REPORT

Electric Drive Buses

December 2013

advanced energy

Primary Investigators / Authors
Anna Stokes, Advanced Energy
Lisa Poger, Advanced Energy

Organizations
Advanced Energy

TABLE OF CONTENTS

INTRODUCTION

Electric drive vehicles offer many advantages over their conventionally-fueled diesel counterparts, including environmental improvements, energy security, quieter operation and total fuel-cost savings (Jerram & Gartner, 2012). Over the past 20 years, **light-duty** passenger vehicles have been in the lead as far as adoption of hybrid and battery-electric technologies is concerned; however, the **medium- and heavy-duty** vehicle market is rapidly shifting with increasing adoption of alternatively-fueled buses, including those powered by electric drivetrains. As public policy efforts continue to expand their focus to include greenhouse gas (GHG) emissions reductions, in addition to EPA criteria pollutants, there has been a renewed interest in low-carbon and zero-emission buses. Electric drive buses have the ability to greatly reduce GHG emissions, as well as particulate matter and smog, which allows them to be an ideal technology for urban communities to adopt. Additionally, fixed routes and schedules common to most buses today make them an ideal application for electric-fuel adoption. In North America alone, hybrid electric vehicles now comprise as much as 40 percent of new purchases of transit buses. This has been due largely to thriving research and development in the electric vehicle industry (Jerram & Gartner, 2012). This report provides an overview of the currently available electric drive bus technologies and addresses some of the benefits and barriers to adoption.

TECHNOLOGY OVERVIEW

Electric Drivetrains

Although there are many options for buses that are "greener," this report only addresses electric drivetrain buses. The three types of electric drivetrain buses are:

1. Hybrid Electric;
2. Plug-in Hybrid Electric; and
3. Battery Electric.

These three technologies differ in their design and operation as well as their expected benefits and ideal applications.

The most widely adopted electric drivetrain bus is the hybrid electric vehicle (HEV). HEVs are highway-capable vehicles that utilize both liquid fuels and an energy storage system, such as a battery, to power the vehicle. HEV batteries are designed to capture excess electricity during operation of the vehicle to increase efficiency and reduce fuel consumption and emissions. As opposed to relying on a connection to the electric power grid to charge the battery, HEVs use a combination of regenerative braking and power from the internal combustion engine (ICE) to supply power to the battery. HEV buses utilize a smaller ICE than a standard bus in combination with the electric drive system. Ultra-low sulfur diesel (ULSD) – a fuel blend containing a maximum of 15 parts per million of sulfur designed to decrease emissions – is the most common fuel used with hybrid-electric bus ICEs. The combination of ULSD and hybrid-electric vehicles can help to drastically reduce emissions by transit agencies (North Carolina Department of Transportation (NCDOT), 2008).

Hybrid electric technology is fairly mature and has been explored in the vehicle market for more than a century. Hybrid vehicle sales saw a decline in the early 1900s with the introduction of the assembly line manufacturing approach and self-starting engines, though revival of the hybrid market began again in the late 1960s with increasing fuel prices and pollution concerns. There are currently two classifications of HEVs: ***mild hybrids*** and ***full hybrids***.

Mild Hybrids

Mild hybrids have an electric motor that allows the vehicle to turn off its engine when it is coasting, braking or idling. The electric motor is also able to assist the engine when there is extra power needed. The energy that would normally be irrecoverable is harvested and utilized to charge the battery of the vehicle (EESI, 2007). The mild hybrid differs from the full hybrid vehicle in that the electric motor of the mild hybrid does not have the capacity to power the vehicle on its own.

Full Hybrids

Full hybrids have the ability to power the vehicle using only the engine, only the electric motor or a combination of both. The electric motor also allows the vehicle to turn off the engine when the vehicle is coasting; braking or idling and can assist the engine when extra power is needed, thereby reducing fuel consumption and vehicle emissions.

A plug-in hybrid electric vehicle (PHEV) is a similar to a HEV; however, PHEVs include additional energy storage capacity and are able to recharge from an external power supply, such as the electric power grid. Plug-in hybrid-electric buses have offered anywhere from 25- to- 50 percent fuel economy improvement as compared to an average ICE bus (Jerram & Gartner, 2012). There are two different types of PHEVs in the vehicle market today, ***parallel*** and ***series***. Likewise, there are differences in the system configuration and ideal application for each type (Jerram & Gartner, 2012).

Parallel Hybrid Electric Vehicles

Parallel hybrid electric vehicles contain both an ICE and an electric motor. The two components are connected independently to the transmission and can power it together or independently. The ICE is designed to power the vehicle at higher speeds, such as on the highway or interstate, while the electric motor provides power to the vehicle during situations of stop-and-go traffic. The battery can be recharged using regenerative braking which helps to recover lost energy, or by connecting to the electric power grid. In general, a parallel hybrid system is better utilized in applications where there is both stop-and-go as well as higher speed or steady speed driving (Jerram & Gartner, 2012).

Parallel hybrid vehicles require smaller and simpler batteries and motors than series hybrid vehicles, often making them a more affordable option.

Series Hybrid Electric Vehicles

Series hybrid-electric vehicles contain both an ICE and an electric motor. Only the electric motor is connected to the transmission. The ICE of the series hybrid is connected to an electric generator, which converts the energy produced by the ICE into electric power for the electric motor. The electric generator is also utilized to recharge the vehicle's battery, supplying extra power to the electric motor (EESI, 2007). With a series hybrid-electric vehicle, the ICE can operate at a more optimum rate, allowing itself to be switched off temporarily; as it is not directly connected to the wheels (Callaghan & Lynch, 2005). Unlike the parallel hybrid system, the series hybrid-electric system is more suited to low speeds and stop-and-go traffic and is often seen in urban settings (EESI, 2007).

In series hybrids there is no need for a complicated multi-speed transmission and clutch. This is because only the electric motor is used to directly drive the transmission, which may only even have a single gear. Series hybrids also have smaller and more efficient gasoline engines due to the fact that they do not directly power the vehicle, and are therefore not subject to energy demands of driving in stop-and-go traffic. Because of these design features, series hybrids are more suited for urban and suburban driving conditions where a great deal of stop-and-go traffic is seen (Randall).

Also called "all-electric" vehicles, these vehicles are solely driven by an electric motor and have no on-board ICE. The vehicles must be plugged into an external power source to be recharged in order to run (Advanced Energy). The technology behind battery electric buses is much less mature than the technology seen in hybrid-electric systems, but does offer additional benefits like zero tailpipe emissions, low-noise operation and an increased potential to help shift the transportation sector away from petroleum dependence (Jerram & Gartner, 2012).

Battery electric vehicles are widely under development and demonstration throughout the majority of world. China, for example, has undertaken an impressive initiative to accelerate the deployment of battery electric vehicles. The "Ten Cities, Thousand Vehicles Program" is meant to expedite the widespread adoption of all types of electric vehicles. Since the program's beginning in 2009, hundreds of battery electric buses have been successfully deployed throughout China. This effort has helped to establish China as a leading developer of battery electric buses. More than 10 battery electric bus manufacturers are located there. Although China is expected to continue to lead the world in the deployment of electric buses, the United States, Canada and many countries in Europe are following suit with many new original equipment manufacturers (OEMs) between them. With vast support from government funding, these countries have the potential to eventually surpass China in the production and deployment of battery electric buses (Jerram & Gartner, 2012).

Given their limited range and reliance on electric charging infrastructure, battery electric buses are well suited for defined routes with a central return point for fueling.

Charging Infrastructure

Charging infrastructure is required to safely transfer electric fuel to plug-in electric vehicles. Charging infrastructure, also known as charging stations, is the means by which the electric vehicle is able to connect to the electric power grid for fuel. There are two modes of electric vehicle charging: alternating current (AC) and direct current (DC). The equipment options for these two modes of charging offer a range of charge times and infrastructure complexity.

The majority of electric drivetrain buses available today are AC charge compatible, meaning they are able to charge from 120 or 208/240 Volt AC outlets using an appropriate connector. This method however is time consuming as the speed of charge is limited by power availability and therefore is not widely used. .

For higher speed charging, DC fast charging equipment is required. Although this technology requires a higher power utility supply, it is still preferred as it is able to supply DC power directly to the batteries allowing them to charge at a much faster rate. Several manufacturers are looking into development of DC fast charge systems for plug-in electric buses. The electric bus manufacturer Proterra has developed a FastFill™ Charging Station. This on-route charging station offers a rapid and convenient method for charging bus fleets (Proterra, 2013).

The fast charge system can charge a bus with a 40 mile range in roughly 10 minutes. If necessary, the system can reach at least a 92 percent charge in as little as six minutes and is generally located at specific stops along a bus route. The bus is charged during an automatic connection that links the bus to a high-capacity charger through an overhead system without any involvement needed from the driver. The re-fueling system is able to identify the electric bus from a conventional ICE bus and then automatically guides the bus to a successful connection. Many buses operate with a 10 minute layover at one or more stops making the fast charge system a convenient method for charging (Proterra, 2013).

Proterra reports the following benefits of their FastFill Charge Stations:

- On-route charging which allows for easier, more convenient vehicle use by eliminating the need to return the vehicle to an off-route service center for battery charging throughout the day
- Has lower on-board energy requirements which results in lower individual vehicle weight and investment cost than its standard ICE counterparts

The absence of mechanical parts in battery-electric drive system significantly reduces maintenance costs. The extremely wide approach and departure tolerances also help to enable easy on-route placement of charging stations (Proterra, 2013)

Inductive charging systems are wireless and operate when the electric current is passed through the air. Inductive charging for buses is not nearly as developed as the fast charge systems; however, a regional bus operator in Germany, Rhein-Neckar-Verkehr GmbH (RNV), is hosting a trial version of this type of charging. The expectation is for the system to be up and running by the second quarter of 2014 to provide RNV customers with a quiet and CO_2-free ride (Bombadier, 2013).

In this PRIMOVE Manneheim project, RNV will utilize inductive charging technology called PRIMOVE developed by the German company Bombardier. This technology eliminates the constraints and hassle of cables, meeting the flexibility needs of urban transportation. Vehicles can be charged while moving, through dynamic charging along the route, or while they're stopped, through static charging (Bombadier, 2013).

The retrofitted buses will run along an inner city urban route and will recharge wirelessly during stops while waiting for passengers to get on and off of the vehicle. The project will start with two electrically powered and inductively charged buses, as well as an electric van also retrofitted with PRIMOVE technology. PRIMOVE Manneheim will help to determine the ideal framework for infrastructure, batteries, inductive energy transfer and day-to-day operation of this new technology. The aim is to prove that this technology is a viable option for urban bus fleets and public transportation systems around the world (Bombadier, 2013).

Bombardier reports the pros of inductive charging systems to be:

- Invisible
- Clean and quiet
- No recharging constraints
- Competitive with other charging systems
- Convenient and safe
- A smaller, lighter system
- Reliable under all conditions
- Easy integration
- Flexible (Bombadier, 2013)

BENEFITS OF ELECTRIC DRIVE BUSES

Environmental: Emissions

One obvious benefit of electric drive buses is environmental improvement (Malouff, 2011). Hybrid electric and plug-in hybrid electric buses are more fuel efficient than their ICE counterparts because of their battery powered electric drive systems. Improved fuel efficiency results in reduced fuel consumption, as well as reduced, or even zero, mobile emissions. Electric-drive bus fuel efficiency is also improved through a regenerative braking system captures energy that would otherwise be lost and stores it as electricity in the onboard battery (EESI, 2007).

When compared to conventional diesel buses, diesel-electric hybrid buses are estimated to cut emissions by as much as 75 percent. (North Carolina Department of Transportation (NCDOT), 2008) In addition, hybrid electric buses were found to have 30- to- 40 percent lower nitrogen oxide (NOx) emissions than traditional diesel systems, as well as the lowest carbon monoxide (CO) emissions of any buses tested in a study conducted by Northeast Advanced Vehicle Coalition (NAVC) (EESI, 2007).

Economic & Environmental: Fuel Use and Cost Savings

Electric drive buses have proven to have significant increases in fuel economy when compared to standard diesel buses. In fact, according to the National Renewable Energy Laboratory (NREL), hybrid buses offer an average 37 percent fuel economy improvement over conventional diesel buses (EESI, 2007). NREL also conducted a study comparing the fuel economy of hybrid-electric buses to their more conventional ICE counterpart in four districts within the Seattle, Washington area covered by King County Metro Transit. These districts were: Central Business District (CBD), Manhattan (MAN), Orange County (OCTA), and King County Metro (KCM). The two test vehicles were:

- A 2004 New Flyer bus powered by the Caterpillar C9 8.8L 330 hp diesel engine (as the baseline traditional test vehicle)
- 2004 New Flyer platform also incorporated the Cat C9 engine along with Allison's EP50 hybrid electric drive train (as the hybrid test vehicle; this is a parallel hybrid) (Hayes, Williams, Ireland, & Walkowicz, 2006)

In the study, the fuel economy of the two different types of buses, hybrid-electric and conventional ICE, were measured by miles per gallon. The hybrid-electric bus showed higher fuel economy in comparison to the conventional bus. Figure 1 shows the difference in fuel economy between the two different vehicles. In order to accurately evaluate the effects auxiliary loads have on the performance of the vehicles, both the CBD and KCM districts were trialed with and without air-conditioning, and KCM was also trialed with and without grad simulation. It was found that the hybrid buses experienced a slightly larger penalty in reduced fuel economy savings due to auxiliary loads then the conventional buses did (Hayes, Williams, Ireland, & Walkowicz, 2006).

There was an improvement of 74.6 in fuel economy (mpg) for hybrid-electric vehicles in contrast to the conventional vehicles in Manhattan, a 50.6 percent improvement for OCTA, a 48.3 percent improvement for CBD, and a 30.3 percent improvement for KCM. Benefits of the hybrid powertrains for fuel economy were most noted in the districts with lower speed, stop-and-go driving. Figure 1 displays the difference in fuel economy savings for each district tested (Hayes, Williams, Ireland, & Walkowicz, 2006).

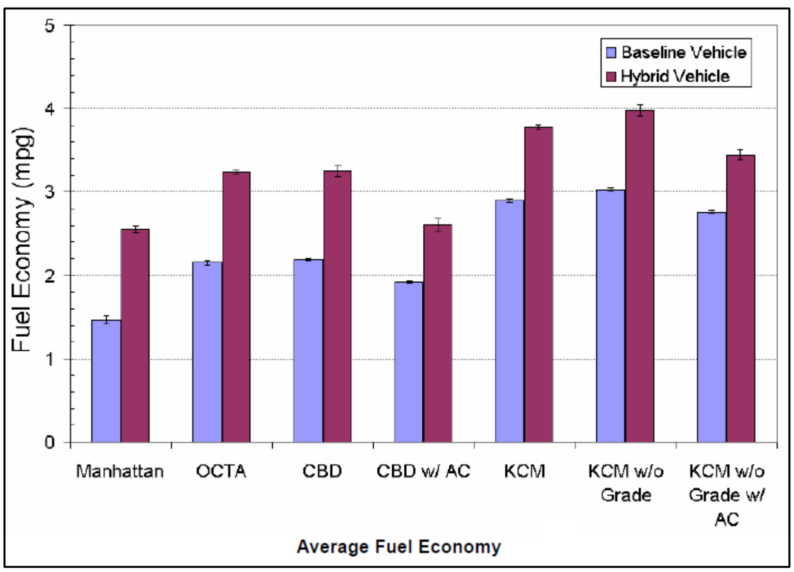


Figure 1. Fuel Economy in Hybrid Electric Bus versus Conventional Bus
Source: King County Metro Transit: Allison Hybrid Electric Transit Bus Laboratory Testing (Hayes, Williams, Ireland, & Walkowicz, 2006).

Improved Performance

Another huge benefit of electric-drive buses is their improved performance. These vehicles provide a quieter and smoother ride as compared to buses with more traditional ICE engines, giving passengers a more enjoyable ride (Malouff, 2011). Acceleration in electric drive buses is also smoother and faster due to the fact that the electric motors have increased low-end torque (EESI, 2007).

The reduction in the cost of maintenance for electric drive buses is also an improvement to their performance. These buses are expected to have lower maintenance costs due to reduced stress on mechanical components. These components could experience an increase in their usable lifetime by 50- to- 100 percent. Less maintenance for electric drive buses is also due to the bus simply having fewer parts than a traditional transmission (EESI, 2007).

TECHNOLOGY APPLICATIONS

Transit Service

Transit service is a unique operation, differing greatly from other forms of transportation in the way it is facilitated, funded and perceived. These three differences make it a great application for the adoption of hybrid, plug-in hybrid and battery electric vehicles (US DOT Federal Transit Administration, 2011).

Transit vehicles are operated within a large fleet and in most instances; the vehicles are housed, maintained and fueled in a central facility. This can reduce the number of chargers needed for the buses since they can easily be shared between vehicles of the same fleet. Also, transit operations usually have professional operators and mechanics who are employed by their governing entity. These employees are skilled and can be easily trained to work with any type of vehicle the fleet manager decides to purchase, reducing the already low maintenance cost of hybrid, plug-in hybrid and battery electric buses. Another factor making transit service vehicles ideal for electric adoption is their fixed routes and schedules. Obviously, a key aspect of transit service is scheduling and predictability which makes it easy to plan routes that fit into the range of the vehicle and also to install chargers along the routes (US DOT Federal Transit Administration, 2011).

The unique funding sources and opportunities of transit systems is another factor that makes them ideal for the adoption of hybrid, plug-in hybrid and battery electric buses. This helps overcome the barrier of high up-front deployment costs as most transit systems have some form of federal capital funding support. Government entities on the municipal, state and federal level all have an interest in transit operations. This opens many doors for the possibility of adoption, helping all levels to procure federal funding and also receive assistance for developing technologies (US DOT Federal Transit Administration, 2011).

Perception by the public surrounding public transit and its operations is very different than the perception of other forms of transportation. Transit fleets run with high visibility and also have the potential to make significant social impacts, such as reduced vehicle emissions and noise. Most public transit fleets operate within areas that have high population density, giving the fleets broader public exposure and acceptance. Even those who do not frequent public transit vehicles are aware of their existence and often encounter them in their day-to-day life (US DOT Federal Transit Administration, 2011).

Federal Transportation Administration's TIGGER Program

The Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) program is managed by the Federal Transportation Administration's (FTA) Office of Research, Demonstration and Innovation in coordination with the Office of Program Management and FTA regional offices. Working directly with public transportation agencies, the TIGGER program helps implement new transit strategies for reducing greenhouse gas emissions and energy use (Federal Transportation Administration, 2013).

TIGGER program recipients can implement these strategies through operational enhancements, technological enhancements or other innovations. The FTA encourages any project implementation that will align the TIGGER program with other strategic initiatives such as "enhance operational efficiencies, demonstrate innovative electric drive strategies, and create an environment prioritizing public transportation through intelligent transportation systems (ITS) or other related technology approaches to achieve efficiency and sustainability goals" in order to leverage TIGGER funds (Federal Transportation Administration, 2013).

Originally started within the American Recovery & Reinvestment Act (ARRA) of 2009, the TIGGER program was continued in fiscal year 2011 through the Department of Defense and the Full-Year Continuing Appropriations Act of 2011 (Pub. L.112-10). The TIGGER Program has appropriated $49.9 million for grants given to public transit agencies. These grants are to be used for capital investment purposes to reduce energy consumption and/or GHG emissions of their public transportation systems. The TIGGER program defines energy consumption as energy (diesel fuel, compressed natural gas and electricity from power plants) purchased directly by the public transportation agency themselves. Emissions are defined by the TIGGER program as those emitted directly by actions of the public transportation agency themselves and are expressed in carbon dioxide equivalents (Federal Transportation Administration, 2013).

Throughout the three fiscal years that it ran, TIGGER funded 88 projects with a total investment of $225 million (see Figure 2). Of the 88 projects, 43 involved public transit bus fleets while the other projects focused on rail and facility upgrades that met the goals of TIGGER (Eudy, 2012). Nineteen of the 43 projects focused on hybrid-electric buses including diesel hybrids, CNG hybrids and gasoline hybrids (the later consisting of shuttle buses and vans) and resulted in 218 new vehicles and 301 retrofits. The projects also focused on zero-emission buses; which included battery electric buses, mostly with fast charge systems (Eudy, 2012).

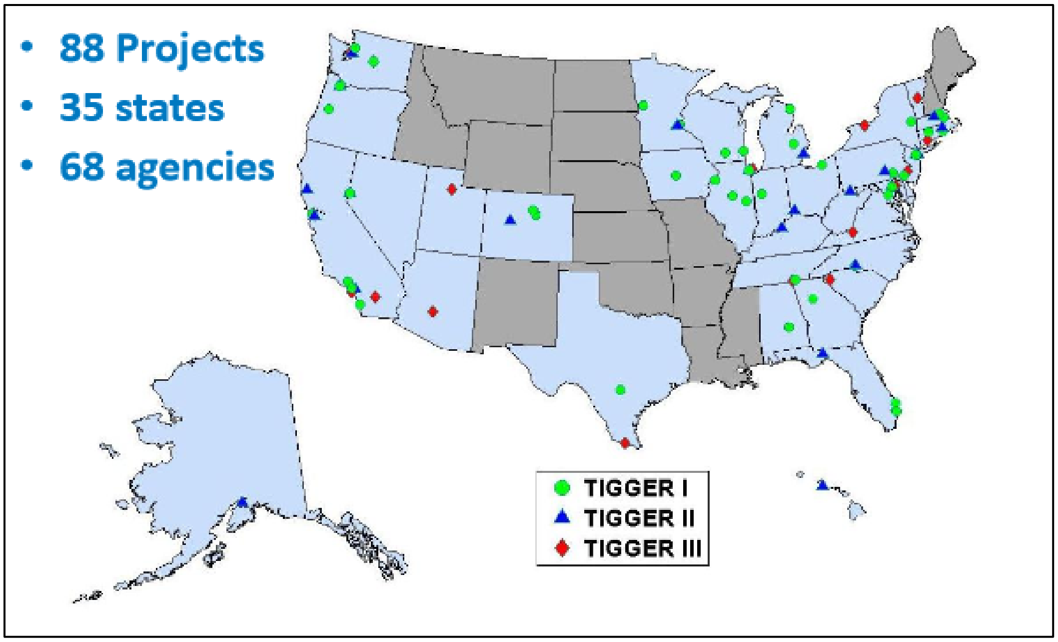


Figure 2. TIGGER-funded projects. Source: (Eudy, 2012).

School Buses

School buses play a significant role in our nation's fuel consumption. Although transporting students by bus is significantly more efficient than transporting them in individual cars, it is still a large source of fuel consumption, consuming more than 800 million gallons of diesel fuel per year nationwide. According to the American School Bus Council, within the United States more than 26 million students are transported by school bus every day (Advanced Energy, 2010).

Aside from having low fuel economies (average of 4 miles/gallon), traditional school buses also have many other concerns, such as the pollutants discharged in the form of tailpipe emissions. Since children are especially susceptible to the negative effects of poor air quality, this is of high concern. Several studies have been conducted that point out the dangers of school bus emissions to the students they transport. Highlighting these negative effects has helped motivate stakeholders within the school bus market to look for solutions and alternatives to traditional transportation (Advanced Energy, 2010).

School buses have potential for vast improvement in fuel economy by switching to electric. The first U.S. bus manufacturer to introduce hybrid models, Navistar, began to sell them in 2007. Their hybrid models improve fuel economy by 30 percent as compared to a conventional internal combustion engine, and their plug-in hybrid electric buses improve fuel economy by up to 65 percent (Ramsey, 2011). It is now common to see hybrid drive trains and advanced engines as options for modern school buses created by many manufacturers. Upgrade services to address the existing school bus fleet also exist, such as enhanced maintenance, fuel additives and retrofit kits marketed to improve the vehicle's performance and reduce its fuel consumption (Advanced Energy, 2010).

School buses are also well suited for all-electric drive systems because of the nature in which they are used. Typically, school buses cover fairly short distances, rarely leaving the limits of the school district in which they're located and travel the same predictable route everyday with few exceptions. Because of this routine and predictability, there is very little chance that the bus would accidentally run out of battery power before finishing the route (Ramsey, 2011). The fuel cost savings of an all-electric bus could be significant, however hurdles still existing on the initial purchase price and charging infrastructure cost.

GLOBAL MARKET

Until 2011 North America was leading market adoption for this technology. Various forms of hybrid-electric buses had captured 30- to- 40 percent of the annual transit bus sales. In 2011 Chinese annual sales of hybrid buses surpassed that of North America reaching nearly 1,700. Although hybrid-electric buses capture a lower percentage of the market in China than they do in the United States, the enormous scale of China's bus market will probably help it continue to stay in the lead in the numbers of vehicles sold annually (Jerram & Gartner, 2012).

Following North America and China is Europe. Their hybrid bus deployments are much lower, but stimulus funding is beginning to change that. In the United Kingdom there has been a 50 percent increase in the sales of hybrid-electric buses over the last few years. In Germany there is now a hybrid-electric bus demonstration program, the PRIMOVE Manneheim, detailed in the inductive charging section earlier in this report (Jerram & Gartner, 2012)

The global market for the varying types of electric drive buses has been growing and is expected to continue to do so. The current estimate is for the market to have a compound annual growth rate (CAGR) of 26.4 percent from the year 2012 until the 2018 (Jerram & Gartner, 2012). Figure 3, prepared by Pike Research, details these global growth estimates.

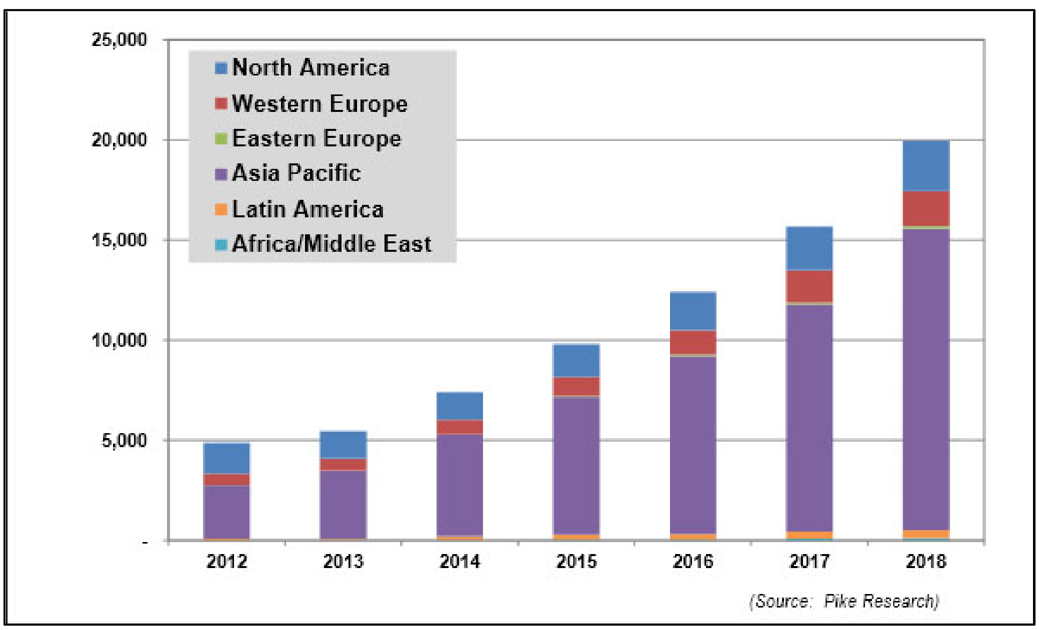


Figure 3. Annual Electric Drive Bus Sales by Region, World Markets 2012-2018. Source: (Jerram & Gartner, 2012)

BARRIERS TO ADOPTION

Although adoption of plug-in electric-drive buses appears to be on the rise, there are still a few challenges to overcome to facilitate and continue their success. One primary barrier is the high up-front cost of electric drivetrain buses. Although bus owners and operators are interested in electric drive train buses and recognize their eventual fuel savings, the high upfront cost makes these vehicles often hard to financially justify (Jerram & Gartner, 2012). One way to battle the high cost barrier is through government subsidies. Stimulus funding from the government organizations around the world has had a significant impact in helping to increase the adoption of alternative fuel buses, including those with electric drivetrains (Jerram & Gartner, 2012). One example with significant impact in the United States is the TIGGER program (previously mentioned), managed by the FTA's Office of Research (Federal Transportation Administration, 2013). In order to justify the high upfront spending, bus operators must either be able to offset the cost with operational savings or with government subsidies (Jerram & Gartner, 2012).

In one effort to address the high up-front cost of adoption electric drivetrain school buses, the maker of the new eTrans bus, Trans Tech, a unit of Transportation Collaborative Inc., plans to price their zero-emission electric and hybrid-electric models so that school districts who choose to invest in them can expect to recoup the initial cost through fuel savings over three- to- five years. Although many of the electric bus options are currently too expensive for some school budgets, a few schools are beginning to make the commitment. Trans Tech made its first sale to King's Canyon School District near Fresno, California. King's Canyon School District's Director of Transportation, John Clements, reports that the district decided to invest in low-emission buses in part because of the poor air quality in the area. After grants, the district will pay a total of $35,000 for its new bus and hopes to buy more in the future. Clements estimates that the electric bus will save the district about $50- to- $60 in diesel fuel each day. Charging the battery will only cost roughly $17 per charge (Ramsey, 2011).

Another barrier is the availability of electric fueling infrastructure (Jerram & Gartner, 2012). With the adoption of plug-in buses comes an imminent need for charging infrastructure. The main purpose of this charging infrastructure is to establish communication with the plug-in vehicle and to transfer power to it while also providing proper grounding, shock protection, overload protection and general safety. The need for proper charging infrastructure will increase the initial adoption price of these vehicles (Advanced Energy). Finally, the environmental benefits of electric drive buses are societal and are not easily quantified. Combine these issues and the motivation to adopt electric drivetrain buses becomes lessened, ultimately threatening to limit their wide adoption and commercial success (Jerram & Gartner, 2012).

DEPLOYMENT PROJECTS

Transit: VIA Metropolitan Transit (A TIGGER Program Recipient)

VIA Metropolitan Transit, located in San Antonio, Texas, received a $5 million TIGGER award. The agency utilized this award to purchase three all-electric, battery powered buses for use in its transit bus fleet. It then powered these buses with 100 percent renewable energy. The buses replaced three conventional diesel transit buses, helping improve the fleet's overall fuel efficiency (Federal Transit Administration, 2012).

The renewable energy used to power the buses was obtained by a partnership VIA had with the program Windtricity, which uses wind power to generate electricity for the grid. Another source of renewable energy for the buses is generated through solar photovoltaic panels located on the bus charging stations (Federal Transportation Administration, 2013).

VIA Metropolitan Transit's new buses will operate along the Yellow Route, an existing downtown circulator route. This route services an estimated 552,000 passengers each year, and includes a brief stop, approximately fifteen minutes, at the downtown transit terminal operated by VIA. The downtown transit terminal, the Robert Thompson Transit Station, is the future site of a bus charging station. This station will be used to recharge each of the three buses onboard batteries during their short layover at the facility (Federal Transportation Administration, 2013).

The buses purchased by VIA Metropolitan Transit were manufactured by the Greenville South Carolina based company Proterra. The EcoRide model is the world's first battery-electric fast-charge transit bus. Proterra describes their buses as being "the cleanest, most fuel efficient and lowest total cost of ownership option in the transit market" going on to say that they're "the natural choice for transit agencies struggling to balance budget constraints, ever-increasing fuel costs and mounting sustainability pressures" (Proterra, 2013). By replacing three conventional diesel powered buses with three of Proterra's battery-electric EcoRide buses, VIA Metropolitan Transit will reduce their greenhouse gas emissions and be able to offer their community the cleanest transit bus operating technology currently available (Federal Transit Administration, 2012).

School Bus: Advanced Energy's Plug-in Hybrid Electric School Bus Program

Advanced Energy, a Raleigh, N.C.-based energy consulting non-profit, saw an opportunity to apply plug-in hybrid technology to school buses to help solve many of the issues associated with diesel buses. These issues include: harmful tailpipe emissions, poor fuel economies and high maintenance costs. As schools across the nation continue to face budget cuts, and fuel prices continue to rise steadily, adoption of plug-in hybrid electric technology within school bus fleets could be a great solution (Advanced Energy, 2010).

Advanced Energy launched its Plug-In Hybrid Electric School Bus program in 2001. The first steps included selecting a manufacturer to build the buses, and working with a buyer's consortium in order to secure the funding needed for the purchase of the buses. Next, Advanced Energy worked to perform fleet testing and monitor the performance of the new buses. They also made it a priority to do education and outreach activities promoting awareness of the new technologies (Advanced Energy, 2010).

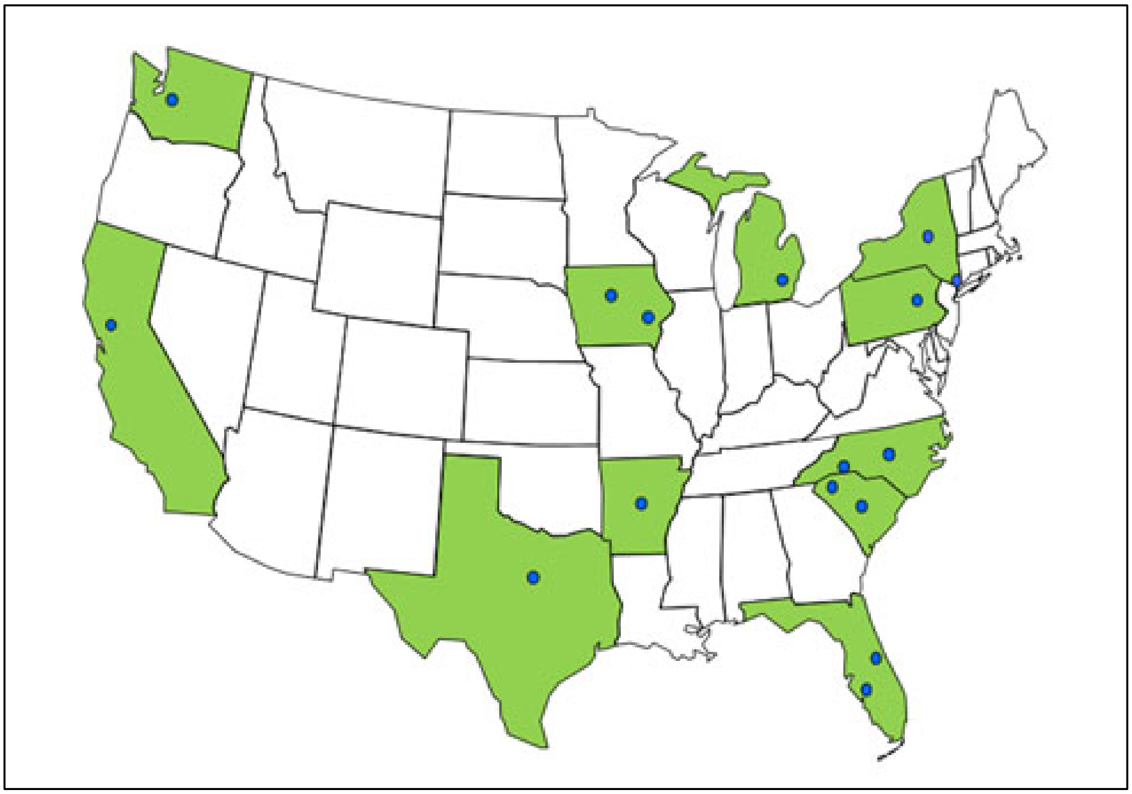
The manufacturer chosen was IC Bus, who partnered with Enova Systems, a hybrid system manufacturer. IC Bus was dedicated to making these vehicles a reality, and built it on a manufacturing line making it the world's first publicly available plug-in hybrid vehicle. In 2007, 16 PHESBs were delivered across 11 states (see Figure 4). The first generation of PHESB manufactured by IC bus included the following parameters:

- 6.0 L, 210 hp diesel engine
- Enova Systems hybrid system with:
- Plug-in capability
- Post-transmission parallel drive
- 80 kW electric motor
- 35 kWh Li-ion phosphate battery pack

There was a $140,000 incremental cost for the hybrid system (Advanced Energy, 2010). Projected performance expectations for the bus included:

- 90-100 percent fuel economy improvement for the first 45 miles
- 40 percent improvement for additional miles beyond 45
- 90 percent reduction in particulate matter emissions
- 60 percent reduction in oxides of nitrogen emissions
- Increased engine, transmission and brake life
- Electricity cost of 60¢ / gallon equivalent (Advanced Energy, 2010)

Following the delivery of the 16 original buses, IC Bus and Enova Systems reported selling additional PHESBs, although these sales were not monitored or tracked by Advanced Energy.



District	State	No. of Buses	Date Delivered
Florida Department of Transportation – Manatee County	FL	2	March 2007
Jennings Transportation – Nazareth	PA	1	April 2007
North Carolina Department of Public Instruction – Wake County and Mecklenburg County	NC	2	May 2007
Little Rock School District	AR	1	June 2007
Lake Chelan School District	WA	1	June 2007
Napa Unified School District	CA	1	August 2007
South Carolina Department of Education – Rock Hill, Columbia	SC	2	October 2007
Austin Independent School District	TX	1	November 2007
Sigourney Community School District	IA	1	December 2007
Nevada Community Schools	IA	1	December 2007
State of New York	NY	2[a]	August 2008
Ann Arbor Public Schools/DTE Energy	MI	1	September 2009
[a] Only one of New York's buses is a plug-in hybrid, the other is a standard hybrid			

Figure 4. States receiving PHESBs in 2007. Source: (Advanced Energy, 2010)

The performance results varied from district to district. In some areas PHESBs were found to perform quite well. Fuel economy improvements were found to be as high as 51 percent; however, in other districts, the improvements were not as high. Some buses achieved significant fuel economy improvements over their standard diesel counterparts, others underperformed. The performance differences were due heavily to factors such as route selection, driving style, availability of charging infrastructure and properly trained maintenance personnel; however, this technology is still found to have real potential for consistent fuel economy improvements. As long as the PHESB are implemented smartly, and utilized efficiently, they should provide the owner's with high quality results.

There are many lessons to be learned from Advanced Energy's PHESB project. These lessons can be split into four key categories where consideration can be made for improvements on similar future endeavors with PHESBs. These categories include:

Route Selection

Routes should be optimized to suit the needs of PHESB. This can be done by assigning PHESB to routes that are shorter and have especially frequent stops as well as slower overall speeds. This will help the PHESB meet their full potential, resulting in the most fuel savings for the district employing the buses.

Driving Style

School districts should ideally train the drivers of their PHESBs to maximize the advantages of the PHESB technology. PHESB drivers should learn the importance of non-aggressive driving, as well as how to maximize mid-day recharging. This can lead to significant decrease in fuel consumption, as well as the maximization of the vehicle's lifetime.

Charging Infrastructure

Districts can increase the efficiency of their PHESB by including additional charging locations, or optimizing the location of singular charging stations. During Advanced Energy's PHESB program, only the minimum number of chargers were installed, and often in a central hub not necessarily suited to the route pursued by the individual PHESBs. This led to PHESBs traveling several miles a day for no reason other than to be able to recharge.

Trained Maintenance Personnel

Districts with PHESBs should train their maintenance personnel to troubleshoot and repair basic issues specific to the electric drive portion of their PHESBs. Proper training can reduce maintenance costs as well as downtime for the vehicles (Advanced Energy, 2010).

CONCLUSIONS

Electric drive vehicles offer an opportunity for bus fleets to impact environmental improvements and energy security while providing better vehicle performance and overall fuel-cost savings. Electric buses have the ability to greatly reduce GHG emissions, as well as particulate matter and smog, and are ideal technology for urban communities looking to improve air quality. With a growing market for electric drivetrain vehicles; manufactures are aggressively researching and developing new technologies. Advanced Energy, as an emerging technologies consultant, can assist bus fleet managers in identifying the best fit technology for their specific application.

APPENDIX A: ORIGINAL EQUIPMENT MANUFACTURERS

OEM	LOCATION	ITEMS MANUFACTURED	NOTES	WEBSITE
United States Manufacturers				
EBus	Downey, CA	Electric	22 foot bus, 22 seats, fast charge capable (30 minutes), 45 miles range between charges	$295,000 (90kW fast charger is priced at $58,000)
ElDorado National	California and Kansas	Diesel/Electric Hybrid Gas/Electric Hybrid	30-35 foot and 35-40 foot buses 30-35 foot bus	
GILLIG	Hayward, CA	Diesel/Electric Hybrid	Transit Buses: 30 foot, 35 foot, and 40-foot	www.gillig.com 510-264-5160
IC Bus	Lisle, IL	Diesel/Electric Hybrid Plug-In Hybrid	School & Commercial Buses: The CE Series hybrid electric has hill-start assist, and can provide school districts with up to a 30 percent improvement in fuel economy, as well as up to 35 percent reduction of NOx emissions, and up to 85 percent reduction of diesel particulates. Plug-in hybrid has 40 miles electric-only range.	www.icbus.com Charge-sustaining hybrid system adds $60,000 to price of bus Charge-depleting hybrid system adds approximately $100,000. ($210,000)
NABI	Anniston, AL	Diesel/Electric Hybrid		
New Flyer Industries	USA and Canada	Diesel/Electric Hybrid	New Flyer's Electric Bus is equipped with an electric drive system, modified to carry advanced lithium ion batteries from MHI	

Nova Bus	USA and Canada	Hybrid, Plug-In Hybrid and All Electric Transit Buses	Currently developing plug-in hybrid and battery electric bus prototypes. Have existing hybrid models.	
Proterra	Greenville, SC	All-electric	35-foot low-floor transit bus, 55kWh battery, seats 37, Fast-fill charging system, 30 miles range, 12 mph top speed, 23 mpg-e	$950,000 (not including fast fill charging station)
Trans Tech	Warwick, New York	Electric	All-electric school buses 130 mile per charge range	
Foreign Manufacturers				
Alexander Dennis	United Kingdom	Hybrid Transit and Coach Buses		www.alexander-dennis.com
Ashok Leyland	India	Transit, Coach and School Buses		www.ashokleyland.com
BYD	China	All-electric	Full size bus, seats 32, 155 miles range, 62 mph top speed.	$550,000
Daimler	Germany	Hybrid and All Electric Buses		www.daimler.com
Optare	United Kingdom	Hybrid and Electric Buses		www.Optare.com
Tata Motors	India	Hybrid Buses		www.tatamotors.com
Van Hool	Belgium	Electric Trolley/Buses		www.vanhool.be
Wright Bus	Ireland	Hybrid Electric Buses		www.wrightbus.com

WORKS CITED

Advanced Energy. (2010). *Plug-In Hybrid Electric School Bus Project*. Retrieved from http://www.advancedenergy.org/transportation/phesb/knowledge_library.php

Advanced Energy. (n.d.). *Community Planning Guide for Plug-In Electric Vehicles*. Retrieved from Advanced Energy: http://www.advancedenergy.org/transportation/resources/Community%20Planning%20Guide.pdf

Bombadier. (2013). *The Evolution of Mobility*. Retrieved from Bombadier: http://www.bombardier.com

EESI. (2007). *Hybrid Buses Costs and Benefits*. Retrieved from Environmental and Energy Study Institute : http://www.eesi.org/files/eesi_hybrid_bus_032007.pdf

Eudy, L. (2012). *FTA's TIGGER Program Supporting Sustainable Transit Operations*. Retrieved from http://ad.apta.com/mc/sustainability/previous/2012/presentations/Presentations/Eudy,Leslie-FTA-TIGGER-Supporting-Sustainable-Transit-Operations.pdf

Federal Transit Administration. (2012, 3 12). *TIGGER Program Information Sheets*. Retrieved from FTA DOT: http://www.fta.dot.gov/about_FTA_14440.html

Federal Transportation Administration. (2013). *FTA's TIGGER Program*. Retrieved from FTA DOT: http://www.fta.dot.gov/12351_11424.html

Hayes, R. R., Williams, A., Ireland, J., & Walkowicz, K. (2006). *King County Metro Transit: Allison Hybrid Electric Transit Bus Laboratory*. Retrieved from National Renewable Energy Laboratory Technical Report: http://www1.eere.energy.gov/vehiclesandfuels/avta/pdfs/heavy/king_co_9-06.pdf

Jerram, L., & Gartner, J. (2012). *Executive Summary: Electric Drive Buses*. Retrieved from http://www.navigantresearch.com/wordpress/wp-content/uploads/2012/08/EBUS-12-Executive-Summary.pdf

Malouff, D. (2011, June 17). *Are Electric Buses in the Future?* Retrieved from Greater Greater Washington : http://greatergreaterwashington.org/post/10930/are-electric-buses-in-the-future/

Proterra. (2013). *Proterra*. Retrieved from http://www.proterra.com

Proterra. (2013, March 7). *Proterra Adds San Antonio to List of Cities Operating its Zero-Emissions Battery-Electric Buses*. Retrieved from Proterra: http://www.proterra.com/index.php/mediacenter/companynews/proterra_adds_san_antonio_to_list_of_cities_operating_its_zero-emissio/

Ramsey, M. (2011, December 28). *Forget the Prius. The Future of Electric Is the School Bus.* Retrieved from Wall Street Journal: http://online.wsj.com/article/SB10001424052970203716204577018471878074352.html

Randall, C. J. (n.d.). *What Are the Advantages and Disadvantages of Series Hybrid Designs.* Retrieved from National Geographic : http://greenliving.nationalgeographic.com/advantages-disadvantages-series-hybrid-designs-20513.html

US DOT Federal Transit Administration. (2011). *U.S. DOT Federal Transit Administration Electric Drive and Fuel Cell Bus Research.* Retrieved from Go Fuel Cell Bus: http://gofuelcellbus.com/uploads/DOT_FTA_Research_Efforts_IFCBW_2011.pdf