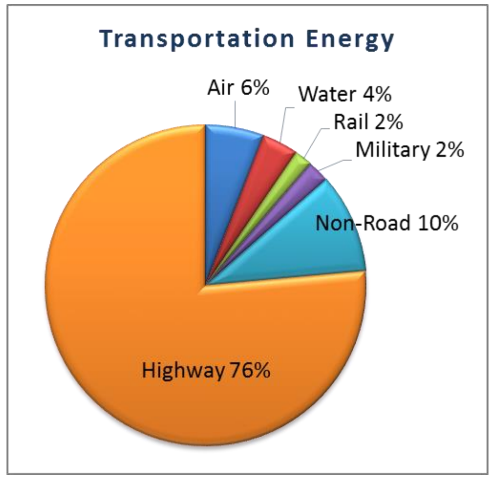
This section provides an overview of various transportation system modes used to provide services, goods movement, and people movement. This overview is intended to give the reader

[2] PHEVs are similar to hybrid electric vehicles but with larger batteries and the ability to recharge directly from an electrical source. They include an electric motor and a combustion engine in a parallel configuration such that either may be used to move the vehicle. Some provide the ability to operate in an electric only mode. Another type of PEV, the extended range electric vehicle (EREV), uses an all-electric drivetrain like the BEV but with a smaller battery and combustion engine that can be used as a generator to recharge the battery if needed. Since the distinction is not relevant to the objectives of this study, EREVs are classified here as PHEVs.

some perspective on the role of each mode within these segments as well as the relative impact that electrification programs in these modes and segments may have on national energy consumption and associated environmental impacts.

1.3.1 Transportation Modes

Transportation accounts for roughly one third of all energy used by the U.S. economy. As shown in Figure 1-1, highway vehicles account for the majority (76%) of the energy consumed by all mobile sources, with light duty vehicles responsible for about 70% of highway consumption. Non-road equipment fleets account for the second largest, though much smaller, quantity of energy consumed. Therefore, light duty highway vehicles have been the primary focus of government energy and emission reduction programs. However, federal emission standards for heavy vehicles and non-road equipment have been tightening and the first fuel consumption regulations for medium and heavy vehicles became effective in 2011. In addition to these newer regulations, there are federal research and development efforts aimed at commercial vehicle electrification, but the level of technological and market maturity lags far behind light duty vehicles.

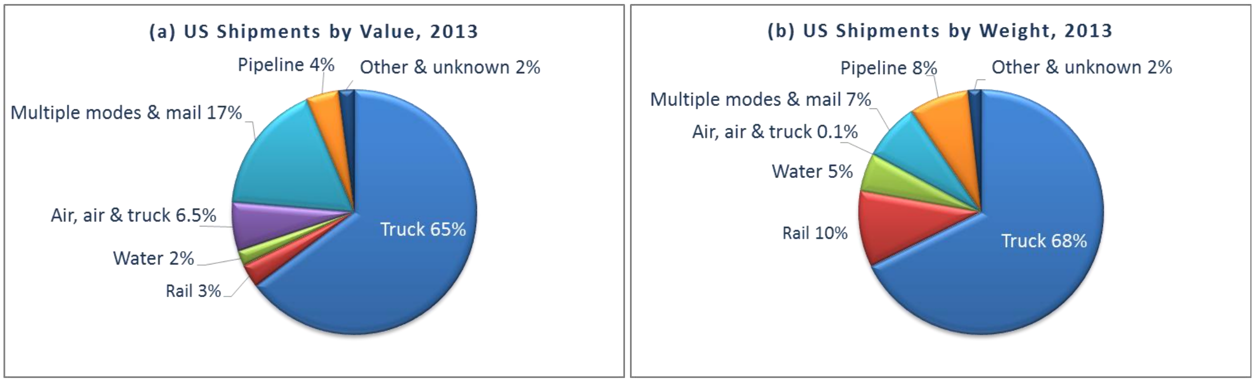


Source: AEO 2016 (EIA, 2016); EPA NONROAD model (U.S. EPA, 2009), analysis by Energetics Incorporated.

Figure 1-1. Estimated 2015 Mobile Equipment Energy Consumption

1.3.2 Goods Movement

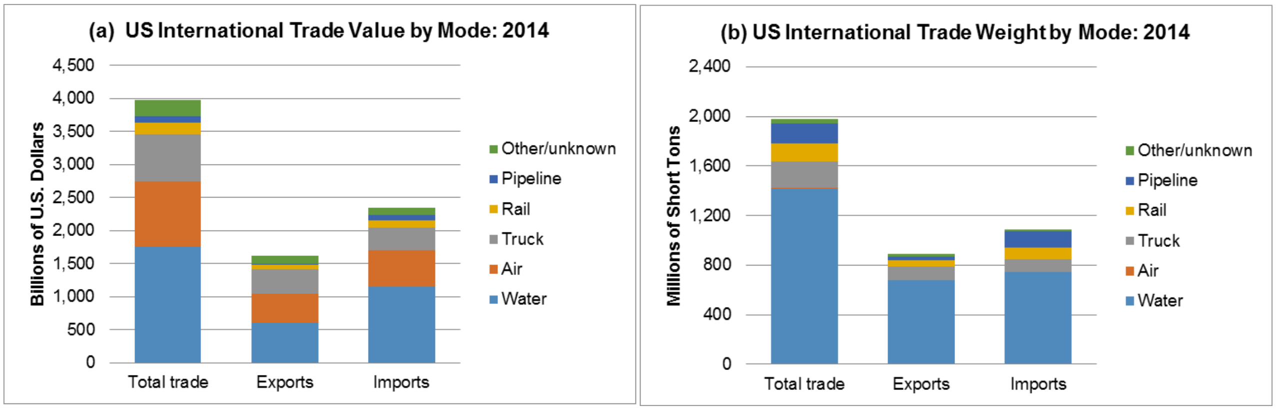
The U.S. Department of Transportation (DOT) estimates that the transportation system moved 20 billion tons of freight in 2013, valued at $18 trillion (2007$). As shown in Figure 1-2, highway trucks move about two thirds of goods as measured by both weight and value. A large portion of goods movement is regional or local, with about 50% of the weight and 40% of the value of goods moved less than 100 miles between origin and destination in 2007. Trucks are the primary choice for local and regional freight, accounting for more than 80% of goods movement under 250 miles whether measured by value, tonnage, or ton-miles. This market segment also includes off road vehicles and equipment that move people and cargo in complex locations such as airports and seaports.



Source: Bureau of Transportation Statistics, *Freight Facts and Figures 2015* (U.S. DOT, 2016).

Figure 1-2. Modal Share of U.S. Freight Shipments by (a) Value and (b) Weight

Figure 1-3 shows that about 2 billion tons of freight passed through U.S. borders in 2014, with U.S. ports handling 72% by weight but 44% by value. Air freight transport is typically reserved for high-value and/or time-sensitive cargo, and airports handled about 25% of freight by value. Trucks are the most common mode used to move imported and exported goods between international gateways and inland locations (U.S. DOT, 2016).

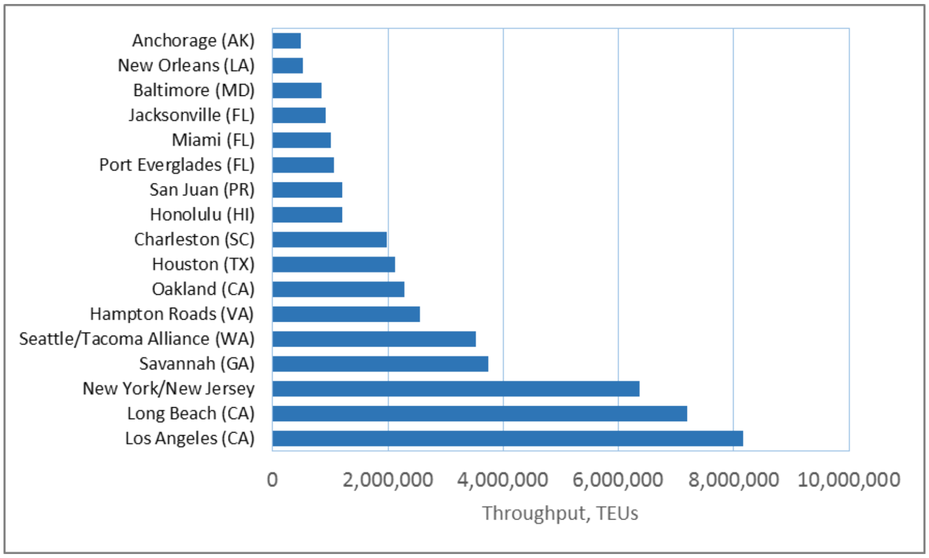


Source: Bureau of Transportation Statistics, *Freight Facts and Figures 2015* (U.S. DOT, 2016).

Figure 1-3. U.S. International Trade by Mode, by (a) Value and (b) Weight

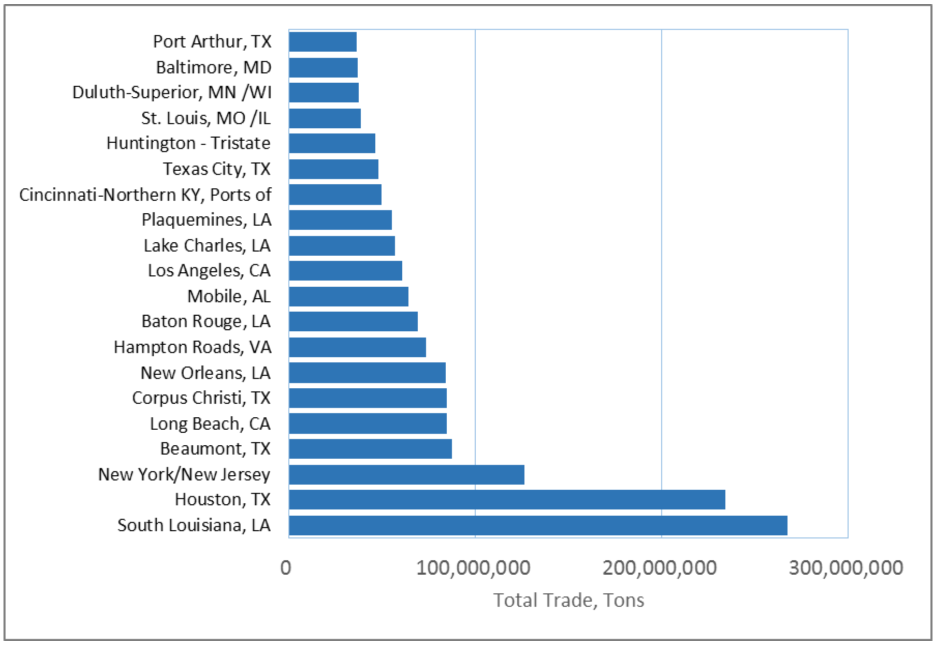
Equipment required to move goods at marine ports depends on the cargo type: containerized (or unitized), bulk (liquid or dry), break bulk (packed), and roll-on roll-off (RORO, e.g. automobiles). Because ports differ in the variety of cargo handled, no single equipment fleet characterization holds across all U.S. ports. Figure 1-4 shows that a large portion of containerized freight, measured by volume in twenty-foot equivalent units (TEUs), passes through West Coast marine ports, with the two largest container ports in the Los Angeles area. The New York/New Jersey and Savannah ports are the third and fourth largest container ports, but cargo at East Coast ports is more diverse. As a result, the Port of New York New Jersey outranks all California ports when measured by total tons of cargo handled, as shown in Figure

1-5. However, due to the large quantities of oil transported through the ports in the Gulf of Mexico, Louisiana, and Houston ports rank highest in the United States in terms of total tonnage.



Source: Western Hemisphere Port Ranking 2015 (AAPA, 2016).

Figure 1-4. U.S. Port Container Throughput, 2015



Source: U.S. Waterway Data, Waterborne Commerce Statistics Center (U.S. Army Corps of Engineers, 2016).

Figure 1-5. Top 20 U.S. Ports by Total Cargo Tonnage, 2014

1.3.3 People Movement

As shown in Table 1-1, public transit provided an estimated 59.6 billion passenger miles in mobility services in 2014, including travel by bus, light vehicles, rail, and ferry (APTA, 2016). Buses accounted for the largest number of passenger miles with heavy rail (also called metro, subway, rapid transit, or rapid rail) a close second. Buses also accounted for the largest number of vehicle miles. However, demand response services (also known as dial-a-ride) accounted for the largest number of vehicles, by a slim margin over buses, and the second largest number of vehicle miles. Demand response typically provides mobility for disabled and elderly people who are unable to drive themselves and may not have easy access to mass transit. Ferries are the smallest public transit mode in terms of passenger miles, vehicle miles, and vehicles, but are vital in many metropolitan areas since they provide transport across bodies of water not easily served by road or rail.

Table 1-1. Public Transit Summary Statistics, 2014

	Vehicles	Vehicle Miles (Millions)	Vehicle Revenue Miles (Millions)	Unlinked Passenger Trips (Millions)	Passenger Miles (Millions)	Average Trip Length
Roadway Modes						
Bus	*64,573*	*2,189.7*	*1,903.0*	*5,113*	*19,380*	*3.8*
Bus Rapid Transit	*440*	*10.2*	*9.5*	*54*	*157*	*2.9*
Commuter Bus	*6,053*	*233.7*	*182.2*	*107*	*2,919*	*27.3*
Total All Bus Modes	71,066	2,433.6	2,094.7	5,274	22,456	4.3
Trolleybus	537	11.4	11.0	96	158	1.6
Demand Response	71,359	1,595.1	1,372.6	233	2,267	9.7
Transit Vanpool	15,056	228.5	228.4	38	1,359	35.8
Publico	2,873	23.5	21.6	28	111	4.0
Total Roadway Mode	**160,891**	**4,292.1**	**3,728.3**	**5,668**	**26,350**	**4.6**
Fixed-Guideway Modes						
Commuter Rail	*7,337*	*370.8*	*342.5*	*490*	*11,718*	*23.9*
Hybrid Rail	*50*	*3.1*	*3.0*	*7*	*91*	*13.0*
Total Regional Railroad Modes	7,387	373.9	345.5	497	11,810	23.8
Heavy Rail	10,551	676.2	657.2	3,928	18,339	4.7
Light Rail	*2,057*	*104.7*	*102.6*	*483*	*2,490*	*5.2*
Streetcar	*337*	*6.1*	*5.9*	*48*	*93*	*1.9*
Total Surface Rail Modes	2,394	110.8	108.5	531	2,583	4.9
Ferryboat	202	4.1	4.0	79	505	6.4
Other Fixed-Guideway	422	10.6	10.4	47	57	1.2
Total Fixed-Guideway Modes	**20,956**	**1,175.5**	**1,125.6**	**5,082**	**33,294**	**6.6**
All Modes Total	**181,847**	**5,467.7**	**4,853.9**	**10,750**	**59,644**	**5.5**

Source: APTA 2016 Public Transportation Fact Book Appendix A: Historical Tables (APTA, 2016). See (APTA, 2015) for complete definitions of all modes.

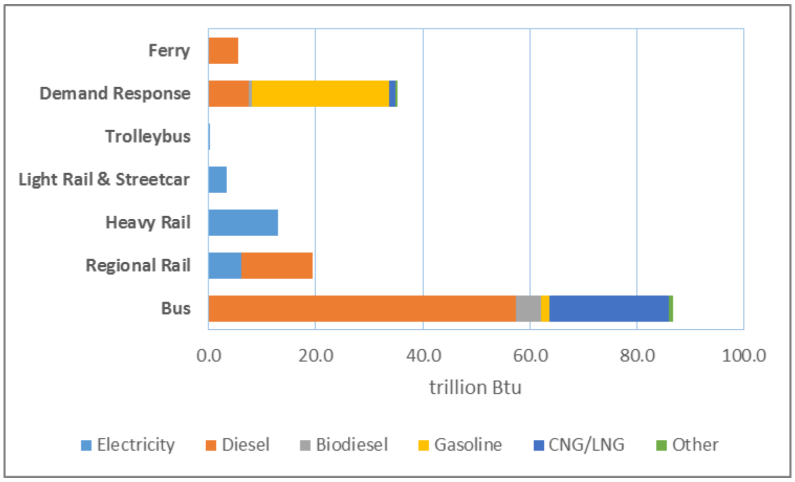
Transit vehicles are powered by a variety of fuel sources as shown in Table 1-2. Heavy rail, light rail, streetcars, and self-propelled commuter rail cars are nearly all electrically powered. However, road modes other than those with fixed guideways are predominantly fossil-fueled. About 56% of buses are powered by diesel while nearly 18% are hybrid-electric and another 18% are powered by natural gas. Commuter buses, however, are still nearly all diesel powered at 96%. Demand response and vanpools, which utilize smaller vehicles, are the only modes heavily dependent on gasoline.

Table 1-2. Public Transit Vehicle Power Sources by Mode, January 2014

	Electricity	Diesel Fuel	Electric and Other (Hybrid)	Gasoline	CNG, LNG, and Blends	Other	Total
Bus	0.1%	56.2%	17.5%	1.0%	17.5%	7.6%	100.0%
Commuter Bus	---	96.9%	---	0.9%	1.8%	0.4%	100.0%
Commuter Rail Self-Propelled Cars	96.5%	3.5%	---	---	---	---	100.0%
Commuter Rail Locomotives	4.1%	95.9%	---	---	---	---	100.0%
Demand Response	<0.0%	31.8%	1.9%	50.6%	7.0%	8.6%	100.0%
Ferryboat	---	60.5%	39.5%	---	---		100.0%
Heavy Rail	100.0%	---	---	---	---	(a) <0.0%	100.0%
Hybrid Rail	---	100.0%	---	---	---	---	100.0%
Light Rail	100.0%	---	---	---	---	---	100.0%
Other Rail Modes	46.7%	---	---	---	---	(a) 53.3%	100.0%
Streetcar	100.0%	---	---	---	---	---	100.0%
Transit Vanpool	0.5%	0.9%	---	82.1%	---	16.6%	100.0%

(a) Unpowered vehicles.
(b) Overhead wire electric with diesel for off-wire operation.
Sample data only, not extrapolated to national total.
Source: APTA 2015 Public Transportation Fact Book Table 10 (APTA, 2015).

Figure 1-6 shows public transit energy consumption by mode. Buses account for the largest energy use with diesel consumption alone larger than the total fuel consumed by any other single mode. Demand response is the second largest, consuming about 40% as much fuel as buses on an energy basis while providing about 10% of bus passenger miles. Demand response is also the only major public transit consumer of gasoline. Buses are the only major users of natural gas and, to a lesser extent, biodiesel.



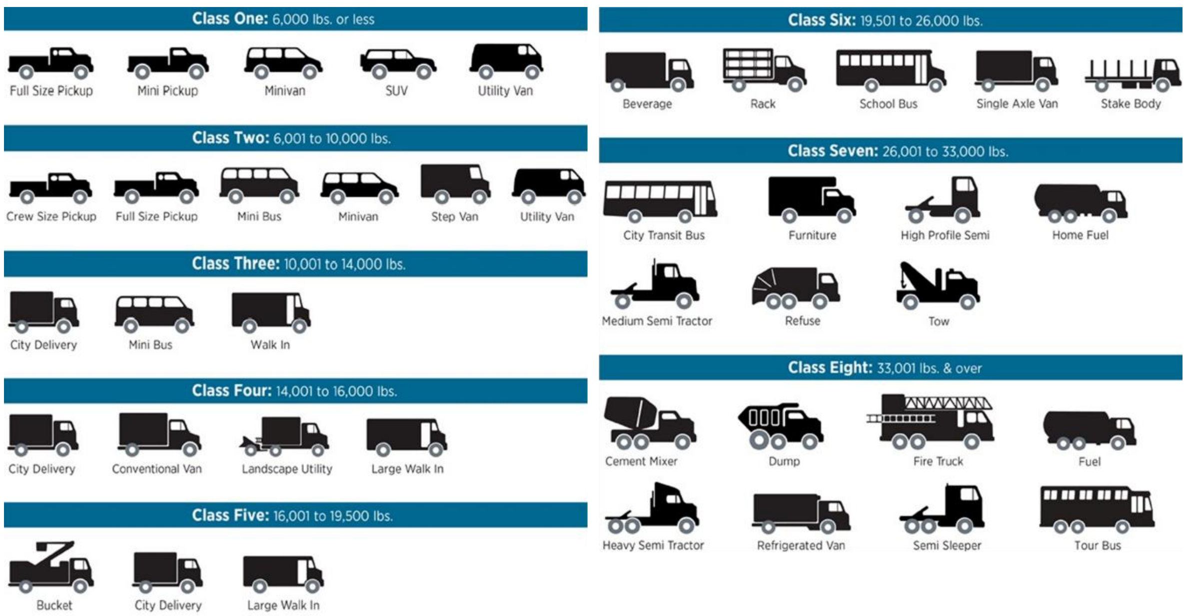
Source: APTA 2016 Public Transportation Fact Book Appendix A: Historical Tables (APTA, 2016).

Figure 1-6. Public Transit Energy Consumption by Fuel, 2014

It should be noted that statistics discussed in this section only provide information on vehicles owned and operated by public transit systems and do not include those used by private or charter services such as taxi, school bus, sightseeing and entertainment, intercity, airport, and military. It also excludes international, rural, rural interstate, and urban park ferry services. Sections 2.5, 4.3, and 5.2 provide additional data on the fleet of vehicles used for people movement.

2. HIGHWAY VEHICLES

For regulatory purposes, highway vehicles are divided into eight classes according to their gross vehicle weight (GVW) ratings. Figure 2-1 provides some examples of the types of vehicles included in each weight class. As discussed further in Section 2.1, medium and heavy vehicle (weight classes 3 – 8) PEV markets are less mature relative to light vehicles. Therefore, this study focuses primarily on classes 3-8.

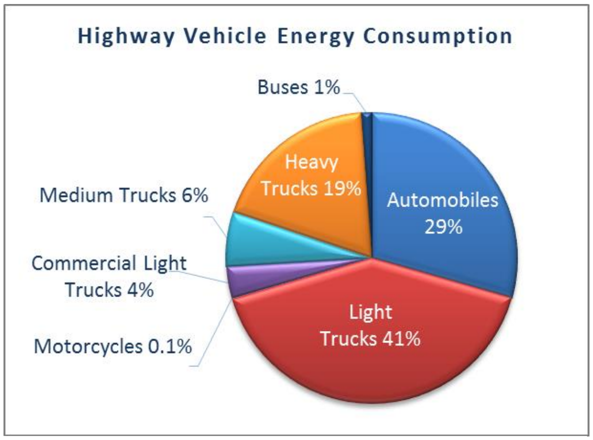


Source: AFDC, http://afdc.energy.gov/data/10381

Figure 2-1. Truck Body Style Examples by Weight Classifications

2.1 INDUSTRY AND MARKET OVERVIEW

The number of light vehicles in the United States vastly outnumbers the number of medium and heavy duty commercial vehicles. In 2014, more than 260 million vehicles were registered for operation in the United States, including automobiles, trucks, buses, and motorcycles. Of these, about 95% were light vehicles while the remaining 5% consisted of 3.5 million class 3 and 8.7 million class 4-8 trucks and buses (U.S. DOT FHWA, 2015; IHS Automotive, 2016). Similarly, 16.1 million light vehicles were sold in 2014 compared to 264,000 class 3 trucks and 406,000 class 4-8 vehicles (Davis, Williams, Boundy, & Moore, 2016). However, commercial vehicles often see higher usage, with new class 8 long haul tractors averaging around 100,000 miles in a year. As a result, commercial vehicles account for about 30% of highway energy consumption as illustrated in Figure 2-2.



Annual Energy Outlook 2016 (EIA, 2016)

Figure 2-2. 2015 Highway Energy Consumption by Vehicle Type

In addition to being a smaller overall market, medium and heavy vehicles are purchased in a vast array of highly customized configurations, with each style produced at even smaller volumes. The range of possible body styles is illustrated by the body types applicable to medium and heavy trucks captured in the Vehicle Inventory and Use Survey (VIUS) as shown in Table 2-1. Some additional custom body styles not shown include buses, ambulances, and fire trucks.

With the exception of pickups, utility vans, and truck tractors, commercial vehicles are built in a multi-stage process that involves several industries. Truck manufacturers produce an incomplete vehicle chassis, while truck body manufacturers build specialized equipment to customize vehicles to specific applications. Custom bodies may be as simple as a box van used for freight movement or as complex and functionally specific as a utility bucket truck. Equipment and trailer distributors, or upfitters, perform the chassis and body integration. Currently available BEV and PHEV powertrains are manufactured and installed by yet another

Table 2-1. VIUS Medium and Heavy Truck Body Types

Body Type Code	Description	% of Class 3-8 (2002)	Fleet Class*
1	Pickup	3.8%	G, P, S
5	Armored	0.1%	S
6	Beverage	0.8%	G
7	Concrete mixer	1.5%	S
8	Concrete pumper	0.1%	S
9	Crane	0.3%	S
10	Curtainside	0.1%	G
11	Dump	12.9%	S
12	Flatbed, stake, platform, etc.	15.4%	G, S
13	Low boy	0.1%	G
14	Pole, logging, pulpwood, or pipe	0.3%	G
15	Service, utility	4.0%	S
16	Service, other	3.1%	S
17	Street sweeper	0.1%	S
18	Tank, dry bulk	0.5%	G
19	Tank, liquids or gases	3.2%	G,S
20	Tow/Wrecker	2.0%	S
21	Trash, garbage, or recycling	1.8%	S
22	Vacuum	0.3%	S
23	Van, basic enclosed	10.0%	G
24	Van, insulated non-refrigerated	0.4%	G
25	Van, insulated refrigerated	1.6%	G
26	Van, open top	2.8%	G
27	Van, step, walk-in, or multistop	5.6%	G
28	Van, other	1.1%	G
99	Other not elsewhere classified	0.0%	NA
blank	Truck Tractor	27.4%	G

*Fleet class assigned by Energetics: G – goods movement, P – people movement, S – service

Source: *VIUS 2002 Microdata Data Dictionary* (U.S. DOC, 2004).

industry consisting of relatively small start-up companies.

IHS Automotive (formerly R.L. Polk) collects data on commercial vehicle registrations in the Polk Truck Industry Profile (TIP). TIP includes the registered owner's vocation and vehicle information gleaned from the vehicle identification number (VIN). However, due to the way heavy vehicles are built, this information cannot definitively determine a truck's final body style or operation. Unfortunately, the most extensive data on the composition and usage of the national truck fleet is VIUS, which was last conducted by the Department of Commerce (DOC) in 2002 (U.S. DOC, 2004). The truck fleet has evolved considerably in that time due to various market, economic, regulatory, and technological factors. One example of these changes is the significant growth of the class 3 market from annual sales of around 53,000 in 1997 to 282,500 in 2015. According to VIUS, there were about 2.1 million class 3 trucks in service in 2002 compared to nearly 3.7 million as of March 2016 (IHS Automotive, 2016). Publicly available data on these trucks is fairly scarce, but the majority are heavy duty pickup trucks and utility vans such as Ford F350s and E350s. According to Polk, pickups accounted for 60% of all class 3 vehicle registrations in 2011 (Weber, 2011).

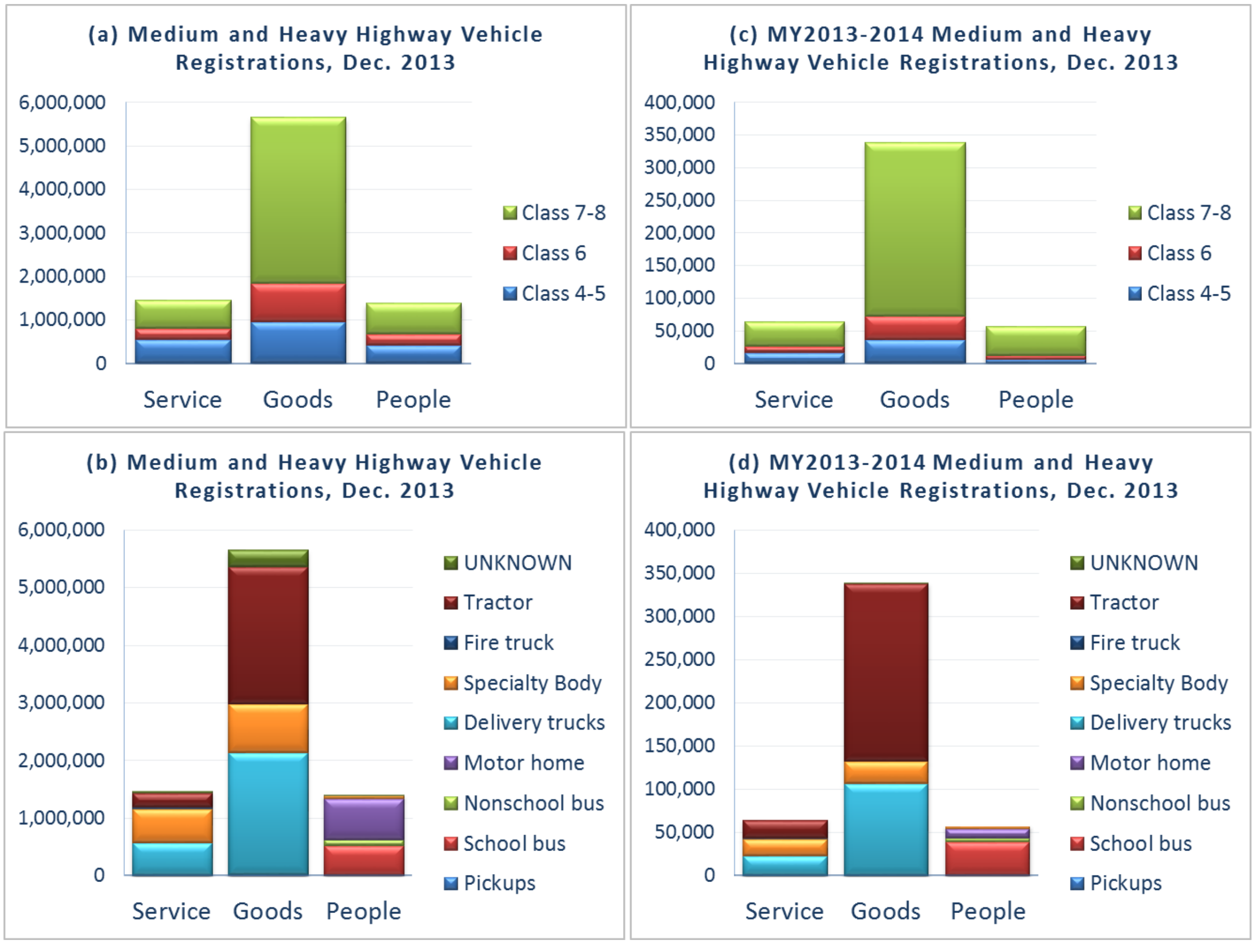
IHS Polk data on class 4-8 vehicles registered as of December 2013 was analyzed to determine the relative size of the service, goods movement, and people movement in-use and new vehicle fleets.[3] Trucks were classified into service, goods, and people movement fleets based on the Polk fields for vehicle type and vocation of the registered owner as shown in Table 2-2. The results, illustrated in Figure 2-3, should be considered rough estimates since the vehicle type field is fairly non-specific. Vehicles of type incomplete, strip, cutaway, and cab chassis were finished by upfitters. While service trucks requiring specialized bodies are very likely one of these types, it is also possible that these vehicle types are fitted with cargo style bodies. The most recent model year (2013-2014) registrations were used to estimate the relative size of the new vehicle markets in these segments and vehicle types.

[3] Only data on classes 4-8 was available to the study team due to time and budget constraints.

Table 2-2. Fleet Classification of IHS Polk Registration Data

	Polk Vehicle Type	
Polk Vocation	Straight Truck Step Van Van Cargo Tractor Truck Gliders	Incomplete (Strip Chassis) Cutaway Cab Chassis Unknown
Agriculture/Farm	Goods	Goods
Beverage Processing & Distribution	Goods	Goods
Bus Transportation	Goods	People
Construction	Goods	Construction and Mining
Dealer	Goods	Goods
Emergency Vehicles	Emergency Services	Emergency Services
Food Processing & Distribution	Goods	Goods
Forestry/Lumber Products	Goods	Goods
General Freight	Goods	Goods
General Freight/Hazardous Materials	Goods	Goods
Government/Miscellaneous	Goods	Service, other
Hazardous Materials	Goods	Goods
Individual	Goods	Goods
Landscaping/Horticulture	Road & Grounds Maint.	Road & Grounds Maint.
Lease/Finance	Goods	Goods
Lease/Manufacturer Sponsored	Goods	Goods
Lease/Rental	Goods	Goods
Manufacturing	Goods	Goods
Mining/Quarring	Goods	Construction and Mining
Miscellaneous	Goods	Goods
Moving And Storage	Goods	Goods
Petroleum	Goods	Goods
Petroleum/Hazardous Material	Goods	Goods
Road/Highway Maintenance	Goods	Road & Grounds Maint.
Sanitation/Hazardous Material	Sanitation	Sanitation
Sanitation/Refuse	Sanitation	Sanitation
Services	Service, other	Service, other
Specialized/Heavy Hauling	Goods	Goods
Unclassified	Goods	Goods
Utility Services	Utility Services	Utility Services
Utility/Hazardous Material	Utility Services	Utility Services
Vehicle Transporter	Goods	Service, other
Wholesale/Retail	Goods	Goods

Note: Vehicles listed with type = Fire Trucks were included in the Emergency Services fleet, regardless of vocation. Vehicles listed with type = School Bus or Bus Non School were included in the People Movement fleet, regardless of vocation.



Source: IHS Polk; provided by NREL as US Vehicle Registration Data for Class 4-8, R.L. Polk and Co. 12/31/2013 (R.L. Polk and Co., 2013). Compiled by CSRA, Inc. Segmentation by Energetics Inc.

Figure 2-3. Class 4-8 Heavy Vehicle Market Size
(a) In-use fleet by weight class; (b) in-use fleet by body type; (c) new (MY2013-2014) vehicles by weight class; (d) new (MY2013-2014) vehicles by body type

A great deal of progress has been made in the last ten years in the electrification of passenger vehicles. There are 27 models of plug-in electric class 1 light duty vehicles (≤ 6,000 lb GVW) that are commercially available today and an additional 10 models that manufacturers have announced will be offered by 2018. According to data collected by Argonne National Laboratories (ANL), more than 400,000 plug-in electric light-duty vehicles were sold between 2011 and 2015, including PHEVs and BEVs. Sales in 2015 topped 115,000 with the four most popular models selling more than 10,000 vehicles each and accounting for 62% of PEV sales (Davis, Williams, Boundy, & Moore, 2016).

Unfortunately, less progress has been made toward electrifying the medium and heavy vehicle fleets. While this study identified more than 30 different models of plug-in medium and heavy highway vehicle models, many have only been deployed in demonstration fleets. No electric commercial vehicle applications have reached the volume of annual sales required to be commercially sustainable. According to participants at DOE's Beyond Light Duty Electrification of Goods and People Movement Workshop, one of the barriers to deployment of electric vehicles in commercial fleets has been the inadequacy of supply, both in terms of available models and production volume. Manufacturers noted several difficulties in scaling up production and offering new models, including:

- Component supply limitations – Suppliers charge high prices to low volume customers or prefer to manufacture for and sell to high volume customers such as truck original equipment manufacturers offering light duty products.

- Time, effort, and expense to certify new models – Many suppliers are upfitters, relying on vehicle chassis from large OEMs. They become the manufacturer of record and are responsible for certifying the vehicle for all Federal and State (California) emissions and safety regulations.

2.2 FEDERALLY FUNDED RESEARCH

DOE has funded several electric vehicle technology development, deployment, demonstration, and evaluation projects specifically addressing non-light duty applications. The following collaborative efforts are a partial list of DOE supported projects (primary partner listed):

- Class 8 drayage trucks developed and deployed by the California South Coast Air Quality Management District and the Houston-Galveston Area Council at the Ports of Los Angeles/Long Beach and Houston/Galveston. The project includes both BEV and PHEV approaches, using compressed natural gas (CNG), liquefied natural gas (LNG), and hydrogen range extenders.

- Medium-duty urban range extended connected powertrain (MURECP) development and demonstration by Robert Bosch LLC. MURECP is a PHEV class 4 delivery truck using proven electric drive components. The project goal is a system with performance and incremental price that result in economic payback of three years.

- Plug-in series hybrid electric class 6 delivery truck development and demonstration by McLaren Performance Technologies. The project goal is a technology scalable across class 3-7 commercial vehicles and with 40 miles of all electric range.

- Plug-in series hybrid electric class 6 delivery truck development by Cummins in partnership with PACCAR and others. The project goal is >50% reduction in fuel consumption and a 3-year payback.

- Multi-speed transmission development for all-electric medium-duty commercial delivery trucks by Eaton Corporation.

- Vehicle deployment projects supported by American Recovery and Reinvestment Act (ARRA) funding. These projects placed 45 plug-in medium and heavy duty vehicles in service through Clean Cities. In addition, more than 200 class 6 Smith

Electric Vehicles were placed in delivery fleets nationwide, with data collection and analysis by the National Renewable Energy Laboratory (NREL).

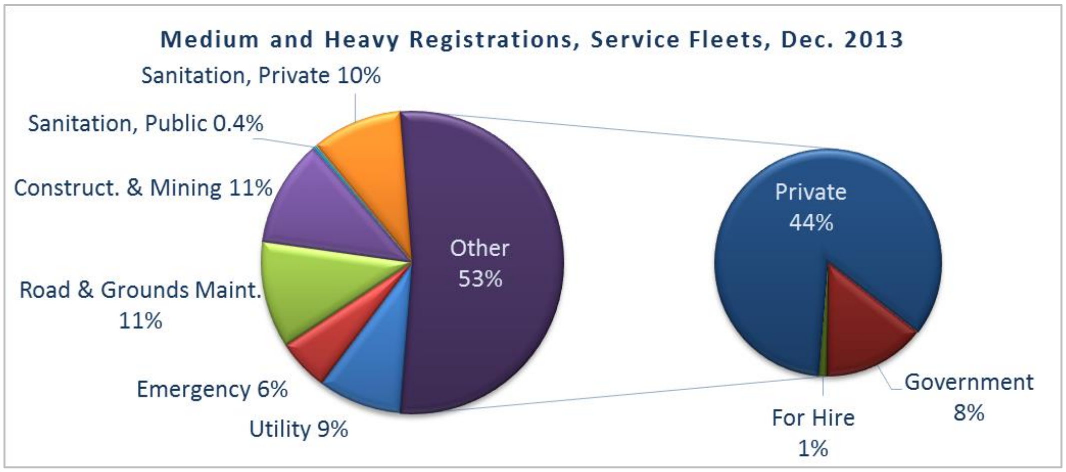
- Medium and heavy duty vehicle field evaluations by NREL. This project has collected data from over 5.6 million miles of travel and provides aggregated, third-party, unbiased information that would not otherwise be available due to intellectual property concerns. The data and analysis is used to guide industry and government technology R&D and application. For example, NREL evaluated 10 class 6 Smith Electric delivery vehicles operated by Frito-Lay North America (FLNA). Nationally, FLNA operates more than 200 PEVs in its delivery fleet.

- Development, testing, and demonstration of a fully automated wireless bi-directional charging system for PHEV medium duty vehicles, including delivery trucks and transit buses. The team includes the United Parcel Service, Oak Ridge National Laboratory (ORNL), Workhorse Group, Inc., Cisco Systems, and CALSTART.

2.3 SERVICE FLEET APPLICATIONS

The highway service fleet comprises vehicles not used for personal transport and whose primary purpose is not the movement of goods or people. In general, these are vocational vehicles used to perform specific work functions such as refuse collection, utility installation and repairs, cement and concrete delivery, etc. The range of service vehicle body styles is illustrated by the classifications shown in Table 2-1. As discussed, vehicles are customized for these applications and sales of specific configurations are small relative to the volumes seen in light vehicles or even freight trucks. Analysis of the Polk registration data suggests sales of less than 70,000 class 4-8 trucks for the service market. However, stakeholders indicate that the market for power take off (PTO) equipped class 4-8 service vehicles is on the order of 140,000 per year (Petras, 2016). This discrepancy is likely due to the mis-categorization of some vehicles due to the lack of specific body style information in the Polk data and highlights the need for reliable and sufficiently detailed data on heavy vehicle population and use.

Figure 2-4 illustrates the distribution of service vehicles by vocation of the registered owner. Vehicles with specific vocation information were fairly evenly distributed at around 10% each for sanitation, construction and mining, road and grounds maintenance, and utilities. About 6% were classified as emergency vehicles. Unfortunately, for more than half of the vehicles, vocation is specified simply as “Services.” These fleets were characterized only by vehicle ownership; 44% of the class 4-8 service vehicles can be classified as providing private services. Some of these vehicles may be employed in the vocations which were specified; additional possible vocations can be drawn from the more extensive list of business types included in VIUS, such as: transportation and warehousing; manufacturing; wholesale and retail trade; information services; arts, entertainment, or recreation services; and accommodation or food services.



Source: IHS Polk; provided by NREL as US Vehicle Registration Data for Class 4-8, R.L. Polk and Co. 12/31/2013. Compiled by CSRA, Inc. Segmentation by Energetics Inc.

Figure 2-4. Service Fleet Composition

The VIUS 2002 data shows that about 80% of trucks with service fleet body styles operate primarily within 50 miles of their home base and trips less than 100 miles account for 90% of their annual mileage, regardless of weight class. However, the duty cycles of service vehicles are unique to the application and include jobsite operations as well as transport. Jobsite power demand fulfilled through hydraulic or electrical systems can range from 10 kW to over 100 kW as shown in Table 2-3. In some applications, stationary jobsite operations may be responsible for the majority of fuel consumption. In addition to variation between different truck applications, the duty cycles for a given application may show significant variation from day to day. These vehicles do not have routine schedules or routes, but rather are deployed wherever and whenever they are needed and for as long as the job requires.

Table 2-3. Service Vehicle Jobsite Power Demand

Application	Power Demand (kW)
Milk Tanker	10
Vehicle Transporter	15-20
Dump	20-60
Bucket / Ladder	18-30
Refrigerated Van	20
Chemical Tanker	20-30
Terminal Tractor	30-60
Crane	35-70
Refuse	30-40
Lift Dump	45-55
Dumpster / Roll Off	45-55
Bulk	40-60
Sewage	30-80
Sewage, Jet-washing	110
Cement Mixer, mixing	15-20
Cement Mixer, discharging	40-90
Concrete Pumper	100-160
Concrete Pumper, extreme	220

Source: (Volvo, 2007)

PHEV and BEV applications are available for bare chassis that can be customized with nearly any body style. Table 2-4 lists the available plug-in highway vehicles applicable to service fleets for weight classes 3-8. Plug-In Vehicle Products provides more details on these products. Specific applications have been developed for utility bucket trucks and have been tested extensively by the Pacific Gas and Electric Co. In addition to the applications shown, VIA Motors has developed a PHEV gasoline-electric class 2 pickup and van based on General Motors chassis and bodies. The VIA TRUX offers all electric range capability and also provides 14.4 kW of export power for jobsite use. Service fleets also have the option to electrify work site power demands to varying degrees using "add-on" technology. Simple inverter technologies are available to supply power from the vehicle battery for smaller demands, such as computers and small tools. Larger systems are available for higher power demands, including some with energy storage, brake energy capture, plug-in capabilities, and the ability to start and stop the vehicle engine while at idle. These systems can meet demands for cab comfort, tools, and devices normally powered through a power-take-off or hydraulic system, including aerial devices. For example, the Altec Jobsite Energy Management System (JEMS) can be configured with up to 18 kWh of energy storage and has three battery recharge modes: plug-in, regenerative braking, and as needed by the truck's engine at the jobsite. The integrated system automatically shuts down and restarts the engine without driver intervention. While at the jobsite, it provides cab comfort and can power hydraulic and electric devices and tools, including 3 kW of exportable power. Terex manufactures a similar system called HyPower and many other commercial products are available with a wide range of capabilities. Jobsite electrification reduces or eliminates engine idling at the job site, reduces fuel consumption, lessens noise pollution and tailpipe emissions, and reduces engine maintenance costs.

Table 2-4. Available Plug-In Highway Vehicles for Service Fleets

Manufacturer & Model	Drive Type	Weight Class	Market / Body	Energy Storage (kWh)	Power (kW)		eRange (miles)	Status
					Peak	Contin-uous		
Electric Vehicles International MD	BEV	5 to 6	Vocational	*	200	120	90	Commercial
Electric Vehicles International REEV	PHEV	5	Utility Truck, Construction, Tree Service	*	200, 260	120	40	In Development
Electric Vehicles International WIV	BEV	5 to 6	Vocational	*	200	120	90	Commercial
Motiv Electrified Ford E450	BEV	4	School Bus, Shuttle, Parcel, Flatbed, Tool	80, 100, or 120	150	*	80-120	Commercial
Motiv Electrified Ford F59	BEV	6	Delivery, Refrigerated, Food, Tool, Bucket	85, 106, or 127	180	*	70-105	Commercial
Motiv Refuse	BEV	8	Refuse	170, 212	280	*	50-80	Commercial
Odyne	PHEV	4 to 8	Vocational	14, 28	70	42		Commercial
ZeroTruck	BEV	3 to 5	Vocational, Delivery	*	*	150	70-75	Commercial

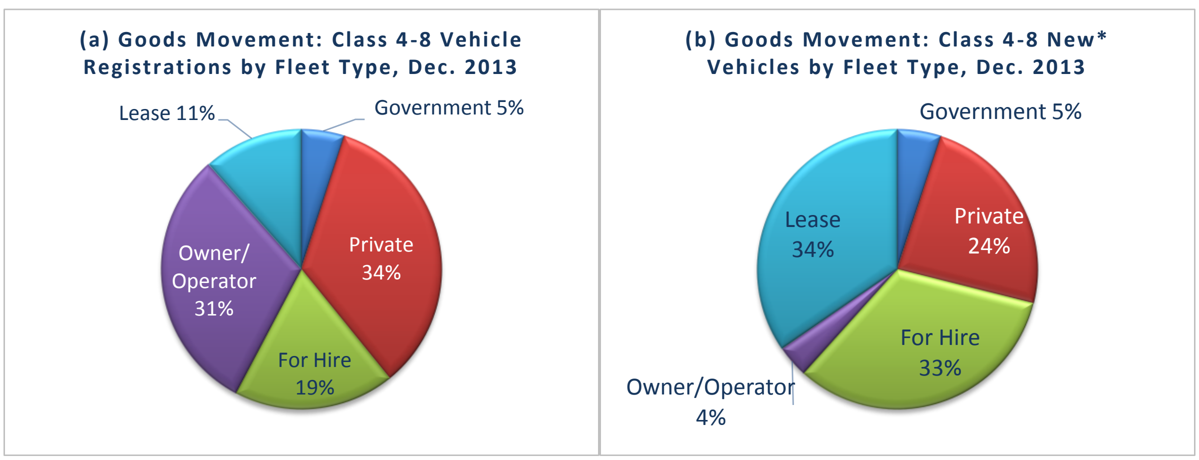
* Information not available.

Status as of June 1, 2016. Products discontinued or no longer in production excluded. For a more complete list including discontinued products, see Appendix A.

2.4 GOODS MOVEMENT APPLICATIONS

Of the three fleets considered in this study, goods movement accounts for the largest number of highway vehicles in use as well as the largest vehicle market. The medium and heavy vehicles included in the goods movement fleet include single unit (SU) trucks and truck tractors. Single unit trucks come in a variety of configurations and may be used for local or regional delivery. Truck tractors come in day and sleeper cab configurations, with the former used for local and regional deliveries and the latter used primarily for long-haul service. However, sleeper cab tractors often enter regional and local delivery fleets after being retired from long-haul service.

As shown in Figure 2-5, about one third of in-use goods movement vehicles are in private fleets, also known as captive fleets since the freight owner is also the vehicle owner and shipper. Another one third of the trucks are owned by independent operators and about one fifth by for-hire logistics firms. However, the ownership distribution for new trucks is quite different, with one third in leased fleets, one third in for-hire fleets, one quarter in private fleets, and very few owned by independent operators. This result indicates that the new vehicle market primarily is driven by leasing companies and for-hire fleets. Therefore, freight owners have less direct control of two thirds of the new vehicle technologies used to ship their goods and the resulting environmental footprint. It also indicates that privately owned vehicles are kept in service longer than leased vehicles, possibly affording longer payback periods for fuel saving technologies. Finally, most independent owner-operators purchase used trucks and they keep them in service the longest. These vehicles are often used for local and regional service providing first- and last-mile delivery. Because of shorter range, lower speeds, and higher frequency of stops, this duty cycle is likely the most promising for electrification.



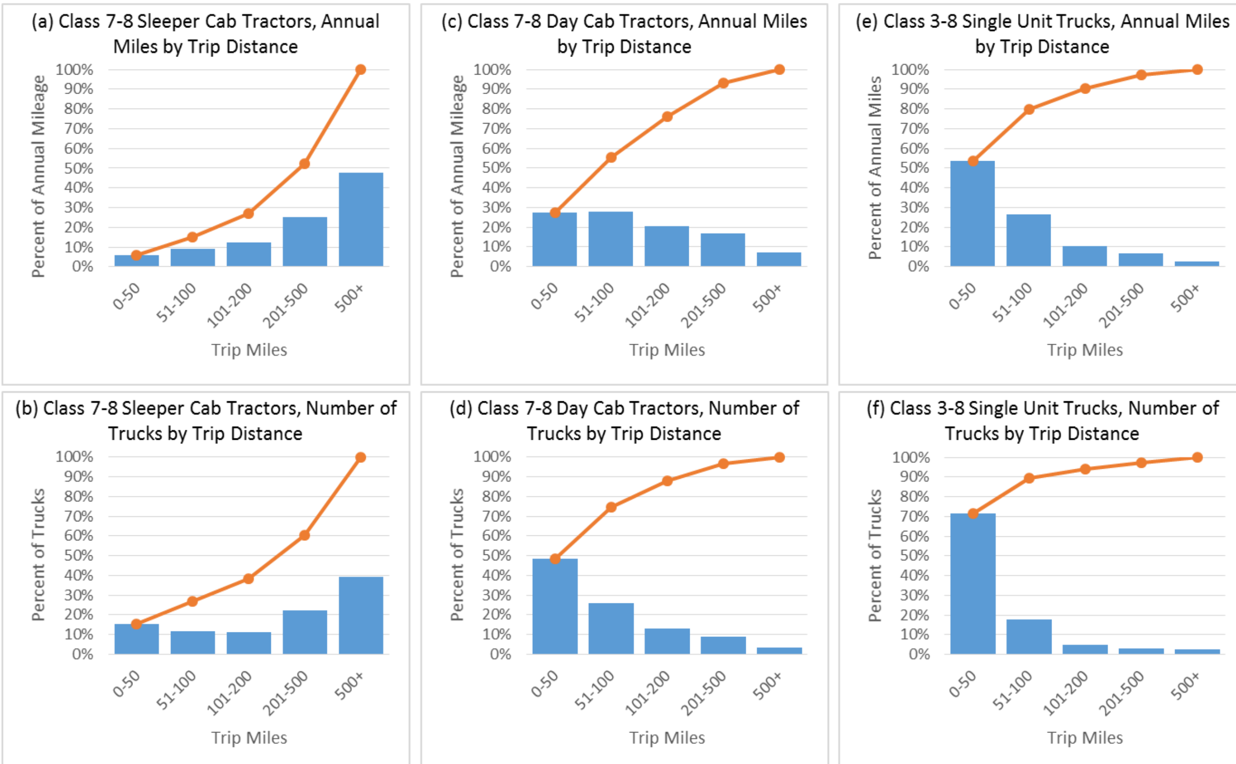
*New vehicles are all model year 2013-2014 vehicles registered as of Dec. 2013.

Source: IHS Polk; provided by NREL as US Vehicle Registration Data for Class 4-8, R.L. Polk and Co. 12/31/2013. Compiled by CSRA, Inc. Segmentation by Energetics Inc.

Figure 2-5. Goods Movement Vehicles by Fleet Type
(a) Vehicles in use; (b) new (MY2013-14) vehicles

Local and regional duty cycles typically entail relatively short daily trips with frequent pickup and delivery stops. The VIUS 2002 data, shown in Figure 2-6, indicates that 90% of single unit trucks with goods movement body styles operate primarily within 100 miles of their home base and that trips of 100 miles or less account for about 80% of their annual mileage. Their duty cycles may also include a significant amount of idle time while at delivery stops.

Meanwhile, VIUS indicates that only 50% of class 7 and 8 tractors operate within 100 miles of their home base and 22% primarily operate 500 miles or more from home. Nearly 40% of sleepers, which account for about 65% of tractor miles, typically operate over a range greater than 500 miles (see Figure 2-6 (b)). Long haul trucks may travel 100,000 or more miles annually and can spend 1,800 hours idling if the truck engine is used to provide cab overnight comfort. Day cab operations are more similar to single unit trucks, with 75% of the tractors driven primarily within 100 miles of their home base (Figure 2-6 (d)). Drayage trucks are a specific application of short-haul tractors used to service sea ports. They are typically used to haul containers and trailers to and from nearby container yards and distribution centers.



Source: VIUS 2002 (U.S. DOC, 2004); analysis by Energetics Inc.

Figure 2-6. Goods Movement Trucks and Annual Miles by Operating Range (a) Sleeper cab tractor miles; (b) sleeper cab tractor trucks; (c) day cab tractor miles; (d) day cab tractor trucks; (e) single unit truck miles; (f) single unit trucks

As shown previously in Figure 2-3, class 7-8 tractors constitute the single largest portion of the heavy vehicle fleet. Due to the high annual mileage of sleepers, tractors have shorter lifetimes on average and therefore account for an even larger share of the sales fleet.[4] Long haul trucks account for the majority of fuel consumption in the goods movement fleet, making them a priority for energy conservation and emission reduction efforts. However, their long trip distances and infrequent stops make these trucks a challenge for electrification. Delivery trucks represent the second largest portion of the heavy vehicle fleet. These trucks are better candidates for electrification since regional and local goods movement duty cycles require less range capability and provide greater opportunities for recharging. In addition, they operate primarily near population centers and are therefore good candidates for criteria emission reduction efforts.

[4] According analysis of IHS Polk registration data by the Energy Information Administration (EIA), the average age of the registered stock of class 7-8 tractors in 2014 was 12.2 years compared to 15.2 years for other class 7-8 trucks and 14.5 for all class 4-8 trucks other than tractors (EIA, 2016).

The project team identified nine PEV applications for the goods delivery market, shown in Table 2-5, of which eight are commercially available. These products span class 3-8 and all target local or regional delivery. Several class 8 tractor BEV applications are available for short haul and drayage applications, with a range up to 125 miles depending on load. Straight truck and van BEV applications have a range of 70 to 120 miles on a single charge, depending on weight class and load. One gasoline PHEV option is available as a class 5 delivery truck. Although the electric range of this truck was not published, it would have essentially unlimited daily driving range since it can be easily refueled to operate on gasoline.

Table 2-5. Available Plug-In Highway Vehicles for Goods Movement

Manufacturer & Model	Drive Type	Weight Class	Market / Body	Energy Storage (kWh)	Power (kW)		eRange (miles)	Status
					Peak	Contin-uous		
Balqon MX-30	BEV	8	Drayage	380	325	*	125	Commercial
Balqon Mule M100	BEV	6 to 8	Delivery, Shuttle Bus	312	225	*	102-150	Commercial
Capacity of Texas, Pluggable Hybrid Electrical Terminal Truck	PHEV Diesel	8	Terminal Tractor, Drayage	*	168	*		Demonstration
Motiv Electrified Ford E450	BEV	4	School Bus, Shuttle, Parcel, Flatbed, Tool	80, 100, or 120	150	*	80-120	Commercial
Motiv Electrified Ford F59	BEV	6	Delivery, Refrigerated, Food, Tool, Bucket	85, 106, or 127	180	*	70-105	Commercial
TransPower ElecTruck	BEV	8	Yard Tractor, Tractor	150	*	*	*	Commercial
TransPower On-Road Truck	BEV	8	Tractor	*	*	*	100	Commercial
Workhorse E-GEN	PHEV Gaso-line	5	Delivery, Walk-In Van	80 (60 usable)	200	*	*	Commercial
ZeroTruck	BEV	3 to 5	Vocational, Delivery	*	*	150	70-75	Commercial

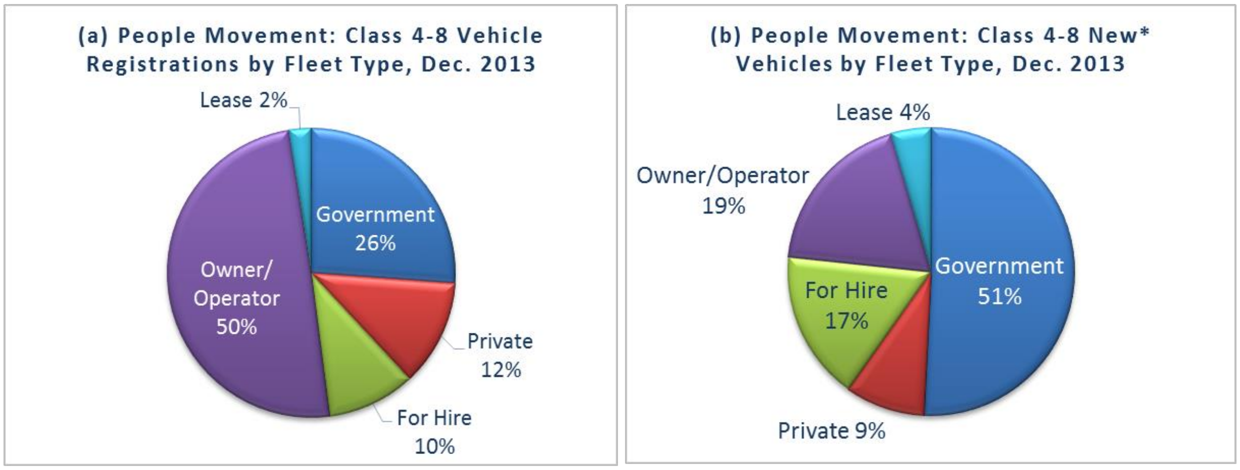
* Information not available.

Status as of June 1, 2016. Products discontinued or no longer in production excluded. For a more complete list including discontinued products, see Appendix A.

2.5 PEOPLE MOVEMENT APPLICATIONS

Figure 2-7 shows that the people movement fleet is comparable in size to the service vehicle fleet. However, a large number (705,000) of the registered vehicles included in this segment are motor homes which are used infrequently and which were not considered further in this study. The majority of the remaining vehicles are school buses (513,000) and the balance includes other buses (112,000) and other body custom styles (53,000). The American Public Transportation Association (APTA) reports that there were 71,000 buses in use by public transit agencies plus an additional 86,000 vehicles in use for public demand response and transit vanpool services.[5] Many of these latter vehicles may be class 1-2 light vehicles. While buses are a relatively small portion of the highway fleet, they operate in population centers and around sensitive populations where criteria emission reductions are highly desirable.

Half of new people movement fleet vehicles are registered to government owners. However, less than 26% of the in-use fleet is registered by a government entity, indicating that either non-government vehicles are utilized less and remain in service longer, or that vehicles retired from government use are sold to private entities and remain in use in a second career.



*New vehicles are all model year 2013-2014 vehicles registered as of Dec. 2013.

Source: IHS Polk; provided by NREL as US Vehicle Registration Data for Class 4-8, R.L. Polk and Co. 12/31/2013. Compiled by CSRA, Inc. Segmentation by Energetics Inc.

Figure 2-7. People Movement Vehicles by Fleet Type
(a) Vehicles in use; (b) new (MY2013-2014) vehicles

According to APTA, 17.5% of buses used in public transit employ hybrid-electric powertrains, but only 0.1% are electric (APTA, 2015). However, the study team identified four companies that currently build BEV transit buses and four that build BEV school buses, as shown in Table 2-6. Two companies manufacture shuttle buses, and it is possible that several of the bare chassis available to the service fleet may be customized for shuttle service.

[5] Demand response services, also called paratransit or dial-a-ride, dispatch passenger vehicles or small buses when called by passengers. The vehicles do not have a fixed route or schedule. Transit vanpool is prearranged ridesharing using vans or small buses to provide round trip transportation between regular boarding points and destinations.

Table 2-6. Available Plug-In Highway Vehicles for People Movement

Manufacturer & Model	Drive Type	Weight Class	Market / Body	Energy Storage (kWh)	Power (kW)		eRange (miles)	Status
					Peak	Contin-uous		
Adomani Conversion Kit	BEV	*	School Bus	*	*	*	*	Commercial
BAE Kenworth Catenary Truck Project	PHEV-CNG	8	Vocational, Public Transit	*	*	*	*	Demonstration
Balqon Mule M100	BEV	6 to 8	Delivery, Shuttle Bus	312	225	*	102-150	Commercial
BYD 35-ft Transit Bus	BEV	8	Transit Bus	*	*	*	165+	In Development
BYD 40-ft Transit Bus	BEV	8	Transit Bus	324-360	180, 300	*	155+	Commercial
BYD 60-ft Transit Bus	BEV	8	Transit Bus	547	360	*	170	In Development
GreenPower Bus EV250, EV300, EV350, EV400, EV450, EV500, EV550	BEV	8	Transit Bus	210-400	*	*	175-240	Commercial
GreenPower Bus EVS 01, 02, 03, 04	BEV	4-6	School Bus	80-150	*	*	100 -125	Commercial
Motiv All-Electric Class A Schools Bus	BEV	4	School Bus	80, 100	150	*	80-100	Commercial
Motiv Electrified Ford E450	BEV	4	School Bus, Shuttle, Parcel, Flatbed, Tool	80, 100, or 120	150	*	80-120	Commercial
Motiv Starcraft e-Quest XL	BEV	8	School Bus	80, 100, or 120	150	*	85	Demonstration
New Flyer Xcelsior XE40	BEV	7-8	Transit Bus	200-300	160	*	80-120	Commercial
Proterra Catalyst 35-ft and 40-ft	BEV	8	Transit Bus	53-321	220	*	50-180	Commercial
Transpower EESB / ElecTruck	BEV	7-8	School Bus	111	150	100	35-60	Commercial

* Information not available.

Status as of June 1, 2016. Products discontinued or no longer in production excluded. For a more complete list including discontinued products, see Appendix A.

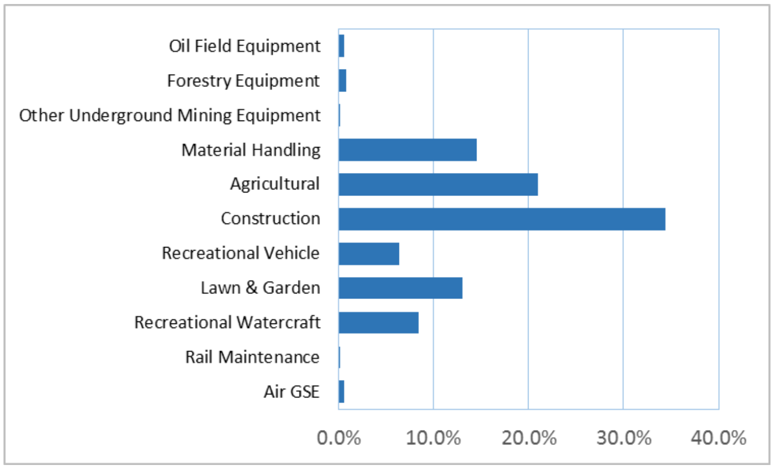
3. NON-ROAD EQUIPMENT

This section covers land-based equipment used in the goods movement and service segments that is not operated on public roadways. Section 3.1 provides an overview of the non-road market. Section 3.2 examines electrification in the construction industry. Section 3.3 discusses electrification for equipment specific to ground cargo handling and, separately, other material handling equipment used in commercial and industrial applications. This section does not discuss aircraft or equipment used at airports or marine vessels or equipment directly supporting these vessels; these fleets are discussed in Sections 4 and 6 respectively. This study does not include non-road equipment used for agriculture or lawn / grounds maintenance, although additional analysis of these markets is recommended.

3.1 MARKET OVERVIEW

Non-road heavy equipment is vital to the movement of goods and people and to service related industries, including construction, agriculture, forestry, mining, freight transport, and public safety. The non-road mode is predominantly powered by diesel internal combustion engines which are a significant source of criteria pollutant emissions, particularly nitrogen oxides and particulate matter. As personal highway vehicles have become cleaner and more efficient, government attention has begun to focus more on commercial vehicles and equipment. However, the equipment and engines are necessarily built for operation in rugged conditions, and this durability leads to long useful lives. As a result, older engines with higher emissions remain in use long after emission standards become effective.

There is very little public data available on the size, usage, or fuel consumption of the non-road equipment fleet. The U.S. Environmental Protection Agency's (EPA's) NONROAD model, which is the most frequently used source, provides estimates for this information based on population surveys, estimated growth rates, and sampled emission rates.[6] Based on output from the NONROAD model for 2015, shown in Figure 3-1, construction equipment is the largest non-road fleet in terms of energy consumption, followed by agriculture, material handling, and then lawn and garden. However, Figure 3-2 illustrates that the lawn and garden fleet is by far the largest in terms of number of engines and sales, though only 10% of these are owned by commercial fleets with the vast

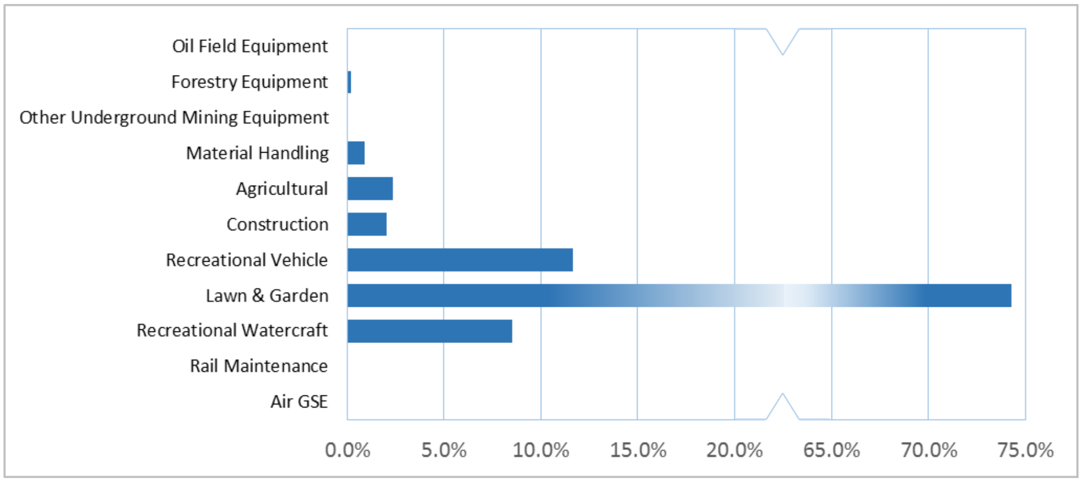


Source: EPA NONROAD2008a model (EPA, 2009); analysis by Energetics Incorporated.

Figure 3-1. Estimated 2015 Non-Road Energy Consumption

[6] See https://www3.epa.gov/otaq/nonrdmdl.htm for documentation of the methodology used for NONROAD.

majority privately owned (residential). Recreational vehicles and watercraft account for the second and third largest fleets by number of engines. These residential and recreational fleets are not included in the scope of this study.



Source: EPA NONROAD2008a model (EPA, 2009); analysis by Energetics Incorporated.

Figure 3-2. Estimated 2015 Non-Road Engine Stock

As with the highway service vehicle fleet, productivity is a key driver in the non-road equipment industry. To succeed, technologies must optimize fuel efficiency, productivity, and cost, while meeting ever tightening emission standards. A technology that enhances core mission performance while providing fuel savings is much more likely to achieve market success.

3.2 SERVICE FLEET: CONSTRUCTION EQUIPMENT

The construction industry is responsible for a significant share of non-highway mobile energy use and pollutant emissions. However, there are large uncertainties in estimates of these emissions due to the lack of published data. According to the EPA NONROAD2008 model, construction equipment consumes the largest share of energy within the non-road mode. The model estimates that there are over three million pieces of construction equipment in the United States, of which about two thirds are diesel powered and consume around 7 billion gallons of fuel per year.[7] Non-road construction and mining equipment consist of a large diversity of applications, mechanical demands, and duty cycles, including (Balmer-Millar, Fluga, & Peterson, 2015):

[7] 2015 estimates based on analysis of EPA NONROAD2008a model by Energetics Incorporated.

- Off-highway Mining Trucks
- Excavators
- Wheel Loaders
- Compactors
- Motor Graders
- Track Loaders
- Landfill Compactors
- Bulldozers
- Backhoes
- Agriculture Tractors
- Skid Steer Loaders
- Pipe-layers
- Material Handlers
- Asphalt Pavers
- Telehandlers

Fuel costs for heavy equipment are a significant portion of operating costs, averaging around 20-25% in the United States (Balmer-Millar, Fluga, & Peterson, 2015). Hybridization and full electrification could save fuel and reduce emissions while also offering advantages in terms of reducing noise pollution in urban areas. Electric drive systems can eliminate jobsite idling and can allow reduction in parasitic losses through electrification of accessory and auxiliary loads. In addition, electric drive systems offer infinitely variable speed without shifting, allowing greater operator attention to and control of job functions.

The study team identified a number of hybrid products for construction equipment which reportedly reduce fuel consumption up 25%. Hybrid non-road equipment incorporates many different architectures, including hydraulic hybrids and diesel-electric hybrids from micro to full systems in parallel and series configurations. They may use batteries or ultra-capacitors and one or multiple motors. Full series electric hybrids enhance core job performance by decoupling the engine speed from the vehicle speed, increasing traction control, reducing tire spin out and tire wear, improving ease of operation, and reducing operator fatigue.

The recent downward trend in fuel costs has a negative impact on payback, which presents a challenge for market acceptance. However, future reductions in hybrid component incremental cost and possible fuel price increases could result in more favorable payback periods for hybrid electric construction equipment. Plug-in hybrid and battery electric equipment face greater hurdles in the near term. The industry perspective at this time is that, while hybrid concepts are feasible for many applications, pure electric operation is feasible only for smaller equipment (less than 19 kW). This conclusion is driven by the high additional cost of batteries, the amount of space required to package them on the equipment, and the time required for recharging. Alternative fuel-saving technologies present additional challenges. Compared to electric and electric hybrids, hydraulic hybrids have the advantage of using systems that are familiar to operators and that have a mature and robust supply chain. In addition, they currently have a power density advantage over electric systems of around 10:1. High power applications challenge battery technology in terms of rapid storage and discharge, while hydraulics use accumulators that can be charged and discharged quickly (SAE, 2016).

Construction fleets do, however, have a number of near-term opportunities for improving energy consumption and a few studies have investigated using a more systematic approach. Researchers at Caterpillar concluded that the potential for fuel savings from advanced technologies is significantly enhanced if they are considered within the context of equipment functions and with an integrated system level approach (i.e., engine, controls, hydraulics, cooling systems, etc.). In addition, they found substantial savings looking beyond the equipment and considering human factors, operator efficiencies, and the entire job site (Balmer-Millar, Fluga, & Peterson, 2015). Similarly, Volvo Construction Equipment investigated electrification at a quarry by addressing job site functions rather than using an equipment focus. They determined that a number of functions were sufficiently stationary to be served through electric cabling, with the potential to reduce energy use by 71%. Looking toward the longer term, Volvo is using this platform to consider development of plug-in hybrid and eventually fully electrified machinery. An ultimate goal would be "the possibility of fully autonomous, driverless machines guided by computer" (Stoikes, 2016).

The mining industry provides an excellent example of non-fuel cost benefits that can arise from electrification. The deeper miners and equipment go into the earth, the less cost effective it is to use machinery running on diesel technology due to the large amount of ventilation infrastructure that is necessary to keep the job site safe. Up to 30% of an underground mine's total running costs go towards powering large-scale ventilation systems. In order to meet the increasing emissions, safety, and energy efficiency concerns of the mining industry, the development of electric-powered machinery has become widespread. Incorporating battery technology into mining equipment systems offers several performance benefits, provides for a lower life cycle cost, and is safer for workers to operate. In addition to the overall increased efficiency electric/battery powered vehicles can offer, there are also cost benefits. Fuel and maintenance costs are drastically reduced with batteries by eliminating oil changes, transmission maintenance, and replacement of filters (Jensen, 2013).

3.3 GOODS MOVEMENT: CARGO AND MATERIAL HANDLING

3.3.1 Port Ground Equipment

Most ports are located within or near major cities and emissions from port operations often impact fairly densely populated areas. Due to serious air quality issues, California and a number of other ports launched clean port programs aimed at reducing diesel fuel consumption and emissions. Fleet modernization and exhaust retrofits can help with fuel and emissions. In addition, most of these ports have investigated electrification of cargo handling equipment (CHE) and other port operations, citing several advantages including: reduction of air and noise pollution, reduction in operating and maintenance costs, and higher efficiency.

CHE operating at port terminals include equipment used to move cargo (containers, bulk, break-bulk, and RORO cargo) to and from marine vessels, railcars, and on-road trucks. The equipment discussed in this section operates at marine terminals, rail yards, and transfer stations, but not on public roadways. The diversity of cargo requires a wide range of equipment types designed for specific port functions. In addition to common material handling equipment (e.g., forklifts, bulldozers, loaders, and excavators) which is discussed in Section 3.3.2, the most common (mobile) port equipment includes:

- Yard Tractors
- Side handlers
- Top Handlers
- Reach stackers
- Straddle carriers
- Sweepers
- Rough terrain forklifts
- Rubber tired gantry (RTG) cranes

Unfortunately, there is no national inventory of port CHE. However, the state of California has invested heavily in port equipment inventories as part of their emission reduction programs. In 2014, the Port of Long Beach (POLB) inventoried 1,204 pieces of CHE and determined that 79% of the engines were diesel-powered, followed by 11% powered by propane, and 8% by gasoline. Yard tractors constituted the largest fraction of the POLB inventory count at 45%, with forklifts coming in a distant second at 8% (POLB, 2014). Yard tractors (also known as yard hostlers, yard goats, and terminal tractors) are used to move truck trailers or shipping containers on chassis around cargo yards at ports, rail facilities, and warehouses. It should be noted that POLB and the Port of Los Angeles (POLA) are the busiest container ports in the United States (see Figure 1-4), handling over 15 million TEUs in 2015 (AAPA, 2016). Therefore, the POLB CHE inventory cannot necessarily be generalized to other ports, particularly those that handle other types of cargo.

Manufacturers have developed a number of hybrid electric solutions that save fuel through idle reduction, energy recapture from lifting operations, and, in the case of series hybrid configurations, through optimization of engine speed. Only a few port-specific products with PHEV or fully electric capabilities are currently available, as shown in Table 3-1. Some ports are currently deploying these products with assistance from federal grant programs. For example, the Port of Savannah has electrified 45 of 169 RTGs and plans to electrify the remainder by 2022 (GPA, 2016). However, some deployments of RTGs have shown that the high frequency of battery cycling for cranes results in very short battery lives. For this reason, Konecrane offers RTGs powered through electric cabling via a reel system or busbar. Hydrogen fuel cells may offer a future solution to this challenge.

Table 3-1. Plug-In Port Cargo Handling Equipment

Manufacturer & Model	Drive Type	Application	Status
Capacity HETT	BEV	Terminal Tractor	Demonstration
Capacity PHETT	PHEV	Terminal Tractor	Demonstration
Kalmar FastCharge Hybrid Straddle Carriers	PHEV or EV	Container Handling	Commercial
Kalmar E-One² Zero Emission RTG	BEV	Container Handling	Commercial
Konecrane RTG	EV, cable reel or busbar	Container Handling	Commercial
OrangeEV T-Series	BEV	Terminal Tractor	Commercial
Terberg YT202-EV	BEV	Terminal Tractor	Commercial
TransPower ElecTruck	BEV	Terminal Tractor	Commercial
TransPower Port yard tractor	BEV	Terminal Tractor	Commercial

As with construction equipment, examining the entire port operational system offers additional fuel savings opportunities. One such opportunity currently being used internationally is automation of container handling using electric equipment. The push toward automation is chiefly driven by the evolution toward ever-larger container ships and the need to minimize the loading and unloading time. Automation and electrification increase safety and productivity while decreasing fuel consumption of handling containers within the port. It also streamlines scheduling and loading of container pickup by on-road trucks, which reduces the amount of time trucks spend idling and creeping while queued at the port and also reduces traffic congestion at the terminal gate.

Automation requires investment in new CHE, personnel training, new operating systems, and major site and power infrastructure upgrades. APM Terminals' Maasvlakte II facility at the port of Rotterdam, Netherlands, now considered the world's most advanced container terminal, has automated all parts of the container moving process at a build cost of over $535 million (Mongelluzza, 2015). Because of high up-front costs, automation reportedly is only cost effective at higher volume terminals that handle more than 1 million containers per year (Mongelluzzo, 2016).

In the United States, only a few terminals have implemented some form of automation, and none are completely automated. The APM terminal in Norfolk, VA, was the first to pursue automation, deploying a semi-automated rail-mounted gantry crane in 2007. Operations at the TraPac terminal in POLA and the Middle Harbor terminal in POLB are currently semi-automated and both terminals plan to be fully automated by 2020. The remaining 11 California container terminals have not disclosed whether or not they will pursue automation and the projected container volumes and physical layout may not be favorable at some. However, the state has committed to deploying zero or near-zero emission freight movement equipment. Purchasing electric CHE instead of conventional equipment during the normal replacement cycle over the next 30 years would cost California ports an estimated $16 billion, while full automation, if pursued, would add another $12 billion (Mongelluzzo, 2016).

3.3.2 Other Material Handling

Material handling for industrial applications includes forklifts and equipment also used in construction. Electric forklifts are widely used and the technology is mature. Therefore, this study did not examine other material handling.

4. MARINE

Marine transport includes ocean going vessels (OGVs) and harbor craft. Both classes of vehicles can be used for goods and people movement and for recreation. The majority of OGV fuel use occurs while underway in international waters and near coastlines. However, OGVs also use main or auxiliary engines while at berth to meet "hotel" loads for lighting, crew comfort, shipboard operations, and for maintaining cargo condition (e.g., refrigerated cargo and crude). Commercial harbor craft include tug- and towboats used to escort OGVs through coastal waters and maneuver them while close to port; work boats used for such functions as dredging sea lanes; ferries; and excursion vessels. As with OGVs, harbor craft keep one or more auxiliary engines running to meet hotel loads while docked.

This section provides information on electric technologies applicable to commercial harbor craft and to meeting hotel loads for harbor craft and OGVs. This study does not address fuel saving options for OGVs while underway or for vessels operating on inland waterways. Since this study focuses on commercial equipment, this report also does not discuss recreational watercraft. However, commercial harbor craft technologies may be applicable to some of these vessels.

4.1 TUG- AND TOWBOATS

There are between 4,000 and 5,400 tug- and towboats in the United States, including vessels operating at marine ports, the Great Lakes, and the Mississippi River System / Intercoastal Waterway (AWO, 2016; Army Corps of Engineers, 2014). Tugs often run 24 hours a day, spending a large amount of time at the dock or "loitering" in the harbor while waiting to be dispatched. As a result, the engines spend a significant amount of time at idle then must produce short bursts of high power when escorting or moving OGVs (McKenna, 2013). Overall, the majority of operating time is spent with the engine operating at below a 20% load factor where engine efficiency is low and emissions tend to be high (Foss Maritime, 2013).

Table 4-1. Example Tugboat Operating Modes

Mode	Load	Engine(s)	Duty Time*
Docked	Hotel	Auxiliary	55%
Standby	Hotel, readiness	Auxiliary and Main	7%
Transit	Propulsion	Auxiliary and Main	16%
Harbor Duty	Propulsion, OGV handling	Auxiliary and Main	5%
Ship Assist	Propulsion, escorting OGV	Auxiliary and Main	17%

*Example data for two dolphin class tugboats operating in POLA and POLB. Time in mode may not be representative for other locations (UC Riverside, 2010).

Marine port operations can be classified into five modes: docked; standby; in transit to duty; harbor duty handling OVGs; and ship assist escorting OGVs in coastal waters. Time in mode can vary significantly by port due to differences in coastal transits and obstacles, but Table 4-1 provides an example from a California Air Resources Board (ARB) hybrid tug project. For two tugs operating in the POLA and POLB, researchers analyzed actual operating data and found that, on average, the tugs spent 22% of engine-on time performing the two working modes (UC Riverside, 2010). A later sampling for one of the vessels showed an increase in total working time to 33% (McKenna, 2013).

The ARB funded feasibility and demonstration projects for hybrid electric tugboats, the first with a conventional lead-acid battery and the second with a lithium polymer battery. The second project, completed in 2012 at a final cost of $2.3 million, showed reduction in emissions of nitrogen oxides by 31%, carbon dioxide by 30%, and PM by 29%. The project met several challenges, including a clutch failure and a battery compartment fire. However, the project closed successfully with the vessel and hybrid system operating seamlessly (McKenna, 2013).

The New York State Energy Research and Development Authority (NYSERDA), in partnership with the New York State Department of Transportation (NYSDOT), sponsored an all-electric dredge tender work boat on the Erie Canal in the Utica, New York area. Elco Motor Yachts retrofitted a diesel-powered 86 year-old tug-boat with lead acid batteries and two 100 horsepower (hp) AC induction motors powering a single propeller shaft (NY State, 2014).

Though not a focus for this study, a few diesel hybrid electric pleasure vessels are in production. Most notably, the Seaway Greenline yachts incorporate lithium ion batteries that can be recharged from the engines, from roof mounted solar panels, or from a shore connection to the grid.

4.2 VESSEL SHORE POWER

Vessel shore power refers to the connection of marine vessels to the electrical grid while at berth in order to meet hotel loads. This practice is also known as cold ironing, since the main and auxiliary engines are shut down, allowed them to go “cold.” Cargo ship hotel loads can be as high as 6 MW and use of shore power reportedly can cut at-berth fuel consumption by 50% and nitrogen oxide emissions by up to 95% (Port of San Diego, 2014). Implementation was initially hindered by the lack of international design standards. This barrier was overcome in 2012 with establishment of IEC/ISO/IEEE 80005-1:2012 which provides design, installation, and testing standards for high voltage systems, on board the ship and on shore.

The estimated cost to retrofit vessels with the necessary connection and on-board distribution equipment ranges from $500,000 to $1.7 million, depending on the type of vessel (POLA, 2014; Meeks, 2013). As a result, it is most cost effective for vessels with high hotel loads, long dwell times (berthing duration), and a high frequency of calls at ports with power connections. Cruise ships are particularly well-suited to shore power as they have the added benefit of being essentially electric vessels that utilize their engines as generators.

Significant investments are also required to install electrical infrastructure at the port and power availability can be a concern. Hotel loads for a single cargo vessel can range from 300 kW to 6 MW, with bulk and RO-RO on the lower side and tankers on the high side. Cruise ships require even more power at berth with demand in the range of 7-11 MW. Upgrades to existing power infrastructure may be required or the installation of new substations. It is particularly important that the power supply be reliable. If use of shore power is required, a power outage would mean shutting down terminal operations.

Under the “At-Berth Regulation,” the ARB requires fleets to implement shore power or use alternative control technology that achieve equivalent emission reductions. Requirements begin at 50% of vessel calls in 2014-16 and ramp up to 80% of calls by 2020. The regulation is applicable to container, refrigerated cargo, and cruise ship fleets whose vessels cumulatively make 25 or more visits annually to any one of the Ports of Los Angeles, Long Beach, Oakland, San Francisco, San Diego, and Hueneme. Alternative control technologies include: non-grid-based shore power, such as distributed generation equipment fueled by natural gas; emission after-treatment controls installed on the vessels; use of alternative fuel on the vessel; and emission controls installed at the wharf, such as a bonnet emission capture and treatment system. California terminals that receive 50 or more vessels annually, including those that are privately owned, are required to install shore power. Table 4-2 lists all U.S. ports with installed shore power. The only implementations outside of California are cruise terminals at Juneau, Seattle, and New York.

Table 4-2. Shore Power Installations at U.S. Ports

Port	Terminals	Number of Berths	Cost (Million$)
Long Beach	ITS Pier G Pier T (tanker, crude) SSA Terminals / Matson Pier C	*	$200
	Middle Harbor Piers D, E, F	*	Underway
Los Angeles	All marine container terminals (8) World Cruise Center	25	$180
San Diego	B Street Pier Cruise Ship Terminal	-	*
	Tenth Avenue Marine Terminal	2	$4.25
Oakland	Ports America Outer Harbor	2	~$60
	TraPac	2	
	Ben E. Nutter (Evergreen)	2	
	Oakland International Container Terminal (OICT)	5	
	Matson	2	
	Charles P. Howard	1	
Hueneme	Terminals for refrigerated cargo ships	3	$13-15.2
San Francisco	Cruise Terminal	*	*
Seattle	Terminal 91 – cruise ships	2	*
Juneau	Princess Cruise Terminal	*	*
New York New Jersey	Red Hook Cruise Terminal	*	$19.3

* Information not available

There are several companies with experience designing grid connected shore power systems and a few that market modular systems, such as the ShoreBoX by Schneider Electric (Schneider Electric, 2016). Costs to install port side equipment are highly variable, depending on site conditions and required upgrades to the power supply such as new substations. Cochrane Marine's Shore Power System costs an estimated $3.5-5 million on top of any power supply costs (Cochran Marine, 2015). The Port of San Diego reported a cost of $4.25 million to install shore power at the Tenth Avenue Marine Terminal which handles bulk and refrigerated cargo. Installation for 25 berths at POLA cost around $180 million.

4.3 FERRIES

In some major metropolitan areas, ferries are a vital component of urban commuter transportation systems. They provide transport across bodies of water not easily served by bridges or tunnels and are used for emergency evacuations in case of natural or other disasters. U.S. DOT survey results show that, in 2013, a total of 128 ferry operators maintained 499 vessels with 476 in active service in the United States and its territories as shown in Table 4-3.[8] Most ferries are diesel powered but operators reported 3 electric powered ferries. Ferries have very long useful lives; the DOT reports that the average vessel age is 28 years and the oldest vessel is 101 years. At 95%, nearly all ferries carry passengers; 47% carry vehicles, and 22% carry freight. Ferries carried around 115 million passengers and over 30 million vehicles in 2013 (U.S. DOT, 2016).

Table 4-3. Passenger and Vehicle Ferry Boarding Estimates by Census Region (2013)

Census Region	Vessels in Service	Passengers	Vehicles
Northeast	181	30,852,000	3,456,000
Midwest	63	10,406,000	2,377,000
South	108	26,442,000	9,121,000
West	120	45,846,000	14,864,000
Other*	4	1,549,000	471,000
Total	**476**	**115,095,000**	**30,289,000**

*Includes U.S. territories and non-U.S. ferry operations that served U.S. terminals

Source: 2014 Highlights of Ferry Operations in the United States (U.S. DOT, 2016)

There have been a few experiments internationally with electric and hybrid diesel-electric ferries. For hybrid ferries, batteries may be charged from the diesel engine while in motion and from grid-connected or distributed generation shore power where facilities are available. They can be designed to operate in all electric mode for portions of travel routes. In the United States, San Francisco, Washington State, and New York City have considered or completed hybrid ferry demonstrations.

In the San Francisco Bay, Alcatraz Cruises operates a hybrid ferry as part of their concession services to Alcatraz Island for the National Park Service. Commissioned in 2008, the Hornblower Hybrid is powered by solar panels, wind turbines, grid electricity, and diesel engines. The vessel can operate solely on propulsion batteries for over an hour while cruising. While docked, hotel loads may be met from stored battery power or the grid. The vessel was designed and built using private funds. Hornblower Cruises also operates a hybrid excursion vessel in the New York Harbor. The New York Hornblower is powered by hydrogen fuel cells, solar panels, and wind turbines. It can accommodate 600 passengers and operates between Battery Park, Ellis Island, and Liberty Island (Hornblower, 2016).

Washington State proposed a hybrid ferry retrofit in 2013 but the project has not been completed and the State may pursue an LNG conversion instead due to cost. It was estimated that the hybrid conversion would reduce fuel consumption by an estimated 15.71% or nearly 4.5 million gallons

[8] Data are based on the 2013 National Census of Ferry Operators (NCFO). The Bureau of Transportation Statistics identified 202 operators deemed to be within scope of the survey and received responses from 128 operators. The actual number of operators likely is larger than 128. Not all operators report passenger or vehicle counts due to concerns about privacy; missing data are imputed.

of diesel and 45,000 metric tons of CO_2 equivalent over the vessel's remaining 19 year useful life (WSDOT, 2011; WSDOT, 2015).

In 2010, the City of Los Angeles Harbor Department obtained a DOE grant to retrofit the Angelena II tour boat with a hybrid-electric propulsion system. The project encountered major challenges with an automatic charging system and thermal monitoring of battery cells. Ultimately, the vessel proved unreliable. The team was unable to meet U.S. Coast Guard requirements for a Certificate of Inspection and the project was terminated in 2014. The total project cost was $4.05 million, including $3.01 million in labor and $469,000 in materials and contractual costs (POLA, 2015).

There are more hybrid electric ferries internationally. A number of projects were showcased at the Electric & Hybrid Marine World Exposition, 2016 in Amsterdam. For example, Siemens and Fjellstrand developed the Ampere, a 360 passenger Norwegian electric ferry driven by two electric motors. The ferry's lithium-ion batteries have a capacity of 1,000 kWh, allowing the vessel to make a few trips between two fjord communities on a single charge. The ferry's schedule would only allow about 10 minutes for recharging at the dock between trips and the power grid in the region does not have sufficient capacity for fast charging. Instead, a lithium-ion battery installed at each pier serves as a buffer, supplying electricity while the ferry is docked. The pier-side batteries can recharge slowly until the ship returns. The vessel is made of aluminum rather than steel, which requires less maintenance and contributes to overall lower operating costs (Siemens, 2016).

5. RAIL

5.1 FREIGHT RAIL

For over 180 years, U.S. railroads have delivered goods and served almost every industrial, wholesale, retail, and resource-based sector of the economy. The freight rail system includes over 140,000 miles of track, 25,000 locomotives, and 374,000 freight cars. As shown in Table 5-1, Class I railroad freight systems move nearly 1.8 billion tons of freight annually, for a total of 1,740 billion revenue ton-miles. At approximately 40%, rail accounts for more intercity freight volume by weight than any other mode of transportation (Davis, Diegel, & Boundy, 2015; AAR, 2016).

Table 5-1. Summary Statistics for Class I Freight Railroads

Year	Number of locomotives in service	Number of freight cars (thousands)	Train-miles (millions)	Car-miles (millions)	Tons Originated (millions)	Average length of haul (miles)	Revenue ton-miles (millions)	Energy intensity (Btu/ton-mile)	Energy use (trillion Btu)
1990	18,835	659	380	26,159	1,425	726	1,033,969	420	434.7
1995	18,812	583	458	30,383	1,550	843	1,305,688	372	485.9
2000	20,028	560	504	34,590	1,738	843	1,465,960	352	516.0
2005	22,779	475	548	37,712	1,899	894	1,696,425	337	571.4
2010	23,893	398	476	35,541	1,851	914	1,691,004	289	488.1
2013	25,033	374	504	35,253	1,758	990	1,740,687	296	514.9

Source: Transportation Energy Data Book Edition 34 (Davis, Diegel, & Boundy, 2015).

Freight rail companies are required to fund infrastructure maintenance and installation. According to the American Association of Railroads, between 1980 and 2015, privately owned freight railroads invested approximately $600 billion in locomotives, freight cars, tracks, bridges, tunnels, and other infrastructure and equipment, with an estimated $29 billion spent in 2015 alone (AAR, 2016).

Modern locomotives are diesel-electric machines, using diesel engines to power the wheels via a generator or alternator and wheel-mounted electric traction motors. The engines are typically 12 to 16 cylinders and produce 3,000-6,500 hp. Compared to a direct drive configuration, the diesel-electric locomotive is mechanically less complex, more fuel efficient, requires less maintenance, and can deliver maximum torque to the wheels at low vehicle speed.

Diesel locomotive engines are extremely durable and are designed to be remanufactured several times. Historic annual replacement rates of the existing locomotive stock range from 3% to 5%, resulting in a fleet turnover time of about 30 years for Class I railroads. Used line haul locomotives often are purchased by short haul railroads or enter into switcher service and some may remain in use for fifty years. New freight locomotives cost around $1.5-2.5 million and U.S. production is typically in the range of 500 to 1,000 units per year (U.S. EPA, 2008; Tita & Hagerty, 2014).

The following technologies provide opportunities for full or partial electrification of rail systems (SCAG, 2012; U.S. DOT, 2014):

Straight-electric locomotives powered from overhead wires (catenary) are common for passenger travel and are in use for freight movement outside the United States. Of the full electrification technologies, the Southern California Association of Governments (SCAG) deemed only straight-electric catenary systems to be mature enough to be deployed in the next 10 to 15 years (SCAG, 2012). However, unless the entire rail line is electrified, long-haul locomotives must be swapped at the end of the catenary system.

Battery-electric locomotives are in development but are still experimental. With DOE and other support, prototype switchers using absorbent glass mat lead-acid batteries were tested and evaluated in 2009 and 2010 for yard operations. Higher performance advanced batteries, including lead carbon chemistries, are under investigation as solutions for larger, more powerful long-haul applications.

Dual-mode locomotives can be powered by an electrified catenary and can operate on diesel alone where no catenary is available. Dual-mode locomotives are in use for passenger service worldwide, with one application in the United States by the New Jersey Transit commuter rail which is deploying Bombardier ALP-45DP locomotives. The SCAG identified a few in use outside the United States for last-mile light freight and switching operations. This technology is flexible and can utilize existing infrastructure. However, since these locomotives must still carry a large diesel engine, they do not realize the weight savings and associated fuel efficiency gains that straight-electric systems do.

Linear synchronous motor systems use permanent magnetics on vehicles and linear synchronous motors, mounted on guideways, to levitate and propel them. For rail, General Atomics has proposed retrofitting existing infrastructure with the motors mounted on ties between the rails. The magnets would be mounted on passive "locomotive" helper cars. This concept is still in development but, if successful, would eliminate the need to move heavy onboard engines, batteries, or motors.

Hybrid-electric locomotives utilizing advanced batteries can operate in battery-only mode, then switch to diesel-electric mode to simultaneously power the locomotive and recharge the batteries. In 2010, GE demonstrated a prototype hybrid diesel-electric Evolution locomotive that utilized regenerative braking and used the recovered energy, after storing in batteries, to offset fuel consumption up to 15%. Larger energy storage would be required to enable all-electric operation. It does not appear that the hybrid version of the Evolution locomotive is in commercial production. Hybrid genset locomotives have been developed for switcher applications, largely with public funding.[9] It appears that these locomotives have proven unreliable, that sales have been sluggish, and that many innovators have gone into receivership.

[9] Genset locomotives use 2 - 4 smaller diesel engines, in place of a single large engine, to provide power on demand, with one or more engines shut down automatically when they are not needed. Switcher locomotives are used in and around rail yards, ports, industrial facilities, etc., to assemble and disassemble trains, move rail cars around, and make short transfer runs.

Battery electric tender cars, placed behind diesel-electric locomotives, carry batteries capable of powering the locomotive for short distances near population centers or environmentally sensitive areas.

Compared to diesel-electric, fully electric locomotives are more efficient and have lower operating costs. However, Table 5-1 shows that long haul freight is moved nearly 1,000 miles on average, making battery-electric technology infeasible. Therefore, electrification of long haul freight using current or near term technology would require use of straight-electric locomotives and grid connection infrastructure such as a catenary system. The SCAG estimated catenary infrastructure costs at $4.8 million per track mile and an additional $5 million per straight-electric locomotive or $8 million per dual-mode locomotive (SCAG, 2012). The initial high cost of these systems does not provide a satisfactory return on investment for private long-haul railroads which are already responsible for maintenance of existing infrastructure.

While the diesel-electric locomotive configuration lends itself easily to mild hybridization, at a minimum, long-haul freight trains have very limited potential for regenerative braking. First, they travel long distances at relatively constant speed with infrequent stops. In addition, slowing or stopping the train requires significant power due to the train's weight. As a result, the locomotive actually performs only a small fraction of the braking and most is accomplished by the mechanical brakes on the freight cars.

Electrified short haul rail cold be more feasible and at least one such line is in operation today. The isolated Black Mesa and Lake Powell Railroad in Arizona uses electric locomotives to transport coal along a 78-mile catenary system from the mine to a power plant at its terminus (American Rails, 2016). Similar systems could be cost effective for movement of raw materials or finished products between production facilities and warehouses, and movement of containers from seaports to local or regional distribution centers or hubs. However, installation of the required infrastructure remains expensive, and it is not clear what the payback period would be for local applications. Also, short line railroads typically purchase older used locomotives, which magnifies the incremental up-front cost for the equipment and further increases the payback period.

Straight-electric, hybrid-electric, and possibly battery-electric locomotives are most feasible for switcher type applications in ports, rail yards, and large industrial facilities or complexes. The Federal Rail Administration estimates the payback period for hybrid switchers at 8 years (U.S. DOT, 2014).

5.2 PASSENGER RAIL

While many different classifications are possible, this section divides passenger rail travel by range into transit, regional, and inter-city rail service. Relative to the public transit rail modes discussed in the segment overviews in Section 1.3, transit rail includes the APTA classifications of heavy rail (subway), light rail, and streetcar; regional rail includes the APTA classifications of commuter and hybrid rail; and intercity rail, which is not included in the APTA data, covers longer distance travel.

Transit rail operates within metropolitan areas and is characterized by frequent stops. It includes subway or raised rail on dedicated tracks as well as short, light trains (e.g. streetcars, tramways, or trolley cars) operating on fixed rails in the roadway. Table 5-2 provides summary statistics for transit rail. Nearly all transit rail systems are powered by electricity (APTA, 2015).

Table 5-2. Summary Statistics for Transit Rail

Year	Number of passenger vehicles	Vehicle-miles (millions)	Passenger trips (millions)	Passenger-miles (millions)c	Average trip length (miles)	Energy intensity (Btu/passenger- mile)	Energy use (trillion Btu)
1990	11,332	560.9	2,521	12,046	4.8	3,024	36.4
1995	11,156	571.8	2,284	11,419	5.0	3,340	38.1
2000	12,168	648.0	2,952	15,200	5.1	2,797	42.5
2005	12,755	715.4	3,189	16,118	5.1	2,783	44.9
2010	13,614	759.6	4,007	18,580	4.6	2,520	46.8
2013	12,434	774.3	4,275	20,381	4.8	2,404	49.0

Source: Transportation Energy Data Book Edition 34 (Davis, Diegel, & Boundy, 2015)

Regional rail provides passenger service between a metropolitan area and its outlying suburbs. This service often makes use of current or former freight lines using either self-propelled cars or locomotives. Table 5-3 provides summary statistics for regional rail. Some regional rail systems are electrified, but the majority use diesel as shown in Figure 1-6.

Table 5-3. Summary Statistics for Regional Rail

Year	Number of passenger vehicles	Vehicle-miles (millions)	Passenger trips (millions)	Passenger-miles (millions)	Average trip length (miles)	Energy intensity (Btu/passenger- mile)	Energy use (trillion Btu)
1990	4,982	212.7	328	7,082	21.6	2,822	20.0
1995	5,164	237.7	344	8,244	24.0	2,632	21.7
2000	5,498	270.9	413	9,402	22.8	2,551	24.0
2005	6,392	303.4	423	9,473	22.4	2,743	26.0
2010	6,927	345.3	464	10,874	23.4	2,897	31.5
2013	7,310	359.1	480	11,862	24.7	2,737	32.5

Source: Transportation Energy Data Book Edition 34 (Davis, Diegel, & Boundy, 2015)

There currently are only two rail systems in the United States that can be classified as intercity: Amtrak and the Alaska Railroad. The Alaska Railroad is operated by the Alaska Railroad Corporation (a public corporation of the State of Alaska) and provides freight and passenger service from the ports of Whittier, Seward, and Anchorage to Fairbanks, Denali National Park, and military installations (U.S. DOT, n.d.). Amtrak, or more formally the National Railroad Passenger Corporation, is a private, for-profit corporation that operates intercity passenger rail services in 46 states and the District of Columbia. Summary statistics for Amtrak are shown in Table 5-4.

Table 5-4. Summary Statistics for Intercity Passenger Rail (Amtrak)

Year	Number of locomotives in service	Number of passenger cars	Train-miles (thousands)	Car-miles (thousands)	Revenue passenger-miles (millions)	Average trip length (miles)	Energy intensity (Btu per revenue passenger-mile)	Energy use (trillion Btu)
1990	318	1,863	33,000	300,996	6,057	273	2,505	15.2
1995	422	1,907	31,579	282,579	5,401	266	2,501	13.5
2000	385	1,891	35,404	371,215	5,574	243	3,235	18.0
2005	258	1,186	36,199	264,796	5,381	215	2,709	14.6
2010	282	1,274	37,453	294,820	6,420	220	2,271	14.6
2013	418	1,447	38,410	324,949	6,810	218	2,118	14.4

Source: Transportation Energy Data Book Edition 34 (Davis, Diegel, & Boundy, 2015)

Amtrak operates mostly diesel locomotives but also has electric locomotives and powered cars used in the Northeast Corridor (NEC) and Philadelphia to Harrisburg Main Line. The NEC, which serves Washington, Baltimore, Philadelphia, New York, and Boston, is one of the highest volume rail corridors in the world. Shared by Amtrak, 8 regional rail operators, and four freight railroads, it carries 2,000 regional and Amtrak passenger trains daily. The NEC spans a total of 899 miles, including a 457-mile mainline connecting Washington, D.C. to Boston, MA, and branches to Harrisburg, PA, Springfield, MA, Albany, NY, and Richmond, Va. Due to increasing urbanization and congestion in this megaregion, rail ridership in the NEC grew 37% between 2000 and 2014. Much of the rail infrastructure is 80-150 years old and portions of the line were electrified with catenary lines beginning in 1930 (Amtrak, 2012; NEC Commission, 2014; NEC Commission, 2016). As part of a $4 billion improvement program between 1976 and 1998, Amtrak electrified a final 155 miles of railroad between New Haven and Boston, enabling the high speed Acela Express service which began operating in 2000 (Amtrak, 2016).

Electric passenger rail is common worldwide, particularly for transit and regional systems. Electric power is ideally suited to the frequent stops and starts and need for low speed-high acceleration events found in these modes. Nearly all transit rail is electrically powered as is some regional rail, particularly in highly urbanized areas like the NEC. This commitment to electrification is likely to remain unchanged. For example, the current FY17-21 investment plan for the NEC includes $5.3 billion in basic infrastructure improvement plan, of which $348 million is estimated for repairs and upgrades to the electric traction equipment. Electrical upgrades are also included in the plan's special projects, which are budgeted at $18.5 billion (NEC Commission, 2016). Electric passenger rail is likely to expand in the future due to increasing urbanization. For example, the Caltrain Modernization Program will electrify regional rail connecting San Francisco San Jose (Caltrain, 2016).

Technology for electric locomotives powered via catenary wire is very mature. Expansion of its use, particularly in transit and regional applications, is limited only by cost, which is driven mainly by electric infrastructure needs. Use of dual-mode locomotives could mitigate the infrastructure issue at an estimated cost of $8 million per locomotive (see Section 5.1). Hybrid locomotives may also be suitable for regional rail and some shorter intercity routes where they and could operate in all-electric near metropolitan hubs. However, the lower frequency of stops in intercity rail will reduce the benefits of hybridization. Advanced technologies like the linear synchronous motor concept face infrastructure challenges similar to catenary systems and are still in the development stage.

6. AIRCRAFT GSE

This study has not considered electrification of air transport for either goods or people movement. While researchers are pursuing a number of approaches for reducing the emissions from aircraft, a recent National Academy of Sciences report concluded that hybrid-electric and all-electric systems were not a research priority. According to the study committee, it is unlikely that batteries with the requisite capacity and specific power could be developed and certified for commercial aircraft applications within the next 30 years (NAS, 2016). Therefore, this report has focused on electrification of the ground support equipment (GSE) used at airports.

Airport GSE classification includes a wide range of products from air start units to baggage lifts. Applications include: aircraft maintenance, cleaning, maneuvering, and refueling; airfield maintenance; deicing and snow removal; emergency response; payload moving; and restocking of provisions. This study does not include the following as airport GSE: construction vehicles and equipment, airport staff fleet vehicles, and airport patron, employee, and cargo vehicles that travel to and from the landside of airports (ACRP, 2015). The potential for electrification for these types of vehicles is covered in other sections of this study.

Some GSE has tractive power - the vehicle is moved by the onboard power source (for example, baggage tugs or aircraft pushback tractors). Other powered equipment does not move under its own power but is towed by other equipment. Examples of this include ground power and preconditioned air units for supplying electricity and cabin comfort to parked aircraft. Although both types of equipment could be electrified, this report only examines electrification options for self-powered GSE.

6.1 MARKET OVERVIEW

Although there is no open source database with up to date national population estimates of airport GSE, there are studies that quantify specific airport populations as part of emissions estimates. For example, The Air Transit Association (ATA) of America conducted a survey of GSE at three major airports in the Houston/Galveston ozone nonattainment area. As a point of reference, the study estimates that the three airports (Houston Intercontinental, Ellington Field, and William P. Hobby Airports) had a combined total of 3,154 GSE in 2007 (ATA, 2000).

More recently, the Airport Cooperative Research Program (ACRP), in coordination with FAA, produced a report entitled Airport GSE: Emission Reduction Strategies, Inventory, and Tutorial. Among eight other research objectives, this report included an estimated inventory of powered GSE based on a specific sampling of large-hub, medium-hub, small-hub, and non-hub airports that is representative of airports located in varying climates and with a range of equipment requirements. They estimate the nationwide GSE inventory at 108,578 (ACRP, 2012). Table 6-1 illustrates the distribution of GSE by equipment type. Excluding light duty vehicles and buses, the largest specific categories of GSE are baggage and cargo tugs, belt loaders, and aircraft tractors.

The ACRP study highlighted the difficulty in locating accurate and reliable estimates of the number of GSE vehicles and their usage characteristics. The study specifically notes that "Estimating an airport's contribution to a region's overall air quality is often required for State Implementation Plans, Health Risk Assessments, National Environmental Policy Act analyses, other emission inventory programs, and for grant applications, such as FAA's Voluntary Airport Low Emissions program. Although airport GSE can provide significant contributions to an airport's overall emissions, little guidance is available to help airports accurately capture actual GSE activity at their facilities in a manner suitable for the FAA's approved emissions models, EDMS and the AEDT." (ACRP, 2015)

Table 6-1. Estimated National Inventory of GSE by Equipment Type

GSE Type	Number	Percent of Fleet
Baggage Tugs & Cargo Tugs	25,367	23.6
Cars, Pickups, Vans, SUVs	*13,361*	*12.4*
Other	10,566	9.8
Belt Loaders	10,494	9.7
Aircraft Tractors & Tugs	7,857	7.3
Deicing Trucks	5,732	5.3
Fork Lifts	5,078	4.7
Lifts	4,917	4.6
Cabin Service & Catering Trucks	4,373	4.1
Air Conditioners & Heaters	4,238	3.9
Carts	4,168	3.9
Generators, Ground Power Units (GPUs)	2,679	2.5
Cargo Loaders	1,963	1.8
Lavatory Trucks & Carts	1,465	1.4
Fuel Trucks	1,454	1.4
Hydrant Trucks & Carts	1,181	1.1
Passenger Stairs	1,089	1.0
Maintenance Trucks	616	0.6
Air Start Units	500	0.5
Light Carts & Stands	454	0.4
Buses	*86*	*0.1*
Total	**108,578**	**100**

NOTE: Total shown is a modeled value and does not equal the sum of the individual equipment types. Fleet distribution calculated from total sum of types.

Italicized types are not included as airport GSE in this study.

Source: Transportation Research Board, Airport Cooperative Research Program (ACRP, 2012)

A recent feasibility study of electrified GSE for the Los Angeles International Airport assessed the distribution of equipment by type, which can be instructive in supporting the estimates of the types of GSE most commonly found. Of the roughly 3,000 pieces of GSE at the Los Angeles airport (LAX) in 2006, the largest fleet was baggage tractors, at 19.7% of the total (600 vehicles). Belt loaders were the second largest group, with 280 vehicles or 9.2% of the total. Forklifts were third, at 251 vehicles and 8.2% of the total. LAX had around 700 electric GSE in its fleet, and the majority of these were baggage tractors (293 units, or 40% of total electric GSE). The airport also had more than 100 electric belt loaders (CDM Smith, 2015).

Southwest Airlines has committed to entering new markets with energy-efficient electric belt loaders and baggage tractors, among other GSE types. Southwest began their electrification rollout in 2011 in three cities: Charleston, South Carolina; Greenville, South Carolina; and Newark, New Jersey. Airport fleet managers continue to show interest in electrifying GSE where it makes sense and does not jeopardize operational and financial integrity. Fleet managers consider operation size, cost of infrastructure retrofits if battery charging is not in place, electric-powered GSE duty cycle limitations, and required charge times. Electrified GSE must be able to perform core job functions and consideration of power needs are crucial. For example, aircraft tractors must be capable of towing out-of-service aircraft to a maintenance hangar for repair. Climate must also be considered, since electric equipment may not be as reliable in extremely cold weather (Southwest, 2016). ACRP estimates approximately 10% of the GSE units currently in use in the United States are electric. Electric GSE leads all other alternative fuel types such as ethanol, LPG, natural gas, methanol, and hydrogen.

Airports have been interested in electrified GSE chiefly for the emissions reduction opportunities and associated local air quality benefits they offer. This is particularly important since airports are often located near population centers and in emission non-attainment areas. Airports have typically not been as interested in adopting electrified GSE for fuel displacement or fuel cost saving purposes.

Most GSE duty cycles consist of short periods of high-load operation followed by extended periods of idle or engine off. The engine load factor can account for differing operating conditions over a long period of operation and has to be considered (ACRP, 2012). Table 6-3 displays ACRP estimates operating Time-in-Mode (TIM) of passenger aircraft GSE by aircraft type - wide-body, narrow-body, and small-body aircraft (ACRP, 2015). TIM is measured in minutes per aircraft serviced.

Similar information is shown in Table 6-3 for cargo aircraft GSE. As these tables illustrate, operating time can range anywhere from as little as 4 to as much as 91 minutes depending on aircraft and GSE type. Operating time is also dependent on airport size (ACRP, 2015).

GSE idling time varies across multiple units of the same type, across airlines, and airports. In severe circumstances where idle periods represent the major portion of the duty cycle, the load factor approaches zero while the actual emission rate per unit work performed approaches infinity (ACRP, 2012).

Table 6-3. Passenger Aircraft GSE Operating Time

GSE Type	Time-in-Mode Wide-Body Aircraft	Time-in-Mode Narrow-Body Aircraft	Time-in-Mode Small-Body Aircraft
Aircraft tractor	12	7	9
Baggage tractor	53	28	13
Belt loader	42	47	22
Cabin service/catering truck	28	21	6
Cargo/container loader	50	-	-
Lavatory truck	17	8	4
Air conditioner	-	41	-
Auxiliary Power Unit (APU)	25	15	-
Fuel/hydrant truck	37	17	9
Service truck	11	9	-
Water service	5	5	-
GPU	-	35	35

Time-in-Mode = Operating time, in minutes, per aircraft serviced. Values shown are defaults proposed by ACRP for Aviation Environmental Design Tool (AEDT) model.

Source: Transportation Research Board, Airport Cooperative Research Program (ACRP, 2015)

Table 6-3. Cargo Aircraft GSE Operating Time

GSE Type	Time-in-Mode Wide-Body Aircraft	Time-in-Mode Narrow-Body Aircraft
Aircraft tractor	7	5
Belt loader	23	4
Cargo tractor	29	13
Cargo/container loader	91	47
Fuel/hydrant truck	24	25
Lavatory truck	6	-
Service truck	3	-
GPU	55	66
Other	-	11

Time-in-Mode = Operating time, in minutes, per aircraft serviced. Values shown are defaults proposed by ACRP for Aviation Environmental Design Tool (AEDT) model.

Source: Transportation Research Board, Airport Cooperative Research Program (ACRP, 2015)

Table 6-4. Estimated Aircraft GSE Purchase Costs

GSE Type	Fuel	Cost
GPU	Diesel	$17,000
Baggage Tractor	Gasoline	$26,000
	Diesel	$28,000
	Electric	$35,500
Belt Loader	Gasoline	$28,500
	Diesel	$32,200
	Electric	$35,500
Pushback Tug	Diesel	$86,200
	Electric	$93,000
Cargo Loader	Diesel	$475,000

Source: (ACRP, 2012)

Although conventionally fueled GSE is less expensive, incremental cost for electric technologies is not prohibitive. As shown in Table 6-4, estimated electric GSE costs about 8% to 26% more than conventional diesel equipment (ACRP, 2012). In addition, electric GSE typically has lower maintenance and operating costs. In some areas of the United States (specifically air quality nonattainment areas) there is pressure for fleet managers to convert diesel and gasoline GSE to cleaner technologies before the useful life of the original equipment is reached. Retrofits are also possible. However, because the engine often is a large portion of the purchase price, the cost to retrofit may be similar to purchasing new equipment. This is especially true if the retrofit is done on an as-needed or piecemeal basis compared to large lot purchases of new equipment (ACRP, 2012).

6.2 AIRCRAFT SUPPORT APPLICATIONS

There are some self-powered GSE that perform functions that are required regardless of whether the aircraft is used to transport passengers, freight, or both. This includes maneuvering and refueling the aircraft, providing lavatory service, and loading potable water. Table 6-5 lists several electric options for these general functions.

Table 6-5. General GSE Electric Technologies

Manufacturer & Model	Drive Type	Application	Status
Charlatte CLT200E	BEV	Lavatory Service	Commercial
Charlatte CWT300E	BEV	Water Service	Commercial
Charlatte CPB35E	BEV	Pushback Tractor	Commercial
Charlatte TE206	BEV	Tow Tractor	Commercial
Charlatte TE208	BEV	Tow Tractor	Commercial
Tug GT35E	BEV	Pushback Tractor	Commercial

6.3 FREIGHT SUPPORT APPLICATIONS

Table 6-6. Freight GSE Electric Technologies

Manufacturer & Model	Drive Type	Application	Status
Charlatte CT5E	BEV	Cargo Tractor	Commercial
Charlatte CBL100E	BEV	Beltloader	Commercial
Charlatte CBL150E	BEV	Beltloader	Commercial
Charlatte CBL2000E	BEV	Beltloader	Commercial
JBT AeroTech Commander 15i Electric	BEV	Loader	Commercial
Tug 660E	BEV	Beltloader	Commercial

As discussed in Section 1.3, aircraft transport around 25% of U.S. freight shipments by value. Some is moved as additional cargo on commercial passenger airlines; for example, packages and mail for the U.S. Postal Service. This freight is usually consolidated into a specially-designed container to fit the cargo hold of the particular aircraft. Freight is also moved on dedicated aircraft such as those owned by FedEx and United Parcel Service. In either case, GSE is needed to move the freight from the consolidation points (typically a warehouse on or near airport property) to the aircraft themselves, and to load the freight containers into the aircraft.

The specialized equipment used for freight movement includes cargo loaders, belt loaders, and cargo tractors. Table 6-6 list available electrified airport freight GSE. All models are commercial available.

6.4 PASSENGER SUPPORT APPLICATIONS

Some airport GSE is used specifically for facilitating passenger airline operations. Luggage must be moved between terminals and aircraft and from aircraft to aircraft and catering services must be supplied. Because of their short trip distances and airside operations, the passenger support GSE can be a viable candidate for electrification. For GSE that is typically operated at a single aircraft gate, like belt loaders, charging infrastructure can be placed at these gates to provide convenient charging when the vehicle is not being used. GSE that operates across multiple gates or areas of the airport will require access to charging at a central location that is convenient for their daily operation. Table 6-7 lists electrified options for passenger support GSE that are currently available.

Table 6-7. Passenger GSE Electric Technologies

Manufacturer & Model	Drive Type	Application	Status
Charlatte CFB2000	BEV	Baggage Tractor	Commercial
Charlatte CBL100E	BEV	Beltloader	Commercial
Charlatte CBL150E	BEV	Beltloader	Commercial
Charlatte CBL2000E	BEV	Beltloader	Commercial
Charlatte T137-V3	BEV	Baggage Tractor	Commercial
JBT AeroTech Commander 15i Electric	BEV	Loader	Commercial
Tug 660E	BEV	Beltloader	Commercial
Tug MZ Electric	BEV	Baggage Tractor	Commercial

7. IDENTIFYING PROMISING MARKETS

This study included development of a framework to determine what markets are promising for BEV and PHEV solutions. This framework considers technical, operational, economic, and practical issues in vehicle ownership and market development, but also takes into account potential social benefits. When using the criteria to select vehicles for detailed analysis, data availability was also considered.

7.1 SELECTION CRITERIA

DOE priorities and stakeholder feedback were used to identify the following issues, in no particular order.

Duty cycle. How the vehicle is used determines the level of electrification possible, the potential for fuel savings, and the cost effectiveness. In addition, it is critical that commercial vehicles be capable of performing their given functions effectively. Therefore, duty cycle considerations sometimes serve as a go / no-go criteria. At the same time, it may be possible to alter operations in such a way to accommodate the difference in capability between a PEV and a conventional vehicle. For example, all vehicles in a homogenous fleet must be capable of performing the worst case duty cycle, even if that cycle constitutes only a small fraction of expected work shifts. Meanwhile, jobs within a diversified fleet may be allocated according to vehicle capabilities.

Fleet fuel consumption and criteria emissions. Responsible use of public funding dictates that, where possible, priority should be given to applications that have the largest impact in total on fuel consumption and emissions. Where fleet fuel consumption or emissions are not known, the total annual miles (or hours) of operation may be used as a second best proxy and relative fleet size as a third best proxy. Note however that these proxies do not take into consideration differences in per fuel consumption rates, which may be significant.

Market size. Applications with higher vehicle sales offer the possibility to reap rewards more quickly at the in-use fleet level than those with smaller sales. In addition, higher sales volumes offer manufacturers the opportunity to recoup fixed costs more quickly. Meanwhile, for applications with relatively small sales, manufacturers risk not being able to recover these costs at all over the term of the product cycle.

Per vehicle fuel consumption and criteria emissions. Applications with higher per vehicle fuel consumption and emissions may represent "low hanging fruit" where reductions are relatively easy. Even small improvements on a percentage basis can yield large net benefits.

Location of criteria emissions. Vehicles and equipment that operate primarily in population centers, non-attainment areas, or near sensitive populations have disproportionate impact on public health. In addition, emissions that primarily impact disadvantaged populations raise issues of environmental justice.

Added functionality or enhancement of core mission performance. Stakeholders stressed that work vehicles are tools; technology that makes job performance more efficient or easier for the operator are valuable to fleets independent of fuel savings. Those that negatively impact efficiency and ease of use are unlikely to find market acceptance even if they offer fuel cost benefits. Stakeholders identified the following core or added functions:

- Safety
- Automation of vehicle operating modes / elimination of operator actions
- Export power

Other ancillary benefits. Stakeholders identified a number of valuable but unpriced benefits that can arise from electrification. For example, several benefits are attributed to reduction in noise, vibration, and harshness (NVH), including driver satisfaction and retention, ability to extend operating hours to overnight or early morning, and improved community relations ("license" to operate). These benefits may not be accounted for in a strict cost benefit or break even calculation, but may be considered in investment decisions. It is possible that such high-value but unpriced benefits may be the primary motivations for electrification. Stakeholders identified the following ancillary benefits:

- Driver attraction, satisfaction, and retention due to reduced NVH and ease of use
- Extended operating hours due to quiet operation
- Improved community acceptance / relations due to quiet operation and reduced emissions
- Extended equipment useful life
- Safety

Natural extension from existing products. If an existing product has proven reliable and cost effective, similar applications are more likely to be suitable for electrification. The technology is likely to be appropriate; manufacturers have lower redesign and investment requirements; and users may have higher confidence in both the product and the manufacturer.

7.2 ANALYSIS OF HIGHWAY APPLICATIONS

Highway vehicles were evaluated to determine applications worthy of an in-depth analysis of their suitability for electrification. The task of gathering information necessary for the assessment highlights the difficulties in obtaining up-to-date and complete data on vehicles other than light duty. The 2002 VIUS survey represents the most comprehensive heavy highway vehicle data source since it includes information on body style, installed equipment, ownership, usage, annual mileage, and self-reported fuel consumption among a wealth of other metrics. However, this data set is outdated and industry insiders indicate that a number of important market shifts have occurred since 2002. At this time, it remains unclear whether the survey will be re-instated in the near future. Meanwhile, attempts to match disparate sources of data for the various metrics are complicated by differences in level of detail, particularly on body style and vocation.

Table 7-1 represents a partial attempt at integrating current registration data from IHS Polk, fuel consumption data from VIUS, and duty cycle metrics from the National Renewable Energy Laboratory's Fleet DNA database. It should be noted that Fleet DNA represents a sample of vehicles and may not be nationally representative. Quantitative data from Table 7-1 was combined with qualitative understanding of the remaining criteria, namely: relative magnitude of idle time; location of operations; and contribution of electrification to core functionality or addition of new functionality. Finally, in order to determine if an application could be further analyzed, consideration was given to whether duty cycle data for the vehicle type was available in the NREL Fleet DNA database or from the ORNL Medium Truck Duty Cycle (MTDC) project. Figure 7-1 provides a visual representation of the relative scoring of the applications on all metrics. Blank fields in this graphic indicate where data were not readily available, again highlighting the difficulties in obtaining complete data.

Table 7-1. Highway Vehicle Data for Application Evaluation

	Vehicle	Number of Vehicles		Estimated Fuel Use		Sample Duty Cycle Metrics (FleetDNA)					
Vocation	Type	In-Use	New	In-Use Fleet (10^6 gal/yr)	New Vehicles (gal/yr)	Max Speed (mph)	Avg Speed (mph)	Stop Frequency (no./mile)	Avg Stop Time (sec)	Daily Range (miles)	Kinetic Intensity (1/km)
Service											
Utility	Bucket	60,307	2,397	959	1,963	59	29	1	706	27	0.8
Emergency	Ambulance	21,431	573	*	*	*	*	*	*	*	*
	Firetruck	31,220	581	*	*	*	*	*	*	*	*
Road & Grounds Maintenance	Specialty Body	62,097	1,208	1,143	3,301	*	*	*	*	*	*
	Delivery	85,828	1,722	1,130	2,400	*	*	*	*	*	*
Construct. & Mining	Bare Chassis	152,119	2,883	*	*	*	*	*	*	*	*
Sanitation	Box Truck	113,529	4,642	5,722	6,281	8	*	*	*	*	*
	Refuse	11,716	153	591	6,281	58	19	5.6	94	73	1.1
Other	Delivery	278,769	11,885	4,336	2,716	*	*	*	*	*	*
	Bare Chassis	278,769	11,885	7,017	3,330	*	*	*	*	*	*
	Tractor	199,731	18,991	*	*	*	*	*	*	*	*
Goods Movement											
All Fleets	Delivery Trucks	2,120,464	106,970	43,244	3,072	61	26	2.2	715	52	1.2
	Specialty Body	846,516	25,086	19,315	3,639	*	*	*	*	*	*
	Tractor	2,387,284	206,246	263,178	16,542	*	*	*	*	*	*
	Tractor, local	*	*	*	*	70	42	0.3	559	127	0.31
People Movement											
All Fleets	School Bus	513,071	39,071	*	*	57	24	1.4	320	60	1.3
	Bus	112,447	4,161	*	3,697	57	21	2	338	108	1.9
	Motor Home	704,896	10,987	959	1,963	*	*	*	*	*	*

* Information not available.

Sources:

Number of vehicles: IHS Polk; provided by NREL as US Vehicle Registration Data for Class 4-8, R.L. Polk and Co. 12/31/2013. Compiled by CSRA, Inc. Segmentation by Energetics Inc. New vehicles estimated from MY2013-2014 registrations. Note that the registration data obtained does not distinguish between local (day cab) and long-haul (sleeper) tractors.

Fuel Use: Estimated through combination of IHS Polk vehicle population information and analysis of VIUS 2002 usage characteristics (U.S. DOC, 2004).

Sample duty cycle metrics: NREL Fleet DNA composite data; analysis by Energetics Inc. (NREL, n.d.)

		National Impact			Local Impact			Duty Cycle Suitability					Functionality	
		Fleet Size	Sales	Fleet Fuel	Vehicle Fuel	Idling	Location of Ops	Data Avail.	Stop Freq.	Stop Dur.	Daily Range	Kinetic Intens.	Core	Addtl.
Service														
Utility	Bucket Trucks	○○○○	○○○○	○○○○	○○○○	●●●●	●	●	●○○○	●●●●	○○○○	●●○○	●	●
Emergency	Ambulance	○○○○	○○○○			●●●●	●	○						
	Firetruck	○○○○	○○○○			●●●●	●	○						●
Road & Grounds	Specialty Body	○○○○	○○○○	○○○○	○○○○	●●●○	○	○					●	●
	Delivery	○○○○	○○○○	○○○○	○○○○	●●●○	○	○						
Constr. & Mining	Bare Chassis	○○○○	○○○○				○	○						●
Sanitation	Box Trucks	○○○○	○○○○	○○○○	●●○○	○○○○	●	○						
	Refuse	○○○○	○○○○	○○○○	●●○○	○○○○	●	●	●●●●	○○○○	●●●○	●●●○		●
Other	Delivery	●○○○	○○○○	○○○○	○○○○			○						
	Bare Chassis	●○○○	○○○○	○○○○	○○○○			○						
	Tractor	○○○○	○○○○					○						
Goods Movement														
	Delivery Trucks	●●●●	●●●●	●●●●	●●●●	●●○○	●	●	●●○○	●●●●	●●○○	●●●○		
	Specialty Body	●●○○	●○○○	○○○○	●○○○	●●○○		○						
	Tractor	●●●●	●●●●	●●●●	●●●●	●●●●	○	○						
	Local Tractor					●●○○	●	●	○○○○	●●●○	●●●●	○○○○		
People Movement														
	School Bus	●●○○	●○○○			●○○○	●	●	●●○○	●●○○	●●○○	●●●○		
	Bus	○○○○	○○○○			●○○○	●	●	●●○○	●●○○	●●●●	●●●●		
	Motor Home	●●○○	○○○○					○						

Note: Blank fields indicate information not available.

Figure 7-1. Qualitative Evaluation of Highway Vehicle Applications

7.3 RECOMMENDATIONS FOR DETAILED ANALYSIS

Table 7-1 and Figure 7-1 show that the goods movement segment scores very high in terms of national and local impact (fuel consumption and criteria pollution emissions). Due to the high annual mileage of long haul trucks, tractors dominate the fuel consumption of the heavy vehicle fleet. Delivery trucks account for the second highest fuel consumption. Based fuel consumption combined with duty cycle considerations, local and regional goods movement vehicles should be considered high priorities for further analysis.
Of the remaining applications, sanitation vehicles scored relatively high in terms of local impact (per vehicle fuel use and location of operations) and stop frequency. However, the relatively short duration of the stops indicates both little opportunity to reduce idle fuel consumption and to recharge during daily operations. Transit buses, school buses, and utility trucks score highly on these last considerations.

Of these high priority vehicles, the MTDC includes real-world driving data for the following vehicles which were selected for detailed analysis:

- Local delivery tractors
- Transit buses
- Utility bucket trucks

8. SUMMARY OF FINDINGS

Plug-in electric vehicle technology has made significant progress in recent years in the light duty personal vehicle market, in part due to public investment in research and development as well as deployment. While light duty vehicles account for 70% of highway vehicle energy consumption, they account for roughly half of consumption by self-powered mobile equipment. The commercial fleets studied in this report are included in the remaining half of the transportation sector fuel consumption and are significant sources of emissions. Electrification is one technology option with the potential for addressing these “beyond light duty” challenges.

8.1 STATE OF THE MARKET

This study identified product offerings or early development efforts in nearly every segment explored, with the exception of long haul trucking. Several areas have made considerable progress toward electrification, particularly airport GSE and intra-city passenger rail. Significant efforts are underway for a few highway applications, particularly local delivery trucks and transit buses, as well as for cargo handling at ports and for ocean vessel power demand while berthed. Less effort and progress has been made in other applications due to challenging duty cycles, functional requirements, or remote operation. Other technologies, such as hydrogen fuel cells, may be better suited to some of these applications.

8.2 DATA GAPS

An in-depth analysis of opportunities for and benefits of electrification of heavy duty applications would require data covering the following vehicle or equipment parameters:

- In-use stock
- Annual sales
- Annual usage (miles or hours)
- Representative duty cycle(s) (e.g. vehicle speed or engine output vs. time or distance)

This data is required at a level of detail that captures diversity in usage and markets, such as different body types or engine sizes and applications or vocations. For transportation modes other than light duty, regulation of fuel consumption is fairly recent or non-existent. As a result, very few complete, reliable, detailed, and publicly or easily accessible available data sets exist. Most public data sets are developed for government purposes and cover only portions of the information needed. More complete proprietary data sets exist for industry use in market research. These proprietary sets are relatively expensive and their coverage is difficult to assess prior to purchase except through contact with sales representatives. For many commercial vehicles, no single data set covers all parameters needed, and attempts to merge sources is complicated by differences in collection methodologies and detailed parameter classifications. Table 8-1 provides a partial list of data sources identified during the course of this study, the parameters each source addresses, and a qualitative assessment of the data quality and coverage.

Coverage is intended to indicate how complete the data set is in terms of geographic coverage and granular detail.

Table 8-1. Data Sources and Coverage

Metrics	Source	Quality	Cover-age	Comments
Highway Medium and Heavy Duty				
In-Use Stock	IHS Polk	●	◑	Limited body style & vocation info; restrictive license
In-Use Stock	VIUS	◑	●	Sample survey data; nationally representative. Outdated
Sales & Life / Scrap Rate	IHS Polk	◑	◑	Limited body style & vocation info. Multiple years required to track calendar sales
Sales	Wards	●	◑	Limited
Sales	Transport Topics	●	◔	Secondary (Wards)
Usage	VIUS	◑	●	Outdated
Duty Cycle	Fleet DNA	◑	◔	Detailed duty cycle data. Small sample.
Rail				
In-Use Stock, Sales, and Usage	AAR Railroad Facts	●	●	
Tonnage	AAR Freight Commodity Statistics	●	●	
Duty Cycles	EPA	●	◕	Regulatory duty cycles developed with input from industry
Port Cargo Handling				
In-Use Stock	EPA NONROAD*	◔	◕	Older sample data extrapolated temporally and geographically
In-Use Stock	Power Systems Research			Proprietary data. Unknown quality and coverage. Original source for NONROAD inventory (from 2000).
In-Use Stock and Usage	Port Inventories	◕	◔	EPA guidelines but no standards for inventories. Only available for a handful of ports. No requirements for updates.
Sales, Life, & Usage	EPA NONROAD*	◔	◕	Older sample data extrapolated temporally and geographically
Duty Cycle	NA	○	○	
Tugboats				
In-Use Stock	NDC WTLUS	◕	●	U.S. Army Corps of Engineers Navigation Data Center. No information on type of propulsion; diesel assumed for all.
Usage, Consumption	Port Inventories	◕	◔	EPA guidelines but no standards for inventories. Only available for a handful of ports.
OGV / Harbor Craft Hoteling				
Demand, Fuel Consumption	Port Inventories	◕	◔	EPA guidelines but no standards for inventories. Only available for a handful of ports. No requirements for updates. Highly variable.
OGV Calls	IHS PIERS	●	●	Estimated quality & coverage. Unknown cost.
Ferries				
In-Use Stock, Usage, Fuel Consumption	NCFO	◕	◑	DOT National Census of Ferry Operators; survey of population; low response rate in last census. Not all responses are complete (missing and "unknown").
In-Use Stock, Sales	NDC WTLUS	◕	●	U.S. Army Corps of Engineers Navigation Data Center. No information on type of propulsion; diesel assumed for all.
Airport Ground Support				
In-use Stock and Usage	Airport Inventories	◑	◔	ACRP guidelines but no standards or requirements for inventories. Only available for a handful of airports. Some apply default usage information.
In-use Stock, Sales, and Usage	EPA NONROAD*	◔	◕	Older sample data extrapolated temporally and geographically

8.3 PROMISING MARKET GAPS

Commercial fleets purchase vehicles as tools to do specific jobs based on business case analysis. There is an opportunity for electrification for these fleets if the electric drive vehicles can perform the intended mission to the satisfaction of their drivers at a cost of ownership that is equal to or less than conventional vehicles, or that provides valuable added features at an added cost that is still acceptable to the market.

As shown in Section 7.2, several highway applications offer particularly promising potential for significant energy and / or environmental benefits from electrification: transit buses, school buses, regional and local delivery trucks, utility service vehicles, and refuse trucks.

Marine port operations offer another promising opportunity for electrification. Many ports are located near urban areas and / or in National Ambient Air Quality Standards non-attainment areas. Residents in nearby neighborhoods often have lower income brackets, raising issues of environmental justice. The equipment fleets are only operated locally and often for short periods of time. However, low usage implies long payback periods and emphasizes the need for strategies to reduce capital cost or otherwise encourage adoption.

8.4 CHALLENGES

There are challenges associated with getting to a favorable operational and business case for commercial fleets. While electrification in the light duty market is making progress, this success does not translate readily into the commercial vehicle market. Because of the higher, sustained power and daily energy demands, rugged operational environments, and often high lifetime miles or hours for medium and heavy vehicles, light duty technologies cannot simply be scaled up. As a result, electrification of commercial vehicles is at an early stage of development and there are few production vehicle options available. Stakeholders identified several key challenges to expanding in this market:

- Sales volumes are low and resulting costs are high, which is problematic for the business case in getting the payback on investments that most fleets are seeking.

- There are few suppliers of electric drive commercial vehicles and many of these companies are new and relatively small, also resulting in high cost and delivery delays.

- Many fleets are unwilling to consider purchasing equipment from these new and unproven suppliers due to perceived risk.

- Manufacturers have difficulty scaling up to higher volumes because of component supply constraints. As a result, fleets that have successfully completed pilot projects are unable to pursue full-scale deployment or are frustrated by delivery delays. At this time, larger vehicle manufacturers and Tier 1 suppliers for commercial vehicles are not actively participating in the electric drive market to any significant degree.

At the current stage of development, electric drive vehicles (particularly battery electric vehicles) cannot always meet the worst case duty cycle requirements of commercial fleets, limiting use to a subset of the market. The sufficiency of installing charging infrastructure at the fleet location, and its cost, is dependent on fleet operating profiles. System requirements and cost are driven by power and recharge speed demands which, for example, are very different for a transit bus compared to a delivery fleet with frequent and prolonged idling. Where public charging is required to meet operational needs, sufficient infrastructure density is of concern to fleets. Depending upon the location and system requirements, this infrastructure can be costly to construct. The lack of standards for medium and heavy vehicle charging equipment further hinders development of infrastructure.

Electrified work trucks and vocational trucks can be particularly challenging to produce and certify. These vehicles are often produced by upfitting a powertrain and work body to a mass produced chassis. The upfitter then serves as the manufacturer of record and must take responsibility for certification of the vehicle to federal regulations. This process is time consuming and costly and these companies must recoup the cost over their relatively small production volumes. In addition, when the truck OEM makes a change to the vehicle, no matter how small, the upfitter must recertify the vehicle. These companies expressed the need to collaborate more closely with the OEMs.

8.5 STRATEGIES

- The performance, availability, and cost of electric drive commercial vehicles could be improved through basic and applied research in energy storage, electric drives, vehicle systems, and related technologies. The challenges presented by medium and heavy vehicle requirements represent important research gaps.

- Laws and incentives could encourage the development and use of electric drive vehicles in the goods and people movement segments and the development of a resilient electric drive vehicle and component industry.

- Current regulations and certification procedures can either help or hinder the development of electric drive commercial vehicle products. Adjustment of these regulations could encourage additional deployment of vehicle options in the short and long term.

- Fleets can support electric drive vehicle deployment by gaining a better understanding of their drive and duty cycles and the necessary capabilities of fleet vehicles to meet these duty cycles. This understanding will help fleets identify where electric drive vehicles can be applied successfully and avoid early failures due to mismatched vehicles and applications. Fleets can also seek out objective third-party information about electric drive vehicles and their current and future availability to gain a better understanding of the market for their long-term vehicle purchase planning.

- Fleet owners could incorporate into decision-making both the economic and non-monetary value of enhanced vehicle operator and commercial customer satisfaction that electrification conveys. Benefits that are non-monetary or difficult to monetize can be significant and may be the primary motivation for electrification.

- Stakeholders identified the need for objective third parties to provide unbiased and reliable information that explains the benefits and challenges of these technologies and their potential in the future.

APPENDIX A. PLUG-IN VEHICLE PRODUCTS

Table A-1: Plug-in Vehicle Product Listing

OEM	Vehicle/Project Name	Type	Status	Class	Motor Power	Battery Capacity	Range	Target Markets
Adomani	Adomani Conversion Kit	BEV	Commercial		Varies	Varies	Varies	School Bus, Transit Bus
BAE Kenworth	Catenary Truck Project	PHEV CNG-Electric	Demonstration	8				Vocational, Public Transit
Balqon	MX-30	BEV	Discontinued	8	325 hp peak	320 kWh (700 Ah, 380 kWh total)	125 miles	Drayage
Balqon	Mule M100	BEV	Discontinued	6 to 8	225 hp peak	1000 Ah, 312 kWh total	102-150 miles	Delivery, Shuttle Bus
Balqon	Mule M150	BEV	Discontinued	7 to 8	300 hp (224 kW) 230V AC	280 kWh, 324V Li-ion	90-150 miles	Vocational
Balqon	Nautilus XRE-20	BEV	Discontinued	8	200 hp peak	220 kWh	12-16 hours	Yard tractor
Boulder Electric Vehicle	DV-500	BEV	Discontinued	3	220 kW Peak, 665 Ft-Lbs		80-120 miles	Vocational, Public Transit, Step Van
BYD Company	40 ft. Transit Bus	BEV	Commercial	8	90 kWx2- 150 kWx2	324-360 kWh	155+ miles	Public Transit
BYD Company	35 ft. Transit Bus	BEV	Pre-commercial	8			165+ miles	Public Transit
BYD Company	60 ft. Transit Bus	BEV	Pre-commercial	8	360 kW (180 kWx2)	547.5 kWh / 750Ah	170 miles	Public Transit
Capacity Trucks	HETT	BEV	Demonstration	8				Yard Tractor
Capactiy of Texas	Pluggable Hybrid Electrical Terminal Truck	PHEV Diesel-Electric	Demonstration	8	225 hp			Terminal Tractor, Dray
Charlatte	CharlatteAmerica GSE	Hybrid FC-Electric	Commercial	Air GSE				Airports
Charlatte	CFB2000 - Electric Inter-Line Baggage Tractor	BEV	Commercial	Air GSE	30 kW			Airports
Charlatte	CT5E - Cargo Tractor	BEV	Commercial	Air GSE	22 kW	50 kWh		Airports
Charlatte	T137-V3 - Electric Baggage Tractor	BEV	Commercial	Air GSE	30 kW	40-50 kWh		Airports
Charlatte	CBL100E - Electric Regional Beltloader	BEV	Commercial	Air GSE	3 kW	8.4-13.2 kWh		Airports
Charlatte	CBL150E - Electric Intermediate Beltloader	BEV	Commercial	Air GSE	3.7 kW	18-32 kWh		Airports
Charlatte	CBL2000E - Electric Full Size Beltloader	BEV	Commercial	Air GSE	30 kW	27-34 kWh		Airports
Charlatte	TE 206 - Electric Tow Tractor	BEV	Commercial	Air GSE	6 kW	10.6-11.5 kWh		Airports
Charlatte	TE.208 - Electric Tow Tractor	BEV	Commercial	Air GSE	6 kW	15.6-20.4 kWh		Airports
Charlatte	CLT200E - Lav Service Vehicle	BEV	Commercial	Air GSE	30 kW	40 kWh		Airports
Charlatte	CWT300E - Water Service Vehicle	BEV	Commercial	Air GSE	30 kW	40 kWh		Airports
Charlatte	CPB35E - Electric Pushback Tractor	BEV	Commercial	Air GSE	2x 26 kW	48 kWh		Airports
DesignLine	Eco-Smart 1	BEV	Commercial; Defunct	7 to 8	335 hp (total)	261.8 kWh	up to 150	Public Transit
Electric Vehicles International	EVI-REEV	PHEV Diesel-Electric	Development	5	120 continuous; 200/260 kW peak		40 mile e-range	Bucket Truck, Construction, Tree Service
Electric Vehicles International	EVI-Medium Duty	BEV	Commercial	5 to 6	120 continuous/200 kW peak	99 kWh	90 miles	Vocational
Electric Vehicles International	EVI-Walk-in Van	BEV	Commercial	5 to 6	120 continuous/200 kW peak	99 kWh	90 miles	Vocational
Enova	ZE Stepvan	BEV	Discontinued		472 lb-ft (640 N·m) torque	120 kW	150 miles	Step Van
Fuso	E-Cell	BEV	Pilot	3	110	50 kWh	> 62	Delivery
Seaway	Greenline 33	PHEV Diesel-Electric	Commercial	OGV	7 kW	11,5 kWh	20 naut mi erange	Yacht
Seaway	Greenline 40	PHEV Diesel-Electric	Commercial	OGV	2x 7 kW	2 x 11,5 kWh	20 naut mi erange	Yacht
Seaway	Greenline 48	PHEV Diesel-Electric	Commercial	OGV	2x 14 Kw	46 kWh	20 naut mi erange	Yacht
GreenPower Bus	EV250, EV300, EV350, EV400, EV450, EV500, EV550	BEV	Commercial	8		210-400 kWh	175-240 miles	Transit Bus
GreenPower Bus	EVS 01, 02, 03, 04	BEV	Commercial	6 to 8		80 - 150 kWh	100 -125 miles	School Bus
Hornblower Cruises and Events	Hornblower Hybrid- NY	Hybrid FC-Electric	Commercial	Harbor, Excursion	1,400 hp			Ferry

OEM	Vehicle/Project Name	Type	Status	Class	Motor Power	Battery Capacity	Range	Target Markets
Hyster	E30-40XN (Series)	BEV	Commercial	Forklift	18.4 kW			Industrial, Material Handling
Hyster	E80-120XN (Series)	BEV	Commercial	Forklift	21.5 kW			Industrial, Material Handling
Hyster	J30-40XNT/XN (Series)	BEV	Commercial	Forklift	2x, 4.8-5.0 kW			Industrial, Material Handling
Hyster	J45-70XNT/XN (Series)	BEV	Commercial	Forklift	2x 10 kW			Industrial, Material Handling
Hyster	E45-70XN (Series)	BEV	Commercial	Forklift	18.4-23.6 kW			Industrial, Material Handling
Hyster	J80-120XN (Series)	BEV	Commercial	Forklift	2x 14.7 Kw			Industrial, Material Handling
inventev	Energy SWAT Truck	PHEV Gasoline-Electric	Demonstration	5			30-50 miles e-range	Vocational, Bucket
JBT AeroTech	Commander 15i Electric	BEV	Commercial	Air GSE				Airports
Kalmar	Kalmar FastCharge Hybrid Straddle Carriers (FSC 340, 350, 360, 440, 450, 460)	PHEV Diesel-Electric	Commercial	Non-Road				Port Container Handling
Kalmar	Kalmar E-One² Zero Emission RTG	BEV	Commercial	Non-Road				Port Container Handling
Konecrane	Konecrane RTG	Grid-Connected Electric	Commercial	Non-Road				Port Container Handling
Manson Construction	Electric dredge	BEV	Commercial	Harbor				Harbor craft
MHI Marine Machinery & Engine Co., Ltd	HydrocurrentTM Organic Rankine Cycle	BEV	Commercial	OGV			40 miles	OGV
Motiv	Morgan Olson Electric WIV	BEV	Pilot	4	180 kW / 240 hp	85/106 /127 kWh	58-85	Urban Delivery Vehicle
Motiv	All-Electric Class A Schools Bus	BEV	Commercial	4	150 kW / 200 hp	80/100 kWh	80-100 miles	School Bus
Motiv	Electrified Ford E450	BEV	Commercial	4	150 kW / 200 hp	80/100/120 kWh	80-120	School Bus, Shuttle, Parcel, Flatbed, Tool
Motiv	Electrified Ford F59	BEV	Commercial	6	180 kW / 240 hp	85/106 /127 kWh	58-85	Delivery, Refrigerated, Food, Tool, Bucket
Motiv	All-Electric Refuse Truck	BEV	Commercial	8	280 kW / 375 hp	170/212 kWh	50-80	Refuse
Motiv	Starcraft e-Quest XL	BEV	Demonstration	8			Up to 85 miles	School Bus
Navistar	eStar Electric Truck	BEV	Discontinued	3	102 hp, 300 nm torque	80 kw/hr li-io, 220 volt split	60-100 miles	Delivery Van
New Flyer	Xcelsior XE40	BEV	Commercial	7 to 8	215 hp	200-300 kWh	80-120 miles	Transit Bus
Odyne	Odyne	PHEV Diesel-Electric	Commercial	4 to 8	42 kW continuous; 70 kW peak	14.2 or 28.4 kWh		Vocational
OrangeEV	T-Series	BEV	Commercial	8				Terminal Tractor
Plug Power	GenDrive Fork Lifts	Hybrid FC-Electric	Commercial	Forklift				Industrial, Material Handling
Proterra	Catalyst (35 foot)	BEV	Demonstration	8	220 kW peak	53-321 kWh	50 per chg, 180 per XR chg	Transit
Proterra	Catalyst (40-foot)	BEV	Commercial	8	220 kW peak	53-321 kWh	50 per chg, 180 per XR chg	Transit
Proterra	EcoRide BE35	BEV	Discontinued	8	100 kW continuous/ 150 kW peak		30 mi (2-3 hrs)	Public Transit
Schneider Electric	ShoreBoX	BEV	Commercial	NA				OGV, harbor craft, Shorepower

OEM	Vehicle/Project Name	Type	Status	Class	Motor Power	Battery Capacity	Range	Target Markets
Smith Electric Vehicles	The Edison	BEV	Commercial; Suspended	3	90 kW		55-100 miles	Chassis Cab, Panel Van, Mini Bus
Smith Electric Vehicles	The Newton	BEV	Commercial; Suspended	3 to 6	161 hp	Li-ion 40, 60, 80, 100, or 120kWh	40-100 miles	Chassis Cab, Step Van, School Bus
Terberg Special Vehicles	YT202-EV	BEV	Commercial	8	138 kW, 720 N·m	112 kWh (2 batteries)		Yard Tractor
Toyota	Core Electric Forklift (range of models avail.)	BEV	Commercial	Forklift	6.3-18 kW	24.5-55.4 kWh		Industrial, Material Handling
Toyota	Large Electric Forklift (range of models avail.)	BEV	Commercial	Forklift	2x, 9.7-13.2 kW	49-84.5 kWh		Industrial, Material Handling
Toyota	3-Wheel Electric Forklift	BEV	Commercial	Forklift	2x, 4.8-5.0 kW	18-39.6 kWh		Industrial, Material Handling
Toyota	Stand-up Rider Electric Forklife	BEV	Commercial	Forklift	5.2 kW	36.9-44.6 kWh		Industrial, Material Handling
Toyota	80V Electric Pneumatic	BEV	Commercial	Forklift	20 kW	1.7-56 kWh	5 hours	Industrial, Material Handling
TransPower	Catenary Truck Project	BEV	Development	8				Vocational, Public Transit
TransPower	On-Road Truck	BEV	Commercial	8			100 miles	Tractor
TransPower	On-Road Truck	Hybrid FC-Electric	Demonstration	8			200 miles or more	Tractor
TransPower	Catenary Truck Project	PHEV CNG-Electric	Demonstration	8				Vocational, Public Transit
TransPower	Economical Electric School Bus	BEV	Commercial	3 to 6	100 kW continuous/ 150 kW peak	300 ampere hours per cell (v-358)	50-75	School Bus
TransPower	ElecTruck	BEV	Commercial	8		150 kWh total energy storage		Yard Tractor, Tractor
TransPower	High Power Electric Terminal Tractor	BEV	Demonstration	8		215 kWh	40-50 per shift (9-13 hrs)	Yard Tractor
TransPower	Port yard tractor	BEV	Demonstration	8		70kW	Up to 13 hours on a single battery charge	Yard Tractor
Tug	GT35E	BEV	Commercial	Air GSE	2x 32 kW			Airports
Tug	MZ Electric Tractor	BEV	Commercial	Air GSE	30 kW Peak 18 kW Cont.			Airports
Tug	660E	BEV	Commercial	Air GSE				Airports
VIA Motors	VTRUX	PHEV Gasoline-Electric	Commercial	2	100 kW continuous/ 150 kW peak	23 kWh, 380 Volt	40 miles e-range, 400 miles total	Pickup, Passenger Van, Cargo Van
Volvo	Catenary Truck Project	PHEV Diesel-Electric	Demonstration	8				Vocational, Public Transit
Workhorse	E-GEN	PHEV Gasoline-Electric	Commercial	5	200 kW	80 kWh, 60 kWh usable		Delivery, WIV
ZeroTruck	ZeroTruck	BEV	Commercial	3 to 5	150 kW, 480 ft-lbs torque	50 kW temp cntrld li-poly packs	70-75 city driving	Vocational, Delivery

APPENDIX B. HIGHWAY VEHICLE MARKET DATA

Table B-1: Vehicle Registrations as of December 2013, Service Fleets

			Service Fleets							
	Vehicle Type[1]	Total	Utility[2]	Emergency[3]	Road and Grounds Mainten-ance[4]	Construct. & Mining[5]	Sanitation, Public	Sanitation, Private	Service, Other	Service Fleets Total
Class 4-5	Pickups	15,113	37	24	127	631	0	39	695	1,553
	School bus	3,531	10	NA	NA	NA	NA	NA	NA	10
	Nonschool bus	2,964	5	NA	NA	NA	NA	NA	NA	5
	Motor home	369,342	259	NA	NA	NA	NA	NA	NA	259
	Delivery trucks	373,734	3,901	934	22,318	0	135	4,084	68,421	99,793
	Specialty Body	1,145,809	53,875	18,819	46,465	116,625	1,111	7,703	211,065	455,663
	Fire truck	0	NA	0	NA	NA	NA	NA	NA	0
	Tractor	112	1	0	1	0	0	0	11	13
	UNKNOWN	42,035	62	60	294	1,082	2	169	890	2,559
	TOTAL CLASS 4-5	1,952,640	58,150	19,837	69,205	118,338	1,248	11,995	281,082	559,855
Class 6	Pickups	0	0	0	0	0	0	0	0	0
	School bus	59,182	176	NA	NA	NA	NA	NA	NA	176
	Nonschool bus	8,165	37	NA	NA	NA	NA	NA	NA	37
	Motor home	182,196	51	NA	NA	NA	NA	NA	NA	51
	Delivery trucks	740,996	7,788	3,108	26,071	0	378	9,887	103,087	150,319
	Specialty Body	205,323	2,022	624	7,703	18,027	54	1,445	52,490	82,365
	Fire truck	0	NA	0	NA	NA	NA	NA	NA	0
	Tractor	1,793	4	18	42	0	1	16	141	222
	UNKNOWN	186,303	262	690	1,816	6,589	11	878	4,851	15,097
	TOTAL CLASS 6	1,383,958	10,340	4,440	35,632	24,616	444	12,226	160,569	248,267
Class 7-8	Pickups	0	0	0	0	0	0	0	0	0
	School bus	451,361	817	NA	NA	NA	NA	NA	NA	817
	Nonschool bus	101,902	542	NA	NA	NA	NA	NA	NA	542
	Motor home	153,758	90	NA	NA	NA	NA	NA	NA	90
	Delivery trucks	1,568,379	49,189	19,599	37,439	0	3,216	95,829	107,261	312,533
	Specialty Body	134,881	4,410	1,988	7,929	17,467	102	1,301	16,782	49,979
	Fire truck	31,220	NA	31,220	NA	NA	NA	NA	NA	31,220
	Tractor	2,632,075	7,569	2,900	16,103	0	533	19,777	199,579	246,461
	UNKNOWN	93,361	298	866	1,191	7,202	24	600	4,058	14,239
	TOTAL CLASS 7-8	5,166,937	62,915	56,573	62,662	24,669	3,875	117,507	327,680	655,881
All Classes	Pickups	15,113	37	24	127	631	0	39	695	1,553
	School bus	514,074	1,003	NA	NA	NA	NA	NA	NA	1,003
	Nonschool bus	113,031	584	NA	NA	NA	NA	NA	NA	584
	Motor home	705,296	400	NA	NA	NA	NA	NA	NA	400
	Delivery trucks	2,683,109	60,878	23,641	85,828	0	3,729	109,800	278,769	562,645
	Specialty Body	1,486,013	60,307	21,431	62,097	152,119	1,267	10,449	280,337	588,007
	Fire truck	31,220	NA	31,220	NA	NA	NA	NA	NA	31,220
	Tractor	2,633,980	7,574	2,918	16,146	0	534	19,793	199,731	246,696
	UNKNOWN	321,699	622	1,616	3,301	14,873	37	1,647	9,799	31,895
	TOTAL ALL CLASSES	8,503,535	131,405	80,850	167,499	167,623	5,567	141,728	769,331	1,464,003

[1]All vehicles of Polk type Bus School, Bus Non School, and Motor Home are included in people movement with the exception of vocation type "Utility Services."

[2]All vehicles with vocation "utility services" are listed as utility vehicles regardless of carrier type (utility, government, private, etc.)

[3]All vehicles with vocation "Emergency Vehicles" are listed as emergency vehicles, regardless of carrier type, with the exception of vehicle types Bus School, Bus Non School, and Motor Home.

[4]All vehicles with vocation "Road/Highway Maintenance" and "Landscaping/Horticulture" are included as Road and Grounds Maintenance, regardless of carrier type, with the exception of vehicle types Bus School, Bus Non School, and Motor Home.

[5]Chassis vehicles and pickups with vocation type "Construction" and "Mining/Quarring," regardless of carrier type, are assumed to be work trucks. Straight trucks, step vans, and cargo vans with vocation type "Construction" and "Mining/Quarring," regardless of carrier type, are assumed to be used to transport materials and are included in goods movement, commercial.

Source: Vehicles registered as of 12/31/2013, provided by NREL as US Vehicle Registration Data Class 4-8 , R.L. Polk and Co. 12/31/2013. Compiled by CSRA, Inc. 5/27/2016

Table B-2: Vehicle Registrations as of December 2013, Goods and People Movement Fleets

	Vehicle Type[1]	Total	Goods Movement: Govern-ment	Goods Movement Commercial: Private	Goods Movement Commercial: For Hire	Goods Movement Commercial: Owner/ operator	Goods Movement Commercial: Lease	Goods Move. Total	People Movement: Govern-ment	People Movement Commercial: Private	People Movement Commercial: For Hire	People Movement Commercial: Owner/ operator and Personal	People Movement Commercial: Lease	People Move. Total
Class 4-5	Pickups	15,113	11	1,313	161	11,726	307	13,518	16	20	6	0	0	42
	School bus	3,531	NA	NA	NA	NA	NA	0	1,694	638	756	316	117	3,521
	Nonschool bus	2,964	NA	NA	NA	NA	NA	0	804	912	564	561	118	2,959
	Motor home	369,342	NA	NA	NA	NA	NA	0	2,682	18,282	1,756	339,165	7,198	369,083
	Delivery trucks	373,734	8,813	134,928	20,071	70,564	39,565	273,941	NA	NA	NA	NA	NA	0
	Specialty Body	1,145,809	5,486	167,956	24,793	335,153	108,594	641,982	19,126	18,079	10,959	0	0	48,164
	Fire truck	0	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	0
	Tractor	112	10	25	3	60	1	99	NA	NA	NA	NA	NA	0
	UNKNOWN	42,035	28	4,217	176	34,407	516	39,344	44	79	9	0	0	132
	TOTAL CLASS 4-5	1,952,640	14,348	308,439	45,204	451,910	148,983	968,884	24,366	38,010	14,050	340,042	7,433	423,901
Class 6	Pickups	0	0	0	0	0	0	0	0	0	0	0	0	0
	School bus	59,182	NA	NA	NA	NA	NA	0	27,641	16,085	5,609	9,040	631	59,006
	Nonschool bus	8,165	NA	NA	NA	NA	NA	0	2,907	2,423	1,628	817	353	8,128
	Motor home	182,196	NA	NA	NA	NA	NA	0	705	6,369	338	169,918	4,815	182,145
	Delivery trucks	740,996	28,103	257,407	51,331	144,928	108,908	590,677	NA	NA	NA	NA	NA	0
	Specialty Body	205,323	499	36,706	5,697	52,987	24,972	120,861	876	795	426	0	0	2,097
	Fire truck	0	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	0
	Tractor	1,793	175	539	125	699	33	1,571	NA	NA	NA	NA	NA	0
	UNKNOWN	186,303	125	25,020	991	141,728	2,346	170,210	255	695	46	0	0	996
	TOTAL CLASS 6	1,383,958	28,902	319,672	58,144	340,342	136,259	883,319	32,384	26,367	8,047	179,775	5,799	252,372
Class 7-8	Pickups	0	0	0	0	0	0	0	0	0	0	0	0	0
	School bus	451,361	NA	NA	NA	NA	NA	0	264,816	65,802	85,536	23,491	10,899	450,544
	Nonschool bus	101,902	NA	NA	NA	NA	NA	0	38,690	21,214	28,275	8,757	4,424	101,360
	Motor home	153,758	NA	NA	NA	NA	NA	0	347	13,116	647	133,363	6,195	153,668
	Delivery trucks	1,568,379	212,487	607,731	118,146	227,405	90,077	1,255,846	NA	NA	NA	NA	NA	0
	Specialty Body	134,881	466	28,168	3,214	49,513	2,312	83,673	810	295	124	0	0	1,229
	Fire truck	31,220	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	0
	Tractor	2,632,075	23,995	653,376	822,896	611,146	274,201	2,385,614	NA	NA	NA	NA	NA	0
	UNKNOWN	93,361	66	18,398	2,246	56,519	1,306	78,535	206	206	175	0	0	587
	TOTAL CLASS 7-8	5,166,937	237,014	1,307,673	946,502	944,583	367,896	3,803,668	304,869	100,633	114,757	165,611	21,518	707,388
All Classes	Pickups	15,113	11	1,313	161	11,726	307	13,518	16	20	6	0	0	42
	School bus	514,074	NA	NA	NA	NA	NA	0	294,151	82,525	91,901	32,847	11,647	513,071
	Nonschool bus	113,031	NA	NA	NA	NA	NA	0	42,401	24,549	30,467	10,135	4,895	112,447
	Motor home	705,296	NA	NA	NA	NA	NA	0	3,734	37,767	2,741	642,446	18,208	704,896
	Delivery trucks	2,683,109	249,403	1,000,066	189,548	442,897	238,550	2,120,464	NA	NA	NA	NA	NA	0
	Specialty Body	1,486,013	6,451	232,830	33,704	437,653	135,878	846,516	20,812	19,169	11,509	0	0	51,490
	Fire truck	31,220	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	0
	Tractor	2,633,980	24,180	653,940	823,024	611,905	274,235	2,387,284	NA	NA	NA	NA	NA	0
	UNKNOWN	321,699	219	47,635	3,413	232,654	4,168	288,089	505	980	230	0	0	1,715
	TOTAL ALL CLASSES	8,503,535	280,264	1,935,784	1,049,850	1,736,835	653,138	5,655,871	361,619	165,010	136,854	685,428	34,750	1,383,661

[1]All vehicles of Polk type Bus School, Bus Non School, and Motor Home are included in people movement with the exception of vocation type "Utility Services."

[2]All vehicles with vocation "utility services" are listed as utility vehicles regardless of carrier type (utility, government, private, etc.)

[3]All vehicles with vocation "Emergency Vehicles" are listed as emergency vehicles, regardless of carrier type, with the exception of vehicle types Bus School, Bus Non School, and Motor Home.

[4]All vehicles with vocation "Road/Highway Maintenance" and "Landscaping/Horticulture" are included as Road and Grounds Maintenance, regardless of carrier type, with the exception of vehicle types Bus School, Bus Non School, and Motor Home.

[5]Chassis vehicles and pickups with vocation type "Construction" and "Mining/Quarring," regardless of carrier type, are assumed to be work trucks. Straight trucks, step vans, and cargo vans with vocation type "Construction" and "Mining/Quarring," regardless of carrier type, are assumed to be used to transport materials and are included in goods movement, commercial.

Source: Vehicles registered as of 12/31/2013, provided by NREL as US Vehicle Registration Data Class 4-8 , R.L. Polk and Co. 12/31/2013. Compiled by CSRA, Inc. 5/27/2016

Table B-3: New Vehicle (MY2013-14) Registrations as of Dec. 2013, Service Fleets

			Service Fleets							
	Vehicle Type[1]	Total	Utility[2]	Emergency[3]	Road and Grounds Mainten-ance[4]	Construct. & Mining[5]	Sanitation, Public	Sanitation, Private	Service, Other	Service Fleets Total
Class 4-5	Pickups	0	0	0	0	0	0	0	0	0
	School bus	272	0	NA	NA	NA	NA	NA	NA	0
	Nonschool bus	357	0	NA	NA	NA	NA	NA	NA	0
	Motor home	2,906	1	NA	NA	NA	NA	NA	NA	1
	Delivery trucks	15,097	75	86	608	0	4	111	1,677	2,561
	Specialty Body	40,447	2,353	571	1,207	2,870	29	122	7,329	14,481
	Fire truck	0	NA	0	NA	NA	NA	NA	NA	0
	Tractor	0	0	0	0	0	0	0	0	0
	UNKNOWN	0	0	0	0	0	0	0	0	0
	TOTAL CLASS 4-5	59,079	2,429	657	1,815	2,870	33	233	9,006	17,043
Class 6	Pickups	0	0	0	0	0	0	0	0	0
	School bus	1,258	1	NA	NA	NA	NA	NA	NA	1
	Nonschool bus	286	2	NA	NA	NA	NA	NA	NA	2
	Motor home	4,677	4	NA	NA	NA	NA	NA	NA	4
	Delivery trucks	40,489	328	85	355	0	5	202	3,450	4,425
	Specialty Body	5,775	41	0	0	5	0	1	4,914	4,961
	Fire truck	0	NA	0	NA	NA	NA	NA	NA	0
	Tractor	20	0	0	0	0	0	0	0	0
	UNKNOWN	0	0	0	0	0	0	0	0	0
	TOTAL CLASS 6	52,505	376	85	355	5	5	203	8,364	9,393
Class 7-8	Pickups	0	0	0	0	0	0	0	0	0
	School bus	37,589	47	NA	NA	NA	NA	NA	NA	47
	Nonschool bus	3,543	23	NA	NA	NA	NA	NA	NA	23
	Motor home	3,409	0	NA	NA	NA	NA	NA	NA	0
	Delivery trucks	74,568	3,721	640	759	0	153	4,167	6,758	16,198
	Specialty Body	1,082	3	2	1	8	0	1	53	68
	Fire truck	581	NA	581	NA	NA	NA	NA	NA	581
	Tractor	226,978	721	95	409	0	25	511	18,991	20,752
	UNKNOWN	1	0	0	0	0	0	0	0	0
	TOTAL CLASS 7-8	347,751	4,515	1,318	1,169	8	178	4,679	25,802	37,669
All Classes	Pickups	0	0	0	0	0	0	0	0	0
	School bus	39,119	48	NA	NA	NA	NA	NA	NA	48
	Nonschool bus	4,186	25	NA	NA	NA	NA	NA	NA	25
	Motor home	10,992	5	NA	NA	NA	NA	NA	NA	5
	Delivery trucks	130,154	4,124	811	1,722	0	162	4,480	11,885	23,184
	Specialty Body	47,304	2,397	573	1,208	2,883	29	124	12,296	19,510
	Fire truck	581	NA	581	NA	NA	NA	NA	NA	581
	Tractor	226,998	721	95	409	0	25	511	18,991	20,752
	UNKNOWN	1	0	0	0	0	0	0	0	0
	TOTAL ALL CLASSES	459,335	7,320	2,060	3,339	2,883	216	5,115	43,172	64,105

[1]All vehicles of Polk type Bus School, Bus Non School, and Motor Home are included in people movement with the exception of vocation type "Utility Services."

[2]All vehicles with vocation "utility services" are listed as utility vehicles regardless of carrier type (utility, government, private, etc.)
[3]All vehicles with vocation "Emergency Vehicles" are listed as emergency vehicles, regardless of carrier type, with the exception of vehicle types Bus School, Bus Non School, and Motor Home.
[4]All vehicles with vocation "Road/Highway Maintenance" and "Landscaping/Horticulture" are included as Road and Grounds Maintenance, regardless of carrier type, with the exception of vehicle types Bus School, Bus Non School, and Motor Home.
[5]Chassis vehicles and pickups with vocation type "Construction" and "Mining/Quarring," regardless of carrier type, are assumed to be work trucks. Straight trucks, step vans, and cargo vans with vocation type "Construction" and "Mining/Quarring," regardless of carrier type, are assumed to be used to transport materials and are included in goods movement, commercial.

Source: Vehicles registered as of 12/31/2013, provided by NREL as US Vehicle Registration Data Class 4-8 , R.L. Polk and Co. 12/31/2013. Compiled by CSRA, Inc. 5/27/2016

Table B-4: New Vehicle (MY2013-14) Registrations as of Dec. 2013, Goods and People Movement Fleets

			Goods Movement						People Movement					
				Commercial						Commercial				
	Vehicle Type[1]	Total	Govern-ment	Private	For Hire	Owner/operator	Lease	Goods Move. Total	Govern-ment	Private	For Hire	Owner/operator and Personal	Lease	People Move. Total
Class 4-5	Pickups	0	0	0	0	0	0	0	0	0	0	0	0	0
	School bus	272	NA	NA	NA	NA	NA	0	185	18	61	1	7	272
	Nonschool bus	357	NA	NA	NA	NA	NA	0	99	179	48	9	22	357
	Motor home	2,906	NA	NA	NA	NA	NA	0	3	160	1	2,656	85	2,905
	Delivery trucks	15,097	480	5,322	556	545	5,633	12,536	NA	NA	NA	NA	NA	0
	Specialty Body	40,447	237	6,952	1,239	4,665	10,349	23,442	1,074	474	976	0	0	2,524
	Fire truck	0	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	0
	Tractor	0	0	0	0	0	0	0	NA	NA	NA	NA	NA	0
	UNKNOWN	0	0	0	0	0	0	0	0	0	0	0	0	0
	TOTAL CLASS 4-5	59,079	717	12,274	1,795	5,210	15,982	35,978	1,361	831	1,086	2,666	114	6,058
Class 6	Pickups	0	0	0	0	0	0	0	0	0	0	0	0	0
	School bus	1,258	NA	NA	NA	NA	NA	0	947	84	173	37	16	1,257
	Nonschool bus	286	NA	NA	NA	NA	NA	0	145	75	57	4	3	284
	Motor home	4,677	NA	NA	NA	NA	NA	0	12	178	18	4,393	72	4,673
	Delivery trucks	40,489	1,041	8,229	1,965	563	24,266	36,064	NA	NA	NA	NA	NA	0
	Specialty Body	5,775	2	381	157	26	241	807	2	5	0	0	0	7
	Fire truck	0	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	0
	Tractor	20	0	0	20	0	0	20	NA	NA	NA	NA	NA	0
	UNKNOWN	0	0	0	0	0	0	0	0	0	0	0	0	0
	TOTAL CLASS 6	52,505	1,043	8,610	2,142	589	24,507	36,891	1,106	342	248	4,434	91	6,221
Class 7-8	Pickups	0	0	0	0	0	0	0	0	0	0	0	0	0
	School bus	37,589	NA	NA	NA	NA	NA	0	24,869	2,974	7,311	484	1,904	37,542
	Nonschool bus	3,543	NA	NA	NA	NA	NA	0	1,412	757	932	51	368	3,520
	Motor home	3,409	NA	NA	NA	NA	NA	0	8	225	7	3,070	99	3,409
	Delivery trucks	74,568	14,363	22,754	5,438	1,405	14,410	58,370	NA	NA	NA	NA	NA	0
	Specialty Body	1,082	0	94	7	700	36	837	157	3	17	0	0	177
	Fire truck	581	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	0
	Tractor	226,978	888	37,054	101,592	4,634	62,058	206,226	NA	NA	NA	NA	NA	0
	UNKNOWN	1	0	1	0	0	0	1	0	0	0	0	0	0
	TOTAL CLASS 7-8	347,751	15,251	59,903	107,037	6,739	76,504	265,434	26,446	3,959	8,267	3,605	2,371	44,648
All Classes	Pickups	0	0	0	0	0	0	0	0	0	0	0	0	0
	School bus	39,119	NA	NA	NA	NA	NA	0	26,001	3,076	7,545	522	1,927	39,071
	Nonschool bus	4,186	NA	NA	NA	NA	NA	0	1,656	1,011	1,037	64	393	4,161
	Motor home	10,992	NA	NA	NA	NA	NA	0	23	563	26	10,119	256	10,987
	Delivery trucks	130,154	15,884	36,305	7,959	2,513	44,309	106,970	NA	NA	NA	NA	NA	0
	Specialty Body	47,304	239	7,427	1,403	5,391	10,626	25,086	1,233	482	993	0	0	2,708
	Fire truck	581	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	0
	Tractor	226,998	888	37,054	101,612	4,634	62,058	206,246	NA	NA	NA	NA	NA	0
	UNKNOWN	1	0	1	0	0	0	1	0	0	0	0	0	0
	TOTAL ALL CLASSES	459,335	17,011	80,787	110,974	12,538	116,993	338,303	28,913	5,132	9,601	10,705	2,576	56,927

[1]All vehicles of Polk type Bus School, Bus Non School, and Motor Home are included in people movement with the exception of vocation type "Utility Services."

[2]All vehicles with vocation "utility services" are listed as utility vehicles regardless of carrier type (utility, government, private, etc.)

[3]All vehicles with vocation "Emergency Vehicles" are listed as emergency vehicles, regardless of carrier type, with the exception of vehicle types Bus School, Bus Non School, and Motor Home.

[4]All vehicles with vocation "Road/Highway Maintenance" and "Landscaping/Horticulture" are included as Road and Grounds Maintenance, regardless of carrier type, with the exception of vehicle types Bus School, Bus Non School, and Motor Home.

[5]Chassis vehicles and pickups with vocation type "Construction" and "Mining/Quarring," regardless of carrier type, are assumed to be work trucks. Straight trucks, step vans, and cargo vans with vocation type "Construction" and "Mining/Quarring," regardless of carrier type, are assumed to be used to transport materials and are included in goods movement, commercial.

Source: Vehicles registered as of 12/31/2013, provided by NREL as US Vehicle Registration Data Class 4-8 , R.L. Polk and Co. 12/31/2013. Compiled by CSRA, Inc. 5/27/2016

REFERENCES

AAPA. (2016). Western Hemisphere Container Port Ranking 2015. Retrieved June 6, 2016, from http://aapa.files.cms-plus.com/Statistics/WESTERN%20HEMISPHERE%20CONTAINER%20PORT%20RANKING%202015.pdf

AAR. (2016). *Delivering for American Industry and Consumers*. Retrieved from Association of American Railroads: https://www.aar.org/todays-railroads/railroad-101

ACRP. (2012). *Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial.* http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_078.pdf.

ACRP. (2015). *Improving Ground Support Equipment Operational Data for Airport Emissions Modeling.* http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_149.pdf.

American Rails. (2016). *Black Mesa And Lake Powell Railroad*. Retrieved from American-Rails.com: http://www.american-rails.com/black-mesa-and-lake-powell-railroad.html

Amtrak. (2012). *The Amtrak Vision for the Northeast Corridor, 2012 Update Report.* Retrieved from https://www.amtrak.com/ccurl/453/325/Amtrak-Vision-for-the-Northeast-Corridor.pdf

Amtrak. (2016). About the NEC. Retrieved from Amtrak: The Northeast Corridor: https://nec.amtrak.com/about

APTA. (2015). *2015 Public Transportation Fact Book, 66th edition.* Washington, DC: American Public Transportation Association. Retrieved from http://www.apta.com/resources/statistics/Documents/FactBook/2015-APTA-Fact-Book.pdf

APTA. (2016). *2016 Public Transportation Fact Book Appendix A: Historical Tables.* Washington, DC: American Public Transporation Association. Retrieved June 3, 2016, from http://www.apta.com/resources/statistics/Documents/FactBook/2016-APTA-Fact-Book-Appendix-A.xlsx

Army Corps of Engineers. (2014). Navigation Data Center. *Waterborne Transportation Lines of the United States, National Summaries*. Retrieved from http://www.navigationdatacenter.us/veslchar/veslchar.htm

ATA. (2000). *Method to Calculate and Allocate Airport Ground Support Equipment.* https://www.tceq.texas.gov/assets/public/implementation/air/sip/sipdocs/2000-12-HGB/00011sipapa_ado.pdf.

AWO. (2016). *Jobs & Economy*. Retrieved from The American Waterways Operators: http://www.americanwaterways.com/initiatives/jobs-economy

Balmer-Millar, M., Fluga, E., & Peterson, R. (2015). Keynote: Off-Road Mobile Machinery Fuel Efficiency: A Total Systems Perspective. *ICPC 2015- 1.3*, 1-2.

Caltrain. (2016). *Caltrain Modernization Captial Projects*. Retrieved from caltrain.com: http://www.caltrain.com/projectsplans/CaltrainModernization/Modernization.html

CDM Smith. (2015, February 13). *Los Angeles International Airport, Extremely Low Emission Technology Ground Support Equipment Feasibility Study Report.* Retrieved from Los Angeles World Airports: http://www.lawa.org/uploadedFiles/LAX/pdf/LAX-eletGSE-Feasibility-Study-Report.pdf

CIA. (2014). *The World Factbook.* https://www.cia.gov/library/publications/the-world-factbook/rankorder/2246rank.html.

Cochran Marine. (2015). *Shore Power System FAQ*. Retrieved from Cochran Marine: http://www.cochranmarine.com/our-system/faq/

Davis, S. C., Diegel, S. W., & Boundy, R. G. (2015). *The Transportation Energy Data Book Edition 34.* ORNL. Retrieved from http://cta.ornl.gov/data/tedb34/Edition34_Full_Doc.pdf

Davis, S. C., Williams, S. E., Boundy, R. G., & Moore, S. (2016). *2015 Vehicle Technologies Market Report.* Oak Ridge: Oak Ridge National Laboratory. Retrieved from http://cta.ornl.gov/vtmarketreport/index.shtml

EIA. (2016). Annual Energy Outlook 2016.

EIA. (2016). NEMS Archive. *Transportation Module Input Files, Vehicle Stock*.

EPA. (2009). NONROAD2008a. Retrieved from https://www3.epa.gov/otaq/nonrdmdl.htm

EPA. (2014). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014.* https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Chapter-Executive-Summary.pdf.

Foss Maritime. (2013, September 16). Foss Hybrid Tugs. Retrieved from http://egsa.org/Portals/7/Documents/CommitteeDocs/F13_Foss_GreenTug.pdf

GPA. (2016, June 29). GPA Wins EPA Clean Air Award. Retrieved June 29, 2016, from http://www.gaports.com/Media/PressReleases/TabId/379/ArtMID/3274/ArticleID/71/GPA-wins-EPA-Clean-Air-Award.aspx

Hornblower. (2016). *Hornblower Hybrid*. Retrieved from Hornblower Cruises & Events: https://www.hornblower.com/port/yacht/ny+33;jsessionid=A8A8FB0DC2E364C8B6701EA94173E295

IHS Automotive. (2016). *Quarterly Commercial Vehicle Report, March 2016.*

Jensen, S. (2013, December). *Electric Underground*. Retrieved from OEM Off-Highway: http://www.oemoffhighway.com/article/11224086/electrification-of-underground-mining-equipment

McKenna, R. (2013). *Campbell Foss- Hybrid Retrofit Final Report.* Retrieved from http://www.arb.ca.gov/msprog/aqip/demo/demo%20final%20reports/campbell_foss_hybrid_final_report_052913.pdf

Meeks, K. R. (2013, December 30). Ports, vessels get ready for new statewide regulation to lower emissions through shore power. *Long Beach Press Telegram*. Retrieved from http://www.presstelegram.com/general-news/20131230/ports-vessels-get-ready-for-new-statewide-regulation-to-lower-emissions-through-shore-power

Mongelluzza, B. (2015, May 2). New automated Rotterdam container terminal shows how far US lags. *Journal of Commerce*. Retrieved from http://www.joc.com/port-news/terminal-operators/apm-terminals/new-automated-rotterdam-container-terminal-shows-just-how-far-us-lags_20150502.html

Mongelluzzo, B. (2016). *Report: Switching to electric from diesel to cost ports billions*. Retrieved from The Journal Of Commerce: http://www.joc.com/port-news/terminal-operators/report-switching-electric-diesel-cost-ports-billions_20160118.html

NAS. (2016). *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions.* Division on Engineering and Physical Sciences; Aeronautics and Space Engineering Board, Committee on Propulsion and Energy Systems to Reduce Commercial Aviation Carbon Emissions. Washington, DC: National Academies Press. Retrieved May 31, 2016, from http://www.nap.edu/download/23490

NEC Commission. (2014). *The Northeast Corridor and the American Economy.* he Northeast Corridor Infrastructure and Operations Advisory Commision. Retrieved from http://www.nec-commission.com/wp-content/uploads/2014/02/NEC_american_economy_report.pdf

NEC Commission. (2016). *Northeast Corridor Capital Investment Plan Fiscal Years 2017-2021.* Northeast Corridor Commission. Retrieved from http://www.nec-commission.com/capital-investment-plan/report/Northeast%20Corridor%20Five-Year%20Capital%20Plan.pdf

NREL. (n.d.). *Fleet DNA: Commercial Fleet Vehicle Operating Data*. Retrieved May 9, 2016, from National Renewable Energy Laboratory: http://www.nrel.gov/transportation/fleettest_fleet_dna.html

NY State. (2014, June 17). Governor Cuomo Announces Retrofitted Electric Canal Boat to Demonstrate Benefits of No-emission Engine. Retrieved from New York State: https://www.governor.ny.gov/news/governor-cuomo-announces-retrofitted-electric-canal-boat-demonstrate-benefits-no-emission

Petras, J. (2016). Hybrid Systems for Medium and Heavy Duty Trucks. *Electrification Beyond-LDV: Electrification of Goods and People Movement (G&P) Workshop.* Davis, CA: Odyne.

POLA. (2014, January 8). Port of Los Angelse Ready to Meet California's Shore-Side Power Requirements. Retrieved from https://www.portoflosangeles.org/newsroom/2014_releases/news_10814_AMP-Shoreside_Power_Requirements.asp

POLA. (2015, January). Proposed Sale of Marine Vessel Angelena ll. Los Angeles, CA, USA. Retrieved from https://www.portoflosangeles.org/Board/2015/February%202015/02_05_15_Item_5.pdf

POLB. (2014). *Air Emissions Inventory 2014.* http://www.polb.com/civica/filebank/blobdload.asp?BlobID=13033.

Port of San Diego. (2014, February 24). *Port of San Diego Celebrates Shore Power Installation*. Retrieved from Unified Port of San Diego: https://www.portofsandiego.org/maritime/3474-port-of-san-diego-celebrates-shore-power-installation.html

R.L. Polk and Co. (2013, December 31). US Vehicle Registration Data for Class 4-8. provided by NREL.

SAE. (2016, January). *Electrified off-highway powertrains search for marketing power*. Retrieved from SAE International: http://articles.sae.org/14554/

SCAG. (2012). *Analysis of Freight Rail Electrification in the SCAG Region.* Retrieved from http://www.freightworks.org/DocumentLibrary/CRGMSAIS%20-%20Analysis%20of%20Freight%20Rail%20Electrification%20in%20the%20SCAG%20Region.pdf

Schneider Electric. (2016). *Shore Connection Solutions*. Retrieved from Schneider Electric: http://www2.schneider-electric.com/sites/corporate/en/products-services/product-launch/shore-connection/shore-connection.page

Siemens. (2016, March). *Setting a Course for Carbon-Free Shipping*. Retrieved from Siemens-Electromobility: http://www.siemens.com/innovation/en/home/pictures-of-the-future/mobility-and-motors/electromobility-electric-ferries.html

Southwest. (2016). *Ground Support Equipment Fuel Conservation.* http://www.southwestonereport.com/2010/planet_er_gse.php.

Stoikes, J. (2016, June). *Volvo Expands Electrification Strategy to Construction Equipment*. Retrieved from For Construction Pros: http://www.forconstructionpros.com/article/12204204/volvo-expands-electrification-strategy-to-construction-equipment

Tita, B., & Hagerty, J. R. (2014, July 13). Caterpillar Falls Behind GE in Locomotives Race. *The Wall Street Journal*. Retrieved from http://www.wsj.com/articles/caterpillar-falls-behind-ge-in-locomotives-race-1405291739

U.S. Army Corps of Engineers. (2016). *Principal Ports of the United States.* U.S Waterway Data, Waterborne Commerce Statistics Center, New Orleans, LA. Retrieved June 6, 2016, from http://www.navigationdatacenter.us/data/datappor.htm

U.S. DOC. (2004). *Vehicle Inventory and Use Survey 2002.* US Department of Commerce, Economics and Statistics Administration, U.S. Bureau of the Census. Washington, DC: US Department of Commerce.

U.S. DOT. (2014). *Best Practices and Strategies for Improving Rail Energy Efficiency.* Federal Rail Administration. Retrieved from http://www.fra.dot.gov/Elib/Document/3547

U.S. DOT. (2016, September). *2014 Highlights of Ferry Operations in the United States.* U.S. Bureau of Transportation Statistics. Retrieved from DOT- Office of the Assistant Secretary for Research and Technology- Bureau of Transportation Statistics: https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/Special%20Report%20NCFO%202016.pdf

U.S. DOT. (2016). *Freight Facts and Figures 2015.* Bureau of Transportation Statistics, Washington, DC. Retrieved June 7, 2016, from http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/data_and_statistics/by_subject/freight/freight_facts_2015

U.S. DOT. (n.d.). *Alaska Railroad*. Retrieved from Federal Railroad Administration: https://www.fra.dot.gov/Page/P0548

U.S. DOT FHWA. (2015). *Highway Statistics 2014.*

U.S. EPA. (2008). *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder.* Retrieved from https://www.regulations.gov/contentStreamer?documentId=EPA-HQ-OAR-2003-0190-0938&disposition=attachment&contentType=pdf

U.S. EPA. (2009). NONROAD2008a. Retrieved from https://www3.epa.gov/otaq/nonrdmdl.htm

UC Riverside. (2010). *Evaluating Emission Benefits of a Hybrid Tug Boat, Final Report.* Retrieved from http://www.arb.ca.gov/ports/marinevess/harborcraft/documents/hybridreport1010.pdf

Volvo. (2007). Power Take-Offs and Hydryalic Pumps, Fields of Application Calculation Guide. Retrieved from http://productinfo.vtc.volvo.se/files/pdf/lo/Power%20Take-off%20(PTO)_Eng_08_580114.pdf

Weber, R. (2011, April 1). NTEA: 4% increase in 2010 for Class 3-8 vehicles from 2000 model year or newer. *Trailer/Body Builders*. Retrieved from http://trailer-bodybuilders.com/archive/ntea-4-increase-2010-class-3-8-vehicles-2000-model-year-or-newer

WSDOT. (2011). *Hyak Hybrid Ferry Propulsion Project.* Retrieved from http://www.wsdot.wa.gov/NR/rdonlyres/AF8C5114-E659-4FF0-B339-4924D1550779/0/TIGERIIIHyakHybrid102811FINAL.pdf

WSDOT. (2015). Moving Forward: Washington State Ferries. 37. Retrieved from http://leg.wa.gov/JTC/Meetings/Documents/Agendas/2015%20Agendas/Jan7/WSDOT_Ferries.pdf