Electric Buses in America

Lessons from Cities Pioneering Clean Transportation

U.S. PIRG Education Fund

Environment America Research & Policy Center

Frontier Group

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Executive summary

AMERICA'S BUS NETWORK plays a crucial role in the lives of millions of people, providing transportation for those who cannot or do not wish to drive, and carrying up to half of all American children to and from school every day. The majority of America's buses, however, are still powered by polluting fossil fuels such as diesel that pose a serious risk to public health and contribute to global warming.

Battery-powered electric buses can reduce the environmental and health threats posed by diesel buses while also providing a reliable and cost-effective option for cities and school districts. Advances in electric bus technology and a rapid decline in battery costs over recent years have made electric buses an increasingly viable option for many transit agencies and school districts.

However, electric buses are still an emerging technology. Transit agencies and school districts considering electric buses need to know what to expect – and, more importantly, how to get the greatest benefit from their investment.

The experience of six early adopters of electric buses illustrates the challenges that agencies have faced, as well as the benefits many have received from their electric bus pilots. To speed up the rollout of electric buses and ensure that cities see the benefits of these vehicles, state and city officials should commit to a transition to electric buses on a specific timeline and create favorable utility rate structures for transit agencies that include reduced off-peak energy rates and limited demand charges.

Electric buses deliver numerous benefits to the communities they serve.

- By eliminating diesel exhaust emissions, particulate pollution and pollutants that contribute to the formation of ground-level ozone, they improve the air quality in our communities.[1]
- They produce significantly lower greenhouse gas emissions than diesel, diesel hybrid and natural gas-powered buses. Replacing all of the country's diesel-powered transit buses with electric buses could eliminate more than 2 million tons of greenhouse gas emissions each year[2]
- Electric buses can deliver financial benefits, including substantially reduced maintenance costs and, in places where utility rate policies are favorable, reduced fuel costs.
- By reducing air pollution, electric buses can also deliver significant societal benefits, including avoided healthcare expenses resulting from cleaner air.

Electric buses have often performed well in early pilots, and have often been cheaper to fuel and maintain than their

diesel counterparts. But early adopters have experienced a set of technological and economic hurdles that future electric bus programs will need to overcome.

- **Seneca, SC.** In 2014, Seneca became the first city in the world to launch an all-electric bus fleet.[3] The buses have outperformed their diesel equivalents in fuel and maintenance costs and exceeded expectations regarding charging time, range and battery life. Seneca views its electric buses as a successful, scalable model of full-fleet electrification.[4]

- **Chicago, IL.** The Chicago Transit Authority's (CTA) rollout of two electric buses in 2014 was one of the first major tests of electric bus technology in a cold winter climate. The vehicles have performed well, have had no difficulty with extreme temperatures, and have saved the CTA more than $24,000 each year in fuel costs and $30,000 each year in maintenance costs.[5] The agency is currently moving forward with its commitment to full-fleet electrification by 2040.[6]

- **King County, WA.** King County Metro Transit has been testing electric buses since 2016. The buses have performed well in a range of weather conditions, but with occasional problems, including issues with battery life and range. Per-mile fuel costs have been higher than for diesel due in part to high electricity demand charges. Taking into account other factors, such as environmental benefits, the agency nonetheless regards its electric buses as providing a good return on investment and plans a large-scale rollout in the coming years.[7]

- **Albuquerque, NM.** Safety and durability issues with its electric buses, as well as subpar battery life, inadequate range and sensitivity to extreme heat, contributed to Albuquerque's electric bus tests in 2018 ending in disappointment. Having incorporated safeguards into its contract with the manufacturers to ensure it would lose no money in the event of failure, the city cancelled the contract and returned its buses.[8] In August 2019, however, the city announced its intention to buy five new 40-foot electric buses.[9]

- **Twin Rivers, CA.** In 2017, the Twin Rivers Unified School District Transportation Department in California became one of the first school districts in the country to deploy electric school buses.[10] The vehicles have experienced few problems and produced a 75-80 percent savings on fuel costs (largely due to very favorable utility rates), exceeding the district's most optimistic expectations. The district reports a total savings of $15,000 per year on energy and maintenance costs, and believes its experience proves that electric school buses can be a reliable and cost-effective alternative to diesel buses.[11]

- **Massachusetts school bus pilot.** In 2015, the Massachusetts Department of Energy Resources tested electric school buses in three school districts across the state. The vehicles produced significantly fewer harmful emissions than diesel school buses, had no difficulties with range, and cold weather did not affect their performance. Fuel cost savings were smaller than expected, however, mainly due to unmanaged charging of batteries and high electricity demand charges. All three school districts chose to keep their buses after the pilot.[12]

Policy Recommendations

- States, cities, towns and school districts should commit to a full transition to electric buses on a specific timeline.

These commitments will help grow the market, drive technological innovation, and enable transit agencies and school districts to gain the benefits of economies of scale in maintenance facilities, operational experience, and electricity pricing.

- States should provide grant programs and subsidies for agencies to go electric. This will ensure agencies and the communities they serve will experience the benefits of electric buses without additional financial burdens being placed on the agencies themselves.
- Public officials and utilities should implement financing programs in which they front the initial investment for electric buses and allow cities and school districts to pay back on utility bills as they save on fuel and maintenance costs. These "pay as you save" financing programs can help agencies overcome the higher upfront costs of electric buses and deliver monetary savings immediately.
- Public officials and utilities should provide discounted off-peak charging rates, limit excessive demand charges, and experiment with policies and practices that allow battery-electric buses to be used for storage/use vehicle to grid technology.

Transit agencies and school districts considering electric bus deployments should:

- Establish solid collaborative partnerships with utilities from an early stage, and open a dialogue about goals and interests from the outset. Agencies should work with public officials and local utilities to enact a transportation rate for electricity and use rate modeling in the planning process for launching electric bus service.
- Ensure contracts with the bus manufacturers include provisions to guarantee protection in the event that the vehicles delivered do not perform as promised.
- Be realistic about the capabilities of electric buses for particular routes and conditions, and study route modeling data to determine the appropriate type of bus for the route.
- Before going to bid, have electric vehicles from different vendors shadow existing diesel buses and ensure that the bid includes the needs identified in the route study.
- Invest in as large a fleet as possible as soon as proof of concept can be established. Ensure the availability of additional electrical capacity and build the infrastructure to be able to add more chargers, including on-route charging infrastructure where necessary. The larger the fleet, the greater the potential economies of scale, and the greater the opportunity to demonstrate the vehicles' functionality and desirability.
- Acquire as much data as possible from agencies already using the technology. Ask agencies where they've been successful, where they've failed, and where they've worked with manufacturers and utilities to find solutions to issues that have arisen.
- Include environmental and health benefits (for example, the "social cost of carbon") in any evaluation of the costs and benefits of electric buses. Calculations of return on investment should include the total societal cost for the life cycle of an electric bus versus a diesel bus.

Introduction

IN 1893, BICYCLE mechanics J. Frank and Charles Duryea of Springfield, Massachusetts, designed and built America's first successful gasoline-powered automobile. It was a crude machine – not much more than a buggy with a one-cylinder engine strapped to the back – but it worked. Described by Henry Ford as a "masterpiece," the Duryea Motor Wagon became the first automobile to be mass produced in the United States. But the idea of a self-propelled motor vehicle faced a skeptical public. "Get a Horse!" was a cry that drivers grew accustomed to hearing from amused pedestrians as they passed by. Wrote auto pioneer Alexander Winton in 1930, "to advocate replacing the horse, which had served man through centuries, marked one as an imbecile."[13]

Public cynicism was compounded by the fact that the first motorcars were noisy, unreliable, exorbitantly expensive and plagued by mechanical problems. They also required infrastructure that the United States simply did not have. When Winton and a companion embarked on the world's first road-trip in July 1897, the only place to buy gasoline was in a drugstore – and few such establishments stocked the six gallons that their machine needed for a day's drive.

Over time, as people began to see the potential in these vehicles and investors started to pour money into their development and production, the problems that had dogged the early automobiles were ironed out. Technology improved, mass production and rising demand brought costs down, and the country – for better or worse – created the infrastructure that allowed this once-ridiculed contraption to become a taken-for-granted part of modern life.

The introduction of the first public transit buses met with similar cynicism. "All of us believed bus lines would come some day," Winton recalled, but at that time "the public was not ready to accept such a dream." After the first gasoline-powered buses hit the streets of New York City in 1905, however, initial skepticism and the practical difficulties their early incarnations faced were gradually overcome, the technology was refined and improved, and within a matter of decades the diesel-powered bus, introduced in the 1930s, was firmly established as the workhorse of America's public transit system.

Today, buses are still the workhorses of America's transit systems, accounting for nearly half of all public transit use in the United States.[14] In addition, 480,000 school buses carry up to half of all American kids to school each day, making school buses the largest form of public transportation in the country.[15]

Buses bring environmental benefits, but the vast majority are still powered by the same fuel as their early 20th century forerunners: diesel. Diesel exhaust is a dangerous pollutant with proven links to numerous health impacts, including lung cancer, asthma and autism.[16] It is also a significant contributor to global warming.[17]

The benefits of a transition to electric buses could be massive, but taking this new technology to scale will require us to learn the lessons of early adopters.

America is ready for another major technological transition – a transition to vehicles, including buses, that run on clean electricity.

Ten years ago, electric buses were as rare as gasoline-powered vehicles in late 19th century America. Few were on the market at all, and those that were available were prohibitively expensive, had limited range, and often experienced reliability problems. But just as rapid improvements to gasoline-powered vehicles and infrastructure revolutionized transportation at the turn of the 20th century, so too are innovations in electric vehicle technology opening up new opportunities to address the critical environmental and public health challenges posed by transportation in the early 21st century.

There are now more than 500 electric buses on America's streets and thousands more worldwide,[18] with more hitting the streets every day. Radical improvements to electric bus technology and a rapid decline in upfront costs are resolving many of the earlier problems with these vehicles, and a growing number of manufacturers are producing high-quality, increasingly affordable electric buses for use by school districts and transit agencies.

The benefits of a transition to electric buses could be massive, but taking this new technology to scale will require us to learn the lessons of early adopters. This report examines the experiences of six such pioneers, reviewing what has worked, what hasn't, and what steps are needed to ensure that the rollout of electric buses delivers the maximum benefits for the environment, our health and the financial health of transit agencies.

Electric buses have the potential to both reduce the danger posed by diesel pollution and deliver long-lasting financial benefits for transit agencies. Realizing that potential, however, requires both a vision for the future and a willingness to work through the early challenges posed by any new technology. By making the decision to adopt electric buses, the agencies profiled in this report have taken the first steps toward a future of cleaner, more sustainable transportation.

Electric buses deliver health, environmental and financial benefits

PUBLIC TRANSPORTATION provides efficient, environmentally responsible mobility to millions of Americans. But, like every aspect of society, public transportation has a lot of work to do to reduce its impact on the environment and our health.

Fossil fuel buses – especially the majority of American buses that run on diesel fuel – contribute to climate change and release pollutants that threaten public health. Since transit and school buses have lifespans longer than a decade, any new diesel buses purchased today will continue polluting for years to come.

Electric buses hold the promise of delivering efficient public transportation at a reasonable cost while producing significantly fewer carbon emissions and reducing harmful air pollution in our communities and on our streets. They are also often a cost-effective alternative over the long term, and the economic case is only improving.

Cleaner, healthier air

Like other heavy-duty vehicles, fossil fuel-powered buses produce air pollution, impacting the health of the communities they serve. Electric buses can reduce emissions of diesel exhaust, particulate pollution and pollutants that contribute to the formation of ground-level ozone – improving the quality of the air in our communities.

Diesel remains the main fuel used to power America's buses, fueling around half of the country's nearly 70,000 transit buses and 95 percent of its school buses.[19] Diesel exhaust is a dangerous pollutant containing more than 40 toxic chemicals, including known or suspected carcinogens such as benzene, arsenic and formaldehyde.[20] Diesel exhaust itself is classed as a potential cancer agent by the U.S. EPA, and at least 19 of the hydrocarbons it contains are known to cause or are suspected of causing cancer.[21] In particular, exposure to diesel exhaust has been linked to higher rates of lung cancer and greater risk for bladder cancer.[22]

Diesel pollution can lead to decreased lung function, respiratory tract inflammation and irritation, and aggravated asthma symptoms.[23] Diesel soot also contains tiny particles of carbon, metal oxides and heavy

Pollution from a diesel-powered school bus.

Credit: Rockford's New Country Q98.5 via YouTube (with permission).

metals that have been linked to negative health impacts.[24] Studies have shown that inhalation of diesel exhaust can cause respiratory diseases and exacerbate existing conditions like asthma.[25]

Diesel buses also contribute to widespread problems with particulate matter and ozone "smog" pollution across the country. Diesel vehicles produce fine particulates (referred to as $PM_{2.5}$) as well as volatile organic compounds (VOCs) and nitrogen oxides (which are both precursors of ground-level ozone), among other pollutants.[26] A 2017 study linked exposure to fine particulate matter and ground-level ozone to higher rates of mortality, concluding that exposure to particulate matter and ozone, even at levels below national standards, contributes to adverse health impacts.[27] Ultrafine particulate matter (< 0.1 micron in diameter) is especially dangerous since it can enter deep into lower airways, carrying heavy metals that are now linked to Alzheimer's disease, along with odorless, toxic chemicals such as polycyclic aromatic hydrocarbons (PAHs) that irritate the respiratory tract.[28]

A Proterra electric bus. Credit: Frontier Group staff photo.

Pollution from buses poses a particular risk, since buses are in constant use and primarily travel in areas with high concentrations of people, on the busiest roads and close to schools, therefore exposing large numbers of people to emissions.

Vulnerable populations, such as the elderly, children, and people with health conditions, are especially susceptible to the negative health effects of air pollution. Children in particular are at risk, as their respiratory systems are still developing and they inhale more air per pound of body weight than adults.[29] Numerous studies have found that air pollution harms a child's lungs, especially if the child already suffers from asthma.[30] A 2010 study conducted by researchers at Stanford University and the University of California, Berkeley linked exposure to air pollution with altered gene expression among asthmatic children in California.[31]

There is no established safe level of exposure to diesel exhaust for children.[32] Research has shown that exposure to hydrocarbons from diesel exhaust in early childhood increases the likelihood of developing asthma.[33] In 2013, researchers looked at the impact of diesel exhaust particles on children in Cincinnati and concluded that diesel exhaust made the children more susceptible to asthma by turning off certain genes.[34] A 2017 Rutgers University study on asthmatic children living near an industrial New Jersey seaport with heavy diesel truck traffic found that greater exposure to carbon soot coincided with markers for lung inflammation.[35]

By limiting emissions of diesel pollution in our city neighborhoods and near schools, electric buses can reduce health risks from air pollution and contribute to healthier communities.

Less global warming pollution

Electric buses produce significantly less carbon pollution than diesel-powered buses, helping cities, states and the nation as a whole make progress in the effort to limit climate change.

Transportation is the largest source of greenhouse gas emissions in the United States, responsible for more than 29 percent of total emissions.[36] Replacing all of the country's diesel-powered transit buses with electric buses could eliminate more than 2 million tons of greenhouse gas emissions each year, and replacing all school buses with electric models could avoid an average of 5.3 million tons of emissions each year.[37] Benefits would continue to increase as America transitions to clean, renewable energy.[38]

A 2018 study by the Union of Concerned Scientists found that electric buses produce significantly lower greenhouse gas emissions than diesel, diesel hybrid and natural gas-powered buses over their entire life cycle, including the process of generating the electricity that powers them, and that there are benefits across the country, even in places where the electric grid is carbon intensive.[39] Buses charged on California's clean electric grid, for example, had 70 percent lower life cycle emissions than diesel or natural gas buses, but the study found that electric buses consistently produce lower emissions than both diesel and natural gas-powered buses in every area of the country.[40] Over its entire life cycle, an electric bus charged with the national electricity mix produces less than half of the carbon dioxide-equivalent (CO_2e) emissions per mile as are produced by natural gas or diesel-hybrid buses.[41]

By switching to electric buses, transit agencies can help individual cities reduce their contribution to global warming. For example:

- If the Chicago Transit Authority were to replace its entire diesel fleet with electric buses it would save nearly 55,000 tons of greenhouse gases each year, equivalent to taking more than 10,000 cars off the roads.
- The transit agency serving Philadelphia, the Southeastern Pennsylvania Transportation Authority, could avert 22,000 tons of greenhouse gas emissions every year, akin to taking more than 4,000 cars off the roads.
- Replacing Denver's diesel buses would save nearly 47,000 tons of greenhouse gas emissions each year, equivalent to taking more than 9,000 cars off the road.[42]

These figures will improve even further over the coming years as the U.S. grid increasingly moves toward clean, renewable energy.

Saving money

Electric buses can deliver financial benefits, reducing maintenance costs and, in places where utility rate policies are favorable, substantially reducing fuel costs. By reducing air pollution in cities and global warming pollution, electric buses also deliver significant societal benefits.

An average diesel transit bus today costs around $500,000, compared to $750,000 for an electric bus.[43] A diesel school bus costs around $110,000, and electric one around $230,000.[44] Despite these higher upfront costs, electric buses are often a cost-efficient alternative, producing major savings over the course of their lifetime in significantly lower operating costs from reduced spending on maintenance and fuel, while also providing greater predictability in costs due to the relative stability of electricity prices compared to fossil fuel prices.

Electric bus manufacturers tout the economic benefits of their products to transit agencies and school districts. New Flyer says that its natural gas-powered buses start at around $450,000 while their electric version starts at $700,000.[45] Over the lifetime of the bus, however, the company estimates the electric bus saves $400,000 in fuel expenses and $125,000 in averted maintenance costs, more than making up for the higher upfront cost.[46] Proterra says its standard electric transit bus costs $750,000, compared to $500,000 for a conventional diesel bus.[47] The company estimates that its electric buses offer fuel and maintenance savings of up to $50,000 a year over fossil fuel-powered buses, meaning transit agencies can recoup the extra cost in around five years (depending on the bus's purchase price and operational cost variables), continuing to save money every year over the lifespan of the bus.[48] A 2019 analysis by Jacobs Engineering found that the upfront cost of battery-electric buses had fallen over time and was comparable with recent purchases of diesel-hybrid buses in the Boston and Seattle regions.[49]

A six-vehicle electric school bus pilot program in California in 2016 concluded that while upfront costs for an electric school bus are much higher than for a diesel equivalent, reduced operating costs more than make up the difference.[50] The study found

An all-electric Proterra BE35 bus operated by San Joaquin Regional Transit District (RTD), California next to its "Fast Charging" station.

that an electric bus saves around $2,000 a year in fuel and $4,400 a year in reduced maintenance costs.[51] If a bus is equipped with vehicle-to-grid (V2G) capabilities – that is, able to send stored energy back to the electricity grid – it could also potentially generate up to $6,000 each year in V2G revenues, depending on their utility's rates. Factoring in other costs, like replacing the electric bus's battery, the study estimates that an electric school bus equipped with vehicle-to-grid capabilities will more than pay for itself within 13 years of operation, saving more than $31,000 over the bus's approximately 16-year lifetime.[52]

In any individual case, the cost-effectiveness of electric buses depends on factors specific to the buses and the agency operating them – including electricity rate structures. But even though electric transit buses today are still more expensive upfront than their diesel or natural gas-powered counterparts, they are often more affordable than fossil fuel buses in the long run since they have significantly fewer parts, no exhaust systems, their braking systems last longer, and they don't require oil changes or fossil fuels.[53] According to studies of electric buses currently in operation, these vehicles save at least $0.19 per mile in maintenance costs.[54] An analysis by the California Air Resources Board found that an electric bus purchased in 2016 can save $458,000 in fuel and maintenance costs over time compared to a diesel bus, $336,000 compared to a natural gas bus, and $331,000 compared to a diesel hybrid bus.[55]

Government funding and other incentives can make electric buses even more affordable. For instance, California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) currently offers up to $235,000 for electric school buses sold in the state.[56] A 2016 analysis comparing

Electric buses can deliver efficient public transportation at a reasonable cost while producing significantly fewer carbon emissions and reducing harmful air pollution in our communities.

lifecycle costs of an all-electric school bus to a conventional diesel bus found that, with California's voucher program and other incentives, the electric bus cost $79,000 more upfront than its diesel counterpart but was expected to save $10,500 each year over the course of its 16-year lifespan, paying back the extra upfront cost in less than eight years, and continuing to offer savings for years to come.[57] This analysis was completed before the increase in the maximum HVIP incentive to its current level of $235,000, meaning that electric buses are likely even more cost-competitive today.

Another source of financial assistance is the Federal Transit Administration's (FTA) Low or No Emission Program, which provides funding to state and local government agencies to purchase or lease zero-emission and low-emission transit buses and related infrastructure. In 2019 this program allocated just under $85 million in grants to 38 projects in 38 states. While other types of buses are eligible for funding through the program, all of the 2019 grants were for electric buses.[58]

A 2017 study by researchers at Carnegie Mellon University found that, with federal funding to help purchase the buses, all-electric buses had the lowest lifetime costs of any buses on the market, including hybrid, diesel, biodiesel and natural gas vehicles.[59]

The cost of electric buses has fallen dramatically over the past decade and is expected to fall further in coming years as more manufacturers enter the market and technologies improve.[60] A 2018 report from Bloomberg New Energy Finance (BNEF) suggests that electric buses will reach unsubsidized price parity with the upfront cost of diesel buses by 2030.[61] By then, BNEF predicts, battery costs will have dropped to 8 percent of the total price of the bus, down from around 26 percent in 2016. The more electric buses that are manufactured, the more the per-unit cost falls, as has been demonstrated over recent years as electric buses have begun to gain a foothold in the market.[62]

By reducing the amount of harmful pollutants in the air, electric buses also create savings in health care costs.[63] The Chicago Transit Authority, for instance, estimates that a single electric bus saves the city nearly $55,000 every year in avoided healthcare expenses resulting from cleaner air.[64] A study conducted by Columbia University for New York City's Metropolitan Transportation Authority (MTA) calculated that electric buses reduced particulate matter emissions by 97.5 percent compared with diesel buses, producing a healthcare cost savings of approximately $150,000 per bus per year.[65]

The rise of electric buses

A Proterra Catalyst electric bus. Credit: Federal Transit Administration.

THE ELECTRIC BUS MARKET in the United States has expanded dramatically over the last five years. There are a total of 528 fully electric, battery-driven buses currently in service across the country – an increase of 29 percent in 2018 alone.[66] Recent pledges by California, New York City and Seattle to transition to zero-emission fleets mean that 33 percent of all transit buses in the U.S. are now committed to go electric by 2045.[67] Roughly 4 percent of all new public transit bus sales in 2018 were electric buses, and 13 percent of the country's transit agencies currently either have electric buses in their fleets or have them on order.[68] Taking into account those that have received grant funding for electric buses but not yet placed orders, upwards of 18 percent of U.S. transit agencies are now making moves toward electric buses.[69] Major players in the market include manufacturers Proterra, BYD Motors and NFI Group, the parent company of New Flyer of America. Companies bringing out electric school bus models include Blue Bird Corporation, Nova Bus Corporation, The Lion Electric Co., Thomas Built Buses, GreenPower, Collins Bus Corporation and Trans Tech.[70]

California has been at the forefront of moves towards bus electrification. In 2018, the California Air Resources Board approved a statewide rule committing to shift to 100 percent all-electric transit buses by 2040.[71] Large transit agencies in the state will be required to purchase 25 percent electric buses starting in 2023, then 50 percent by 2026, with no new purchases of non-electric buses beginning in 2029.[72] In 2017 the Los Angeles Department of Transportation (LADOT) and Los Angeles County Metropolitan Transportation Authority (LA Metro) committed to full-fleet electrification by 2030.[73] As of 2019, California has 210 electric buses in service and a backlog on order, bringing its total commitment to electric buses to around 450.[74]

Los Angeles Mayor Eric Garcetti unveils a new 100% electric DASH bus.

Credit: Los Angeles Department of Transportation via Flickr, CC BY-NC-ND 2.0.

Other transit agencies have also made large commitments to electrify their fleets:

- New York City's MTA, the country's largest transit network, has committed to an all-electric bus fleet by 2040.[75] In 2018, MTA began a pilot project operating 10 electric transit buses throughout the city, and in 2019 added 15 more to its fleet.[76]
- The Washington Metropolitan Area Transit Authority (WMATA) in D.C. brought 14 all-electric buses online in 2018.[77]
- The Southeastern Pennsylvania Transportation Authority (SEPTA) rolled out 25 electric buses in South Philadelphia in 2019 and has another 10 arriving in 2020 for deployment in 2021.[78]
- The Port Authority of Allegheny County in the Pittsburgh area is testing two electric buses in 2019 ahead of an anticipated deployment of 25 vehicles.[79]
- Minneapolis Metro Transit debuted its first electric bus in 2019 and aims to deploy another 200 over the next decade.[80]

A Minneapolis St. Paul Metro Transit electric bus.

Credit: Eric Wheeler, Metro Transit via Flickr, CC BY-NC-ND 2.0.

New Flyer electric bus outside MTA Headquarters, New York City, April 2018.

Credit: New York Metropolitan Transportation Authority via Flickr, CC BY 2.0.

An important driver of electric bus adoption came in the form of the Volkswagen "Dieselgate" settlement, which resulted from VW's deliberate violation of clean air standards. This settlement has made available billions of dollars for states to invest in zero-emission transportation, including electric buses. New Jersey has allocated a portion of its VW award for the acquisition of eight electric transit buses.[81] In Colorado, VW settlement money has funded 24 electric buses across four transit agencies.[82] Following a rollout of three electric buses in 2017 in Howard County, Maryland, the Maryland Transit Administration is planning to spend a portion of the state's VW settlement award on replacing diesel transit buses with electric buses and implementing an electric school bus pilot.[83]

The market for electric school buses is smaller than the electric transit bus market, but is growing rapidly. At least 450 diesel school buses in 32 states are to be replaced with electric vehicles with funding announced by the EPA in March 2018.[84] California has again taken the lead, with the California Air Resources Board's announcement of a statewide goal to replace all 30,000

The first all-electric school bus in California, outside the California capitol building in Sacramento in 2014.

Credit: Theurv via Wikimedia, CC BY 4.0.

of the state's school buses with electric ones by 2040.[85] In 2017 the Sacramento Air Quality Management District awarded funding to 15 school districts for electric bus purchases, and pilot programs have been launched across the state.[86] In 2015, three school districts in Massachusetts launched a pilot project with a total of three electric school buses (see page 28).[87] In 2017, the first electric school bus arrived in the Midwest in the suburbs of Minneapolis-St. Paul, and in 2018, New York State launched an electric school bus test fleet in the White Plains Public School District of Westchester County.[88] In August 2019, Dominion Energy Virginia announced plans for the country's largest electric school bus rollout to date. Through the fall of 2019, bus manufacturers will have the opportunity to bid for contracts and school districts will be able to register their interest in participating, with a view to taking delivery of the buses potentially as soon as 2020. With this program, Dominion Energy will cover the cost of an electric school bus and charging infrastructure above the standard cost of a diesel bus. The company aims to have 50 electric school buses deployed within its Virginia service territory by the end of 2020, and 1,000 by 2025.[89]

As the number of electric buses across the country has grown, so too has the practical experience of school districts and transit agencies in operating those buses. The experience of electric bus programs across the country has thus far illustrated the benefits of bus electrification, while highlighting challenges officials will need to overcome to make the large-scale rollout of electric buses a success.

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Electric buses in America: the experience of early adopters

ELECTRIC BUSES ARE still an emerging technology, and to a large extent the agencies that have incorporated these vehicles into their fleets over the last half decade have been operating in uncharted waters. The following case studies provide a cross section of some of these early experiences, highlighting examples of success as well as challenges that agencies have been forced to overcome in the process of getting electric bus services off the ground. The lessons learned in these early experiments will be crucial in informing future deployments of this technology.

SENECA, SOUTH CAROLINA

An electric bus pioneer gets better than expected results.

In September 2014, Seneca, SC, became the first city in the world to launch an all-electric municipal bus fleet.[90] Having overcome various challenges presented by the new technology, Seneca views its electric buses as a successful, scalable model of full-fleet electrification.

Seneca's transit fleet is operated by Clemson Area Transit (CAT), one of the country's largest public fare-free transit services, serving an estimated 2 million riders per year – around 153,000 of them in Seneca. Founded in 1996, CAT operates the public transit system in Seneca and four other cities (Clemson, Anderson, Central and Pendleton), as well as four college campuses (Clemson University, Southern Wesleyan University, Tri-County Technical College and Anderson University). More than half of CAT's total fleet now consists of electric buses. Since 2014, all of the buses it operates in Seneca have been electric.[91]

In 2010, the City of Seneca partnered with CAT, the Center for Transportation and Environment (CTE) and the South Carolina Department of Transportation (SCDOT) to apply for a federal grant from the Low or No Emission Program to develop the first scalable model of an all-electric bus transit system in the U.S. In contrast to other cities, which had to that point only deployed one or two electric buses as "parade buses" in their fleets, Seneca intended from the start to convert the entire operation to all-electric

A CAT electric bus. Credit: City of Seneca.

service, and, in collaboration with CTE, developed a deployment methodology for doing so.[92]

Having received the $4.1 million federal grant, CAT and the City of Seneca signed an agreement with Proterra in 2012 to purchase its first four new EcoRide transit buses and two charging stations. Following a period of field testing and driver training, the buses went into passenger service in September 2014. An additional two buses were added shortly afterwards, and in 2017, funded in part by a $3.9 million grant from the FTA's Low or No Emission program, CAT purchased an additional 10 Proterra Catalyst E2 buses and charging infrastructure for deployment in the other areas it serves, making CAT the largest zero-emission fleet in the Carolinas.[93] The agency as a whole currently has a total of 16 electric buses, each of which replaced a diesel bus. Of these 16, six are deployed in Seneca, with the rest in the other areas CAT serves. Seneca remains the only one of CAT's service areas that exclusively operates electric buses.[94]

Both the City of Seneca and the FTA received CAT's initial proposals for full-fleet electrification positively, according to CAT General Manager Keith Moody. Prospective funders recognized that the deployment of electric buses would enable the FTA to demonstrate the viability of this technology to reduce emissions and establish the nation's first transit system with no carbon footprint. Key to the positive response, Moody believes, were a forward-looking City Council and Seneca's proximity to the college town of Clemson, with Clemson University bringing a large and environmentally aware young population receptive to the environmental case for an all-electric fleet. The project was launched with approximately $540,000 from SCDOT and just over $500,000 from the City of Seneca, in addition to its federal grant funding.[95]

Since the all-electric service started in September 2014, CAT's electric buses running in Seneca have consistently outperformed the authority's diesel buses operating in the other areas it serves in fuel economy and maintenance costs.[96] A comparison of the two fleets between 2014 and 2018 shows that the electric fleet achieves 16.5 miles per gallon equivalent (MPGe) compared to the diesel buses' 3.8 MPG; fuel cost per mile is $0.28 compared to the diesels' $0.59, and maintenance cost is $0.55 per mile as opposed to $1.53 for diesel. Four years into their deployment, more than 160,000 gallons of diesel consumption have been avoided and tailpipe carbon dioxide emissions have been reduced by just over 2.7 million pounds.[97]

In several areas the buses are exceeding original expectations. For example:

- **Charging time:** Proterra initially claimed a charging time of 10 minutes to a full charge, which CAT considered unrealistically fast. The reality turned out to be six minutes.[98]
- **Range:** The range of the buses was supposed to be 30 miles. CAT's drivers are getting 40+ miles.[99]
- **Battery life:** The lifespan of the batteries has proved significantly greater than anticipated. Proterra initially believed that heavy use of fast chargers would mean the useful life of the batteries should be at 80 percent after six years, at which point they would need replacing. On this basis, CAT built into the contract a stipulation that the manufacturer would change the batteries every six years. The buses entered their sixth year in September 2019 and were still charging at 98-100 percent as of July 2019.[100]
- **Brake changes:** In contrast to the agency's diesel buses, which require a brake change every 30,000-40,000 miles, five years into the electric buses' deployment

it has not been necessary to replace the brake pads. When Seneca's first electric bus hit 100,000 miles (the first in the U.S. to do so), Proterra inspected the brake pads and found that they had only worn down to 50 percent.[101]

At the outset of the Seneca project, CAT trained one mechanic through Proterra and built into the contract the stipulation that for the first two years of deployment a Proterra mechanic would be at the CAT facility working under the agency's maintenance manager, reporting all mechanical issues and improvements to him so the agency could maintain a record of ongoing developments. CAT's mechanic shadowed the Proterra mechanic, and as the fleet expanded they gradually trained the rest of the agency's maintenance team.

Seneca's electric buses are supported by both on-route fast chargers and depot plug-in chargers. The city situated its two fast chargers in locations served by two different electrical grids in case one loses power. In practice, the bus operators rely primarily on the fast chargers. The City of Seneca is not subject to peak demand charges, instead paying one steady rate. The agency started out on an electricity rate plan with demand charges, with a flat fee of $13 per kWh for first demand on each on-route charging station. After a month, it opted to switch to a rate structure with higher energy use charges but no demand fees, which saw a reduction of energy costs from $1.50 per kWh to $0.90 per kWh.[102] Moody stressed that a major aid to the electrification of transit bus systems would be a flat transportation rate from the utility companies.

As with any new technology, the rollout of Seneca's all-electric fleet has not been without problems. Early phases of deployment resulted in a handful of issues that the manufacturer was required to fix. With temperatures in Seneca reaching an average high of 90°F during the summer and a low of 30°F in winter, there was some initial uncertainty over how the buses would perform in these different conditions. CAT reports that the buses themselves don't have an issue with cold, but use of the heaters and defrosters is a drain on the battery, and manufacturers are aware that this is an issue that still needs to be addressed. In extreme heat, by contrast, the batteries need to be cooled. The system will slow the charging to keep the battery from overheating, leading to a few minutes' increase in charging time. As of July 2019, Proterra was working to address this issue. In addition, an electric bus in another of CAT's service areas was unable to make it up one of the three major hills in the area. This issue was dealt with by the manufacturer and is no longer a problem.

When it comes to performance, however, CAT stresses that its electric fleet radically outperforms its diesel buses. A diesel bus has around 3,700 moving parts while an electric bus only has 70, meaning that many of the problems that affect the diesel buses (cold water leaks, freezing up, etc.) do not arise with the electric buses. They require no oil changes, and save money on wear and tear. "One thing I explain to people," said Moody "is that with electric buses, it's not taking a hammer to it, it's taking a laptop, and just doing a different program."

CAT views its all-electric bus fleet as a resounding success and a source of pride for the City of Seneca. The Seneca experience is the first real test of Proterra technology in a small city environment with a mix of rural, suburban, campus and urban routes.[103] Speaking to *The Municipal* in 2017, Al Babinicz, who was CEO and general manager of Clemson Area Transit during the first few years of the project, described electric buses as "a huge benefit to small cities," and "something that can easily be scaled for larger ones. If it works for six in Seneca, it will work for 600 in Chicago."[104]

Chicago's first all-electric buses. Credit: Chicago Transit Authority.

CHICAGO, ILLINOIS

Electric buses deliver in extreme winter temperatures.

The Chicago Transit Authority (CTA)'s rollout of electric buses in 2014 was one of the first major tests of electric bus technology in a cold winter climate. The buses exceeded expectations and the CTA is currently moving ahead with its commitment to full-fleet electrification by 2040.

The CTA's transit fleet includes approximately 1,800 buses, the majority of them diesel-powered and diesel-electric hybrids.[105] Since 2011, the agency has been engaged in a process of modernizing its fleet, acquiring 450 new buses to replace its oldest vehicles and upgrading more than 1,000 buses purchased between 2007-2008 to extend their lifespan and improve performance, fitting them with new technology to improve fuel efficiency and reduce harmful emissions.[106] In 2012, the agency announced its intention to acquire two all-electric buses.[107]

The $2.5 million electric bus project was funded by the U.S. Department of Transportation's Transportation Investments for Greenhouse Gas and Energy Reduction (TIGGER) II and Clean Fuels grant programs and a Congestion Mitigation and Air Quality (CMAQ) grant from the Chicago Metropolitan Agency for Planning.[108] The bus contract was awarded to New Flyer, and the vehicles' deployment in 2014 made the agency the first in the country to use all-electric buses for regular passenger service.[109] With temperatures in Chicago reaching well into the 80s in the summer months and an average low of 18°F in the winter, it was also one of the first tests by a major U.S. transit agency of the performance of electric buses in extreme hot and cold weather conditions.[110]

Chicago's climate poses a particular cause for concern for the rollout of electric buses. Prior to their arrival, the buses underwent extensive testing at a facility in Winnipeg to ensure that they would be capable of handling varying road conditions, heavy passenger loads, stop-and-go traffic, and extreme temperatures. A particular worry was the reliability of the lithium-ion batteries, which have had performance problems in extreme temperatures. In anticipation of these issues, CTA worked with New Flyer to incorporate various safeguards to enhance the vehicles' reliability prior to the rollout. These included higher quality rechargeable batteries designed to last the full 12-year lifespan of the bus, optional diesel-fired heaters (which consume some fossil fuel, but a minimal amount[111]) to help ensure optimum cabin temperature without draining the batteries and thus maintain the vehicles' range in extreme cold, and a continuous battery management system that automatically disengages a battery cell exhibiting unusual behavior to avoid damage to any other battery cells.[112]

The CTA's first two electric buses entered into service in October 2014 and initially operated on six routes serving the downtown area. According to CTA President Dorval R. Carter, Jr., quoted in *Metro* magazine, the vehicles performed "very well – exceeding expectations and providing reliable, comfortable transportation."[113] The two buses have saved the agency more than $24,000 annually in fuel costs and $30,000 annually in maintenance costs compared to new diesel buses purchased in 2014.[114] They have also had no difficulty dealing with Chicago's weather and extreme temperatures.

The two electric buses are permanent additions to the CTA's bus fleet and are expected to remain in service for the remainder of their projected 12-year lifetime.[115] Following the positive performance of these vehicles, in 2018 the Chicago Transit Board awarded a $32 million contract for the purchase of 20 new electric buses. The contract was awarded to Proterra following a competitive bid process and includes installation of five fast-charging stations capable of charging the vehicles within 5-10 minutes. The buses should be able to travel between 75 and 120 miles on a single charge. The last of the vehicles is expected to arrive by 2020.[116]

The CTA has committed to converting its entire bus fleet to electricity by 2040,[117] and has claimed that its experience with electric buses has demonstrated that these vehicles are a viable way of building a "greener, healthier and more efficient" transit system.[118]

An electric bus in Chicago. Credit: David Wilson via Flickr, CC BY 2.0.

KING COUNTY, WASHINGTON

Optimism in Seattle ahead of a large-scale rollout.

King County Metro Transit (Metro) provides public transit service to King County, WA, serving an area of approximately 2,000 square miles, including the Seattle area. The agency has successfully tested a fleet of battery electric buses since 2016 and has ambitious plans for a large-scale rollout over the coming years. It has committed to transitioning to a fully zero-emission fleet by 2040 and aims to buy only zero-emission buses from 2020 onwards.[119]

Metro's bus fleet consists of approximately 1,500 vehicles, including standard and hybrid diesel buses, electric trolley buses and, since 2016, battery electric buses. The agency currently has a total of 185 zero-emission buses in service: 174 electric trolley buses and 11 Proterra battery electric buses. Since the fall of 2018, it has also been engaged in a trial of two 40-foot vehicles from Proterra and two 40-foot and two articulated, 60-foot buses from New Flyer and BYD.[120] These tests will inform the agency's procurement at the end of 2019 of up to 120 additional vehicles.

King County Metro electric bus at Eastgate Park & Ride, Bellevue, WA.

Credit: SounderBruce via Flickr, CC BY-SA 2.0.

In 2015/2016 Metro identified the opportunity to become a zero-emission transit agency, receiving early political support from elected officials. The environmental argument for going electric, coupled with the agency's reputation as an innovator in the bus industry, made its proposals for electrification "a fairly easy sell" to city officials, reports the agency's General Manager Rob Gannon.[121] Metro's diesel fleet accounts for 60 percent of King County government's greenhouse gas emissions from fossil fuels, so there was motivation from the outset to achieve the major emission reductions available through bus electrification.[122]

Supported by a $4.7 million grant from the FTA, in February 2016 Metro began testing a fleet of three Proterra 40-foot Catalyst battery electric buses.[123] The buses' strong performance during the test period informed the agency's decision to go with the Catalyst when it subsequently decided to move forward with the next phase of electrification, bringing a further eight vehicles into its fleet.[124] These 11 buses are now in service, having completed the testing phase of their deployment. Testing has provided data regarding range, electricity usage, battery sizing, charging methods and limitations of the technology, and has also enabled the agency to develop standards for Information Technology, procurement, training etc. in preparation for a large-scale rollout in the coming years.[125]

A major focus has been establishing the reliability of the buses in hilly, rainy conditions in various road environments. Metro's service area covers a range of terrain, including rural corridors, dense urban and suburban corridors, as well as some large hills. In all of these settings, says Gannon, the buses have performed well, albeit with minor problems that gave the agency "a moment of pause." In some instances, for example, batteries have depleted faster than expected, and the buses' range has not always been as advertised, particularly during the colder months, when the average temperature can drop to around 37°F. While the vehicles' speed and responsiveness have been good and the disparity between predicted and actual performance not large, the problems were enough to justify testing a number of different makes of bus before going "all in" with one manufacturer.[126]

King County Metro has remained committed to electrification and is working to find ways of resolving the issues that arose during the pilot. Essential to this process has been what Gannon describes as a spirit of collaboration between the agency and the manufacturers. Proterra has been responsive to Metro's feedback, he reports, and has worked to adapt the vehicles to meet specific needs the agency has identified.

Metro has also partnered with local electric utilities Seattle City Light and Puget Sound Energy, which have been supportive both financially and with in-kind contributions. For instance, the utilities have partnered with the agency in sharing the costs of connecting the agency's charging infrastructure to the power grid, and are taking an active role in helping with infrastructure planning in preparation for the arrival of 120 new buses, beginning in 2021.

This collaboration is particularly important in light of electricity costs. Metro's electric buses have been more energy efficient than the agency's diesel buses, at 15.9 MPGe versus the diesels' 5.3 MPGe.[127] However, the battery fleet has had much higher per-mile fuel costs ($0.57/mile, versus the diesels' $0.30/mile) due to the average equivalent energy price for electricity being almost five times that of diesel, in part due to high demand charges.[128]

Monthly demand charges – charges assessed by utilities based on a customer's maximum draw from the grid during a defined period of time – have made up as much as 54 percent of Metro's utility bills.[129] Demand charges vary from as high as $8/kW to as low as $0.30 /kW off-peak.[130] When agencies running electric bus pilot programs have only a few buses, those charges are spread across few miles of travel, resulting in relatively high energy costs per mile. As agencies add more buses, and recharge existing buses more often, total electricity use increases, but peak use – which determines the size of the demand charge – does not increase as quickly, and demand charges come to make up a lower share of total electricity costs. In King County, higher per-mile costs have been especially pronounced during the winter, due to a combination of higher electricity rates in the winter months and the buses' slightly lower fuel economy in colder conditions, compounded by the fact that the vehicles traveled fewer miles during the winter, resulting in higher costs from demand charges on a per-mile basis.[131]

Gannon reports that these rates are not prohibitive, not least since the costs of fixed assets (chargers etc.) and demand charges are amortized as utilization rates increase, resulting in lower energy costs in the long run. As more buses are added to the fleet, charging at different times, and as buses are recharged during the day to increase the number of miles they travel, the demand charge does not increase proportionally, and comes to make up a lower share of total electricity costs over time.[132] Metro is confident that as it scales up and implements smart-charging tools and strategies it will be able to reduce energy costs to a level lower than its current expenditure on diesel.[133] In collaboration with the utilities, the agency is also studying rate pilot programs in other parts of the country, the ultimate goal being to develop rates that recognize the public benefit that Metro provides that will enable further reductions in operating costs.

While Metro's spending on energy for its electric buses has been high, Gannon reports that the public health and societal benefits of electric buses more than justified the expense. Metro includes the environmental and health benefits of buses in its evaluation of their costs and benefits, estimating that the total societal cost over the life cycle of a 40-foot diesel-hybrid bus is $121,000, versus $19,000 for a 40-foot electric bus using renewable energy (which Metro's energy provider Seattle City Light provides).[134] Lowering and eventually eliminating Metro's GHG emissions also helps the county meet the environmental goals set out in its Strategic Action Plan. These factors, along with the agency's optimism regarding an eventual radical reduction in energy costs for the buses themselves, combine to make electric buses a good return on investment.

King County Metro has a robust ridership eager for more bus transit, and according to Gannon, customer response to the electric buses has been universally favorable and problems identified in the testing have in no way dented the initial optimism about the

A King County Metro electric bus charging at Eastgate Park & Ride. Credit: SounderBruce via Flickr, CC BY-SA 2.0.

buses. Elected officials are "intrigued," and the agency's utility partners have an interest in its success and have been favorably disposed to it. "People *want* this to work," says Gannon. The conversations have been about "the 'how' and the 'how soon' rather than 'is this the right choice?'"

ALBUQUERQUE, NEW MEXICO

After a disappointing test period, a city postpones its electric bus rollout.

Albuquerque, NM, experienced perhaps the least successful attempt at an electric bus rollout in the United States. A string of mechanical problems with the city's electric buses, coupled with missed deadlines for delivery, inadequate infrastructure planning and a rocky relationship with the bus manufacturer, culminated in the city cancelling its electric bus contract and returning its buses. The city is now moving forward with another electric bus procurement.

Approximately 40 percent of Albuquerque's bus transit ridership is concentrated on Central Avenue, a major east-west roadway connecting downtown Albuquerque with the University of New Mexico, the Presbyterian Hospital complex and the Old Town and Nob Hill historic districts.[135] Under the administration of Mayor Richard Berry, Central Avenue became a focus of bus system upgrades as part of a $135 million project called Albuquerque Rapid Transit (ART). ART set out to transform Central Avenue into a first-of-its-kind, all-electric bus rapid transit corridor, with a nine-mile stretch of bus-only lanes and bus stations.[136] In 2016, Berry announced the city's intention to purchase a fleet of 60-foot articulated battery-electric transit buses for the project.[137] The vehicles were touted as "eco-friendly, high efficiency, long-lasting [buses] with increased reliability and simplified maintenance," which would bring a 50 percent savings on energy and maintenance costs.[138] The city ordered 18 buses from Chinese manufacturer BYD at a cost of $1.2 million per vehicle.[139]

Designed and built in BYD's factory in California, these vehicles were a new product for the manufacturer, with Albuquerque one of the first U.S. transit systems to place orders for this model.[140] The first of Albuquerque's buses arrived in October 2017, and almost immediately began to experience technical problems.[141]

In the early stages of driver training it became clear that the vehicles were failing to achieve the contractually-stipulated range of at least 275 miles per charge, only managing 177 miles – not enough to operate a full day's service.[142] In addition to subpar battery life, ABQ RIDE identified an array of "serious durability and safety issues" with the buses, including doors that opened unexpectedly, air conditioning outages, malfunctioning brakes, faulty electrical wiring, inferior welding of frames, battery cages cracking and separating, unmarked high-voltage contacts, exposed wires, and overheating batteries that the transit network said posed a serious fire risk.[143] In addition, a defective charging system meant that some of the buses could not be charged, and a third-party certification officer wouldn't certify the chargers.[144] Ultimately, the buses were never approved by the FTA for operation, and within months of the vehicles' arrival in Albuquerque, officials announced they were pulling out of the deal and demanded that BYD remove all of their buses and charging infrastructure from the city.[145] Albuquerque subsequently sued BYD claiming breach of contract, breach of warranty, fraudulent and negligent misrepresentation and violations of New Mexico's Unfair Practices Act.[146]

Several explanations have been proposed for the substandard performance of Albuquerque's buses. One possible reason the battery life failed to match BYD's claims is the gradient of the routes. Central Avenue has a roughly 1,000-foot elevation change, and whereas other cities have sought ways of accommodating the technology to their specific geography (Vancouver's TransLink, for example, installed extra layover facilities with rapid chargers ensuring sufficient charge is maintained for reliable and continuous service), ABQ RIDE did not take into account the need for special facilities.[147] A study of the BYD buses conducted by the Center for Transportation and the Environment over the course of their testing in Albuquerque found that the operational plan developed for ART (running the vehicles during the day and returning them to the depot for recharging overnight, as opposed to incorporating on-route charging) would not have worked for the vehicles BYD delivered to Albuquerque, even if these vehicles had been working at full design capacity. To deploy these buses successfully would require modifications to scheduling or the addition of on-route charging.[148]

It is also clear from other cities' experiences with the company's buses that BYD's batteries are highly sensitive to fluctua-

Albuquerque Rapid Transit construction on Central Avenue. Credit: samat k jain via Flickr, CC BY-SA 2.0.

tions in temperature.[149] In Albuquerque, the problem arose from their sensitivity to heat, leading to reduced range during the summer months when the batteries would overheat.[150] During testing of similar BYD buses in Indianapolis, which took delivery of a batch around the same time as Albuquerque, similarly lower-than-expected distances per charge were linked to low outside temperatures.[151] In Indianapolis, in order to fulfil its contractual obligation of a 275-mile range, BYD has agreed to install wireless chargers along the vehicles' routes at no extra cost to the city.[152] Experts familiar with BYD's buses note that their range will drop dramatically in response to weather and other external conditions, and also with the addition of weight, since increased strain on the motors requires more battery power.[153]

Under Albuquerque's contract with BYD, the city was not required to pay any of the $22 million owed under the terms of the original agreement until the buses passed inspection. Consequently, the city never paid BYD and has since used the funds to order a consignment of diesel buses from New Flyer.[154] Approximately $6 million of the federal funding for ART was conditional on the buses being fully electric, and the city has been in talks with the FTA about setting these funds aside for another purchase of electric buses sometime in the future.[155] Officials say they are hopeful that the $3 million the city has already invested in upgrading the electricity system at Transit Department's Daytona Facility in preparation for an electric bus rollout can still be used in a future deployment of electric buses for the city of Albuquerque.[156]

Indeed, despite early difficulties with electric buses, in August 2019 Albuquerque announced its intention to relaunch its electric bus effort with a purchase of five new 40-foot electric buses for use on routes across the city. While the issues with the battery technology of 60-foot vehicles like those deployed in the ART rollout remain unresolved, city authorities are optimistic that it's just a matter of time before these challenges are overcome and the city can start phasing in those buses as well.[157] In the meantime, the new 40-foot electrics could be on the streets of Albuquerque within a year.

TWIN RIVERS, CALIFORNIA

Electric buses prove their worth in the first electric school bus rollout.

In 2017, the Twin Rivers Unified School District Transportation Department in Northern California became one of the first school districts in the country to deploy zero-emission electric school buses. The district, which serves 52 school sites in the Sacramento region, currently has 25 electric buses in its fleet, and plans to add 10 more in the near future.[158]

Twin Rivers worked with two other school districts to win funding for electric buses as part of a 2016 pilot project led by the California Air Resources Board and the Sacramento Air Quality Management District (AQMD). Twin Rivers was awarded a $7 million pilot to purchase 16 buses through the program.[159] Eight of these are electric Lion buses and eight are Motiv-powered Trans Tech electric buses.[160] In 2018, with further grant money plus just over $900,000 from the district, the agency received another nine vehicles – five Blue Birds and four more e-Lions, all currently being prepared for deployment – bringing its total electric fleet to 25.[161]

Twin Rivers USD's school board and superintendent have been enthusiastic about the project from the beginning, seeing the benefits both in creating clean air for the district's children and community and in immediate cost savings resulting from the grants. The average electric bus purchased by Twin Rivers cost around $400,000, of which the district pays between $60,000 and $100,000.[162]

Upfront costs for the first buses and charging infrastructure were met by $7.5 million in grants from CARB through California Climate Investments, a statewide program using proceeds from the state's cap-and-trade program. Additional funds came from the California Energy Commission and the local AQMD.[163] The district has also worked closely with Sacramento Municipal Utilities District (SMUD), through which it secured a rate structuring deal giving the district a preferential electricity rate.[164] SMUD also provided a $1 million investment in new charging infrastructure.[165]

Fuel costs for both the e-Lion and Trans Tech buses are between $0.16 and $0.19 per mile, versus the $0.82-$0.86 it costs to fuel the diesel buses: a 75-80 percent savings.[166] This far exceeds the district's most optimistic expectation of a 60 percent savings.[167] Total savings equate to approximately $15,000 per year on energy and maintenance costs.[168] As drivers learn to operate the vehicles more efficiently, these savings are expected to increase.[169]

In the early stages of the rollout the district experienced a few minor infrastructure issues. A delay getting power to the site led to a slight delay in deployment, for instance, and blown fuses in the smart chargers forced the district to send the chargers back to the manufacturers to be fixed. (Originally designed for car charging, the chargers required an upgrade to be able to charge a larger vehicle). Batteries also occasionally failed to sync correctly and some headlight bulbs burned out (this issue is now fixed). With these exceptions, the e-Lions have experienced very few problems, and the district's Director of Transportation Tim Shannon stressed that Lion has been responsive in fixing those issues that have arisen.[170]

The rollout of the Trans Tech buses was rockier, Shannon reports. These vehicles are powered by sodium-nickel batteries, which, if they go cold, take two days to warm up to the point where they are functional again. One issue the district encountered was a problem (which the manufacturers now believe they have solved) with the 12 volt battery that keeps the nickel batteries warm. It also emerged that use of the onboard heaters creates a slight drain on the systems, which again, the manufacturers are currently working to address. The district is also working to solve a problem with equipment that manages overnight charging, instead charging the vehicles on-demand for the time being. Energy costs are already low ($0.10 per kW/h), but will be reduced further once the managed charging infrastructure is in place.[171]

A Twin Rivers USD e-Lion bus. Credit: Frontier Group staff.

Range has never posed a significant problem for the Twin Rivers buses. In the two instances where buses have gone dead on-route, the problem was due to driver error. All of the vehicles were initially earmarked as route buses only and have been highly successful in that role, Shannon says, but as time has gone on, it has become a source of some frustration that they can't be used for longer trips (e.g., field trips). To allow for a wider range of potential uses, the district is planning to acquire several Lion 155-mile range buses currently in development.[172]

Shannon emphasizes that none of the problems Twin Rivers has faced in its electric bus rollout have been insurmountable. Manufacturers have been responsive in fixing any bugs that have arisen, and with the district's own mechanics becoming more skilled in the technology and Lion based nearby in Sacramento, Shannon dismisses the early issues as minor teething problems. In terms of cost savings and reliability, he says, the buses have been extremely successful. Public feedback, too – including from students – has been positive, and the district plans to add more electric school buses as soon as funding is available. Electric buses, according to Shannon, can outperform diesels, while also reducing labor costs, providing long-term savings that far outweigh the higher upfront costs.

MASSACHUSETTS

Mixed results in three school districts provide lessons for the future.

In 2015, the Massachusetts Department of Energy Resources (DOER) initiated a pilot project designed to explore the potential of electric vehicle technology for school transportation. Electric school buses had at that point only been deployed in small numbers and in warm environments. The Massachusetts pilot was the first to test the technology in a cold climate. Three electric buses were deployed at three school districts across Massachusetts (Amherst, Concord and Cambridge) and their performance was monitored over a period of a year by consulting group Vermont Energy Investment Corporation (VEIC). Based on data collected between February 2017 and February 2018, VEIC's evaluation showed that the vehicles could indeed operate successfully in cold weather environments, but it also noted several problems which suggested that more real-world experience with electric school buses would be needed before this technology could be deployed on a national level in school transportation services.[173]

The pilot project was funded by approximately $2 million in grants through the Regional Greenhouse Gas Initiative (RGGI) and was administered by the DOER. The districts were each awarded grants of up to $400,000 for the purchase of buses and chargers from Canadian manufacturer Lion.[174] These were the first electric buses sold by Lion in the United States. DOER and VEIC's work on the pilot spanned a three-year period from April 2015 to March 2018. The buses were ordered over the summer of 2016 and started to arrive in Massachusetts at the end of 2016, entering into service at the beginning of 2017, from which point VEIC collected performance data for a period of 12 months.

The vehicles generated a great deal of interest and enthusiasm among students, parents and school staff. From an environmental standpoint, the buses performed well. Based on lifecycle emissions, over the course of the pilot they emitted less than half the greenhouse gases of diesel school buses, and considerably lower levels of other harmful pollutants, such as volatile organic compounds (VOCs), carbon monoxide, nitrogen oxides and sulfur oxides. The vehicles had no difficulties with range, and cold weather did not have an impact on their performance. They operated well across a range of temperatures (0°F-75°F), with no significant impact on range.[175]

However, VEIC's evaluation highlighted a number of issues that prevented them from viewing the pilot as an unqualified success.[176] The buses spent a relatively large number of days out of service compared to the average diesel bus, with various maintenance problems ranging from relatively minor glitches, such as faulty headlights, to more significant issues, such as one instance of a battery pack failure and another in which a bus needed to be towed home due to problems with its central computer system. These issues were resolved with telephone support from Lion to the school districts' mechanics as well as site visits from the manufacturer's technicians. Lion was also eventually able to access the buses' computer systems remotely, which helped significantly in the process of identifying and repairing problems. All of the problems the districts encountered were covered by the vehicles' warranty and costs were met by Lion.

Another disappointing finding from the evaluation was that energy cost savings were considerably smaller than expected. In the initial proposal, Lion projected its vehicles' operating efficiency to be 1.3-1.4 kWh/mile. In reality, usage per mile was higher, at 2.38 kWh/mile. VEIC noted that the buses' operating efficiency was inversely proportional to charging duration: the longer they were plugged in, the more energy they used, attributable in part to high 'vampire loads' associated with the auxiliary fans and heaters used to heat or cool batteries during charging. A charging duration of 10 hours or more (such as over weekends and school vacations) could more than double the buses' per-mile energy use, from around 1.5 kWh/mile to more than 3 kWh/mile. VEIC concluded that this could be alleviated through the use of a managed charging system, which would allow the buses to remain plugged in for extended periods without actually charging the battery for more than the 6-8 hours usually required. Such a system would significantly increase the buses' operating efficiency.

The buses also did not deliver the anticipated savings on fuel costs, something which the evaluation again attributed to unmanaged charging of batteries, as well as excess electricity usage and demand charges. The VEIC study recorded an overall operating efficiency of 2.38 kWh/mile over the 12-month pilot period, and total energy costs of $7,240, versus an estimated $4,413 for equivalent mileage in a diesel bus. Nearly the entire difference in costs ($2,608) consisted of electricity demand charges. VEIC emphasizes that these charges can be avoided. Based on the vehicles' minimum range and typical daily mileage, the evaluation argues that it should not have been necessary to recharge them during peak demand hours. Had electricity usage been spread out more evenly throughout the day and had the buses been configured to not use any energy during peak times and draw power from the chargers only for as long as necessary to recharge the battery, this would have avoided $2,608 in demand charges and $1,549 in unnecessary spending on electricity, bringing total energy costs down to $3,083 – a 63 percent reduction compared with actual electricity spending during the program and a significant reduction in fuel costs compared with a diesel bus.

While the VEIC study was clear that electric school buses were at that time still very much an emerging technology, the project provided valuable lessons about how to deal with the challenges that arose, as well as how to improve energy savings and minimize fuel costs. Many of these issues are problems that agencies trialing electric bus technology in other areas of the country have encountered and overcome, and the VEIC evaluation of the pilot suggested straightforward ways that the issues can be dealt with.[177]

Moreover, all three school districts chose to keep their buses after the pilot. Amherst, despite some misgivings over reliability, negotiated new terms with Lion including additional customer support and extensions on vehicle warranties. At the conclusion of the evaluation, Cambridge and Concord had no concerns about the buses' reliability and were enthusiastic about their future with electric bus technology, and both were working with the Massachusetts DOER to find ways of servicing the vehicles using local expertise (being based 4-5 hours away in Quebec, Lion was not always able to provide help as quickly as the districts would have liked during the pilot). Concord, whose major issue was that the limited range of the buses meant that they couldn't be used for field trips or other longer-distance travel, has expressed an interest in purchasing more electric buses if funding were to become available and extra charging infrastructure could be installed.

Conclusions and recommendations

EARLY PILOT PROJECTS show that electric buses can deliver clean, efficient, cost-effective transportation to the millions of Americans who rely on buses to get to work, school, shopping or recreation. There have been challenges and setbacks – each of which provides important lessons for future electric bus deployments. But in the majority of places where they have been tested, electric buses have met or exceeded expectations, functioning successfully in a broad range of climates and types of terrain and often delivering significant cost savings.

Early adopters, however, have experienced a set of technological and economic hurdles that future electric bus programs will need to overcome in order to bring electric buses to scale quickly, and deliver the promised benefits for public health and the environment. The following policies and actions can help make this happen:

- States, cities, towns and school districts should commit to a full transition to electric buses on a specific timeline. These commitments will help grow the market, drive technological innovation, and enable transit agencies and school districts to gain the benefits of economies of scale in maintenance facilities and other infrastructure, operational experience, and electricity pricing.
- States should provide grant programs and subsidies for agencies to go electric. This will ensure agencies and the communities they serve will experience the benefits of electric buses without additional financial burdens being placed on the agencies or on transit riders. Funds raised through carbon cap-and-invest programs (such as California's program and the Transportation and Climate Initiative currently under consideration in the Northeast and Mid-Atlantic) or carbon taxes could help facilitate the transition to zero-emission electric buses.
- Public officials and utilities should encourage the creation of financing programs in which utilities front the initial investment for electric buses and allow cities and school districts to pay back on utility bills as they save on fuel and maintenance costs. These "pay as you save" financing programs can help agencies overcome the higher upfront costs of electric buses and deliver monetary savings immediately.
- Public officials and utilities should restructure electric rates so as to provide discounted off-peak charging, limit excessive demand charges, and experiment with policies and practices that allow the buses to be used for energy storage and employ vehicle-to-grid technology.

Transit agencies and school districts considering electric bus deployments should:

- Establish solid collaborative partnerships with utilities from an early stage and open a dialogue about goals and interests from the outset. Agencies should work with public officials and local utilities to enact a transportation rate for electricity and use rate modeling in the planning process for launching electric bus service.
- Ensure the contract with the bus manufacturers includes provisions to guarantee protection in the event that the vehicles delivered do not perform as promised.
- Be realistic about the capabilities of electric buses for particular routes and conditions, and study route modeling data to determine the appropriate type of bus for the route, (i.e., quick charge or extended range buses). The type of bus deployed and the charging infrastructure used may vary with factors including the round-trip mileage of the route, the total daily mileage of the buses, the topography of the route, the route schedule, and the possible location of charging stations.
- Before going to bid, have electric buses from different vendors shadow existing diesel buses and ensure that the bid includes the needs identified in the route study.
- Invest in as large a fleet as possible as soon as proof of concept can be established. Ensure the availability of additional electrical capacity and build the infrastructure to be able to add more chargers, including on-route charging infrastructure. The larger the fleet, the greater its visibility, and the greater the opportunity to demonstrate the vehicles' functionality and desirability.
- Acquire as much data as possible from agencies already using the technology. Ask agencies where they've been successful, where they've failed, and where they've worked with manufacturers and utilities to find solutions to issues that have arisen. Talk to multiple agencies of different sizes about their experiences and find the closest comparators.
- Include environmental and health benefits in any evaluation of the costs and benefits of electric buses. Calculations of return on investment should include the total societal cost for the life cycle of an electric bus versus a diesel bus.

Notes

1. Vermont Energy Investment Corporation, *Electric School Bus Pilot Project Evaluation*, 20 April 2018, archived at http://web.archive.org/web/20190920175702/https://www.mass.gov/files/documents/2018/04/30/Mass%20DOER%20EV%20school%20bus%20pilot%20final%20report_.pdf.

2. Emissions savings calculated using Argonne National Laboratory's Heavy-Duty Vehicle Emissions Calculator available at https://afleet-web.es.anl.gov/hdv-emissions-calculator.

3. Ron Barnett, "S.C. City Boasts First Battery-Operated Bus Fleet" *USA Today*, 27 February 2015.

4. Keith Moody, General Manager, Clemson Area Transit, personal communication, 3 July 2019.

5. Chicago Transit Authority, *CTA Expands Electric Bus Fleet*, archived at https://web.archive.org/web/20190920232250/https://www.transitchicago.com/cta-expands-electric-bus-fleet/, 15 July 2019

6. Global Mass Transit, *Chicago city approves plan to transition to 100 per cent electric bus fleet*, 15 April 2019, archived at https://web.archive.org/web/20190920234018/https://www.globalmasstransit.net/archive.php?id=33960.

7. Rob Gannon, General Manager, King County Metro, personal communications, 12 July 2019.

8. Susan Orr, "IndyGo OK So Far With Electric Buses, Despite Albuquerque Woes," *Indianapolis Business Journal*, 21 November 2018; Martin Salazar, "ART Project 'A Bit of a Lemon,' Mayor Says as Problems Mount," *Albuquerque Journal*, 9 January 2018; Steve Knight, "Albuquerque's Electric Buses Grounded After Malfunctions," *Government Technology*, 2 November 2018, archived at http://web.archive.org/web/20190212085931/http://www.govtech.com:80/fs/transportation/Albuquerques-Electric-Buses-Grounded-After-Malfunctions.html. Elliott Zaagman, "Briefing: Albuquerque Cancels Deal with BYD Over Bus Quality Issues," *Tech Node*, 19 November 2018, archived at https://web.archive.org/web/20190925014649/https://technode.com/2018/11/19/briefing-albuquerque-cancels-deal-with-byd-over-bus-quality-issues/.

9. Theresa Davis, "City Gets $2.7 Million Grant for Electric Buses," *Albuquerque Journal*, 7 August 2019.

10. Twin Rivers Unified School District, "Electric Vehicles," archived at https://web.archive.org/web/20190920231520/http://www.twinriversusd.org/Students--Families/Transportation-Services/Electric-Vehicles-/index.html.

11. Lion Electric Bus Company, "School Buses Going 100% Electric? Just Common Sense," *School Transportation News*, 1 May 2019 (sponsored content).

12. Vermont Energy Investment Corporation, *Electric School Bus Pilot Project Evaluation*, 20 April 2018, archived at http://web.archive.org/web/20190920221318/https://www.mass.gov/files/documents/2018/04/30/Mass%20DOER%20EV%20school%20bus%20pilot%20final%20report_.pdf.

13. Alexander Winton, "Get a Horse!," *The Saturday Evening Post*, Vol. 202, No. 32, 8 February 1930, 39.

14. American Public Transportation Association, *Transit Ridership Report: Fourth Quarter 2018,* archived at https://web.archive.org/web/20190630010014/https://www.apta.com/wp-content/uploads/2018-Q4-Ridership-APTA-3.pdf.

15. National School Transportation Association, *The Yellow School Bus Industry,* 2013, available at https://s3-us-west-2.amazonaws.com/nsta/6571/Yellow-School-Bus-Industry-White-Paper.pdf.

16. Andrea L. Roberts, et al., "Perinatal Air Pollutant Exposures and Autism Spectrum Disorder in the Children of Nurses' Health Study II Participants," *Environmental Health Perspectives,* 121(8): 978-984, August 2013, DOI: 10.1289/ehp.1206187.

17. U.S. EPA, *Sources of Greenhouse Gas Emissions*, accessed at https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions, 27 July 2019.

18. EB Start, *Electric Bus Industry Continues to Make Strides in 2018* (press release), 31 January 2019, archived at https://web.archive.org/web/20190920232712/https://www.ebstart.co/press-release-1-31-2019; Hexa Research, "Electric Bus Market Size and Forecast, By Product (Purely Electric, Plug-in Hybrid), By Region (China, Europe, U.S.), And Segment Forecast, 2015-2025," archived at https://web.archive.org/web/20190606005806/https://www.hexaresearch.com/research-report/electric-buses-market.

19. School buses: Robert Pudlewski, "When Will Alt-Fuels Replace Diesel, Gas Powered School Buses?" *School Transportation News*, 13 April 2017, archived at https://web.archive.org/web/20180217002454/http://stnonline.com/news/latest-news/item/8512-when-will-alt-fuels-replace-diesel-gas-powered-school-buses; Transit buses: American Public Transportation Association, *2019 Public Transportation Factbook*, accessed at https://www.apta.com/wp-content/uploads/APTA_Fact-Book-2019_FINAL.pdf, 27 July 2019.

20. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, "Health Effects of Diesel Exhaust," 21 May 2001, accessed at https://oehha.ca.gov/air/health-effects-diesel-exhaust, 30 September 2019.

21. U.S. Environmental Protection Agency, *Integrated Risk Information System: Diesel Engine Exhaust*, 28 February 2003.

22. Lung cancer: Debra T. Silverman, "Diesel Exhaust Causes Lung Cancer – Now What?" *Occupational Environmental Medicine*, 74(4): 233-234, DOI: 10.1136/oemed-2016-104197, 2017; Bladder cancer: L. Latifovic et al., "Bladder Cancer and Occupational Exposure to Diesel and Gasoline Engine Emissions Among Canadian Men," *Cancer Medicine*, 4(12): 1948-62, DOI: 10.1002/cam4.544, 2015.

23. C. Li et al., "School Bus Pollution and Changes in The Air Quality at Schools: A Case Study," *Journal of Environmental Monitoring*, 11(5), 1037-1042, DOI: 10.1039/b819458k, 2009.

24. Carbon: S. Steiner et al., "Diesel Exhaust: Current Knowledge of Adverse Effects and Underlying Cellular Mechanisms," *Archives of Toxicology*, 90(7), 1541-1553, DOI: 10.1007/s00204-016-1736-5, 2016. Metal and oxides: A. Mayer et al., "Metal-Oxide Particles in Combustion Engine Exhaust," *SAE International,* DOI: 10.4271/2010-01-0792, 2010, available at http://papers.sae.org/2010-01-0792/; Nickel: K.L. Cheung et al., "Emissions of Particulate Trace Elements, Metals and Organic Species from Gasoline, Diesel, and Biodiesel as Passenger Vehicles and Their Relation to Oxidative Potential," *Aerosol Science and Technology,* 44(7), 500-513, DOI: 10.1080/02786821003758294, 2010.

25. See note 23.

26. İbrahim Aslan Reşitoğlu, Kemal Altinişik, and Ali Keskin, "The Pollutant Emissions from Diesel-Engine Vehicles and Exhaust Aftertreatment Systems," *Clean Technologies and Environmental Policy,* 17(1):15-27, January 2015; Jo-Yu Chin et al., "Gaseous and Particulate Emissions from Diesel Engines at Idle and under Load: Comparison of Biodiesel Blend and Ultralow Sulfur Diesel Fuels," *Energy & Fuels* 26(11):6737-6748, 2012, DOI: 10.1021/ef300421h.

27. Qian Di et al., "Air Pollution and Mortality in the Medicare Population," *The New England Journal of Medicine,* 376:2513-2522, DOI: 10.1056/NEJMoa1702747, 29 June 2017.

28. S. Steiner et al., "Diesel Exhaust: Current Knowledge of Adverse Effects and Underlying Cellular Mechanisms," *Archives of Toxicology,* 2016, available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4894930/; Damian Carrington, "Toxic Air Pollution Particles Found in Human Brains," *The Guardian*, 5 September 2016.

29. Centers for Disease Control and Prevention website, "Protect Yourself from Wildfire Smoke," accessed at https://www.cdc.gov/features/wildfires/index.html, 12 January 2018.

30. Alana Miller and Hye-Jin Kim, Frontier Group, and Jeffrey Robinson and Matthew Casale, U.S. PIRG Education Fund, *Electric Buses: Clean Transportation for Healthier Neighborhoods and Cleaner Air*, May 2018.

31. K. Nadeau et al., "Ambient Air Pollution Impairs Regulatory T-cell Function in Asthma*," Journal of Allergy and Clinical Immunology, 126(4):845-852, October 2010.*

32. See note 23.

33. K.J. Brunst et al., "Forkhead Box Protein 3 (FOXP3) Hypermethylation is Associated with Diesel Exhaust Exposure and Risk for Childhood Asthma," *Journal of Allergy And Clinical Immunology,* 2013, available at https://www.jacionline.org/article/S0091-6749(12)01763-0/fulltext.

34. Ibid.

35. N. Ji et al., "Personal Exposure to Black Carbon, Nitrogen Dioxide, and Chronic Psychosocial Stress: Impacts on Childhood Asthma Exacerbation in a Seaport-Adjacent Community," *American Journal of Respiratory and Critical Care Medicine,* 2017, available at http://www.atsjournals.org/doi/abs/10.1164/ajrccm-conference.2017.195.1_MeetingAbstracts.A4803.

36. U.S. EPA, *Sources of Greenhouse Gas Emissions*, archived at https://web.archive.org/web/20190920202909/https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions, 27 July 2019.

37. See note 2.

38. See note 2. Emissions are lower in areas with cleaner electricity grids. Therefore, as grids across the country transition to renewable sources, emissions will drop.

39. Jimmy O'Dea, Union of Concerned Scientists, *Electric vs. Diesel vs. Natural Gas: Which Bus is Best for the Climate?,* 19 July 2018, archived at https://web.archive.org/web/20190920232331/https://blog.ucsusa.org/jimmy-odea/electric-vs-diesel-vs-natural-gas-which-bus-is-best-for-the-climate?.

40. Ibid.

41. A natural gas bus produces 2,364 grams carbon dioxide equivalent (CO2e) per mile and a diesel-hybrid 2,212 grams CO2e per mile. An electric bus, charged with the national electricity mix, produces 1,078 grams CO2e per mile. See note 39.

42. See note 30. Variations in emissions reductions are the result of state electricity mixes. See Appendix A for emissions savings projections for America's 50 largest transit agencies.

43. Michael Coren, "An Electric Bus Just Snagged A World Record by Driving 1,100 Miles on A Single Charge," *Quartz*, 19 September 2017, archived at https://web.archive.org/web/20180215170252/https://qz.com/1078326/an-electric-bus-just-snagged-a-world-record-by-driving-1100-miles-on-a-single-charge.

44. Clinton Global Initiative V2G EV School Bus Working Group, *ZEV School Buses – They're Here and Possibly Free* (presentation), 22 April 2016, archived at https://web.archive.org/web/20190920204622/https://green-technology.org/gcsummit16/images/35-ZEV-School-Buses.pdf.

45. New Flyer of America, *Country's Largest Transit Bus System on Electric Buying Spree* (press release), 17 October 2017, archived at https://web.archive.org/web/20180215195104/https://www.newflyer.com/2017/10/countrys-largest-transit-bus-system-electric-buying-spree.

46. Ibid.

47. See note 43.

48. Ibid.

49. Jacobs Engineering, "Powering the Future: Electrifying and Expanding the MBTA Bus Network," 2019, available at https://www.abettercity.org/assets/images/8.7.19%20Powering%20the%20Future%20Presentation.pdf.

50. See note 44. The pilot was conducted in Torrance Unified School District, Napa Valley Unified School District, and Edison School District (Bakersfield).

51. See note 44.

52. See note 30. See note 44; Age: Thomas McMahon, School Bus Fleet, *Maintenance Survey,* 2017, available at: http://files.schoolbusfleet.com/stats/SBF0317-MaintenanceSurvey.pdf.

53. Proterra, *The Proterra Catalyst 40-Foot Transit Vehicle,* accessed 15 February 2018, archived at https://web.archive.org/web/20180225060718/https://www.proterra.com/products/catalyst-40ftold/.

54. California Air Resources Board, *Literature Review on Transit Bus Maintenance Cost (Discussion Draft)*, August 2016.

55. California Air Resources Board, *5th Innovative Clean Transit Workgroup Meeting* (presentation – slide 40), 26 June 2017, available at https://ww3.arb.ca.gov/msprog/ict/meeting/mt170626/170626_wg_pres.pdf.

56. California HVIP, *Truck and Bus Voucher Incentives*, archived at https://web.archive.org/web/20190920210006/https://www.californiahvip.org/wp-content/uploads/2019/05/HVIP-Overview-May-2019.pdf, 27 July 2019.

57. Jim Reynolds, Adomani, and Robert Lupacchino, First Priority GreenFleet, *Benefits of Electric School Buses* (presentation), 20 July 2016.

58. Federal Transit Administration, "Fiscal Year 2019 Low or No-Emission (Low-No) Bus Program Projects," archived at https://web.archive.org/web/20190920232535/https://www.transit.dot.gov/funding/grants/fiscal-year-2019-low-or-no-emission-low-no-bus-program-projects.

59. Traffic21 Institute and Scott Institute for Energy Innovation, Carnegie Mellon University, *Which Alternative Fuel Technology Is Best for Transit Buses?,* January 2017.

60. Kyle Field, "No Need To Wait: Electric Buses Are Cost-Competitive Transit Buses Today," *Clean Technica*, 29 April 2018; Bluebird, "Blue Bird Unveils All-New, Electric-Powered Type C School Bus at NAPT Conference," *BusinessWire,* 7 November 2017, archived at https://web.archive.org/web/20180327193431/https://www.businesswire.com/news/home/20171107005511/en/Blue-Bird-Unveils-All-New-Electric-Powered-Type-School; Thomas: Thomas Built Buses, *Thomas Built Buses Debuts New Saf-T-Liner® C2 All Electric School Bus,* 4 November 2017, archived at https://web.archive.org/web/20180327193621/https://thomasbuiltbuses.com/bus-news-and-events/news/thomas-built-buses-debuts-new-saf-t-liner-2017-11-04.

61. Bloomberg NEF, *Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO_2* 29 March, 2018, archived at https://web.archive.org/web/20190920210558/https://data.bloomberglp.com/professional/sites/24/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf.

62. Gina Coplon-Newfield and Conner Smith, Sierra Club, *For U.S. Transit Agencies, the Future for Buses Is Electric,* 21 February 2019, archived at https://web.archive.org/web/20190920232607/https://www.sierraclub.org/articles/2019/02/for-us-transit-agencies-future-for-buses-electric#.

63. İbrahim Aslan Reşitoğlu, et al., "The Pollutant Emissions from Diesel-Engine Vehicles and Exhaust Aftertreatment Systems," *Clean Technologies and Environmental Policy,* 17(1):15-27, January 2015.

64. Chicago Transit Authority, *Electric Bus,* archived at https://web.archive.org/web/20180206213131/http://www.transitchicago.com/electricbus.

65. Judah Aber, Columbia University, *Electric Bus Analysis for New York City Transit*, May 2016.

66. EB Start, *Electric Bus Industry Continues to Make Strides in 2018* (press release), 31 January 2019, archived at https://web.archive.org/web/20190920232712/https://www.ebstart.co/press-release-1-31-2019.

67. Ibid.

68. Ibid.

69. Ibid.

70. Research and Markets, "The United States Electric Bus Market, Forecast to 2024," 26 March 2019, archived at https://web.archive.org/web/20190920232811/https://www.globenewswire.com/news-release/2019/03/26/1768571/0/en/The-United-States-Electric-Bus-Market-Forecast-to-2024-BEB-Estimated-to-See-the-Fastest-Growth-in-the-Future-Because-of-Declining-Battery-Prices-and-Growing-Range-of-Such-Buses.html; Index Markets Research, *School Bus Market Research: Global Status & Forecast by Geography, Type & Application (2015-2025)*, 23 May 2019, available at https://www.indexmarketsresearch.com/report/school-bus-market/194246/#details; Motiv, *Trans Tech Bus and Motiv Power Systems Partner on New All-Electric School Bus* (press release), 22 October 2013, available at http://www.motivps.com/motivps/pressreleases/trans-tech-bus-and-motiv-power-systems-partner-on-new-all-electric-school-bus/.

71. Sustainable Bus, *U.S. Electric Bus Market to Grow 18.5% Yearly Till 2024*, 28 February 2019, archived at http://web.archive.org/web/20190711182449/https://www.sustainable-bus.com/news/u-s-electric-bus-market-to-grow-18-5-yearly-till-2024/.

72. Adele Peters, "California Just Decided to Move to 100% Electric City Buses," *Fast Company*, 14 December 2018, archived at https://web.archive.org/web/20190920232846/https://www.fastcompany.com/90281612/california-just-decided-to-move-to-100-electric-city-buses.

73. Joe Linton, "L.A. City Approves Full LADOT Transit Electrification by 2030," *StreetsBlog LA*, 9 November 2017, archived at http://web.archive.org/web/20190808082601/https://la.streetsblog.org/2017/11/09/l-a-city-approves-full-ladot-transit-electrification-by-2030/.

74. EB Start, *Electric Bus Industry Continues to Make Strides in 2018* (press release), 31 January 2019, archived at http://web.archive.org/web/20190920211007/https://www.ebstart.co/press-release-1-31-2019, 8 July 2019.

75. Phil McKenna, “New York City Aims for All-Electric Bus Fleet by 2040,” *Inside Climate News*, 26 Aril 2018, archived at http://web.archive.org/web/20190816110304/https://insideclimatenews.org/news/26042018/nyc-air-pollution-electric-bus-public-transportation-mta-clean-technology.

76. New York Metropolitan Transportation Authority, *MTA Testing 10 New, All-Electric Buses to Reduce Emissions & Modernize Public Transit Fleet*, 8 January 2018, archived at https://web.archive.org/web/20190701224524/http://www.mta.info/news/2018/01/08/mta-testing-10-new-all-electric-buses-reduce-emissions-modernize-public-transit; CleanTechnica, *New York City Adds to its Zero-Emission Fleet: 15 New Flyer, Low Floor 60-Foot Xcelsior CHARGE Battery-Electric Transit Buses* (press release), 25 March 2019, archived at https://web.archive.org/web/20190920233010/https://cleantechnica.com/2019/03/25/new-york-city-adds-to-its-zero-emission-fleet-15-new-flyer-low-floor-60-foot-xcelsior-charge-battery-electric-transit-buses/.

77. Proterra, *Washington D.C. Circulator Deploys Proterra® Battery-Electric Buses Across Nation’s Capital* (press release), 20 April 2018.

78. Virginia Streva, “SEPTA Releases 25 New Electric Buses for South Philly Routes,” *Philly Voice*, 9 June 2019.

79. Ed Blazina, “Port Authority Getting First Electric Buses, considering fleet for Downtown-Oakland rapid transit,” *Pittsburgh Post-Gazette*, 17 January 2019.

80. Karen Zamora, “Minneapolis’ Metro Transit to Add Electric Buses in 2019,” *Minneapolis Star Tribune,* 26 September 2017; “Metro Transit Puts Electric Buses into Service on New C-Line,” *KSTP,* 8 June 2019, archived at https://web.archive.org/web/20190609185929/https://kstp.com/news/metro-transit-new-c-line-buses-fully-electric/5382548/.

81. Mischa Wanek-Libman, “NJ Transit to Pilot Electric Bus Program with VW Settlement Funds,” *Mass Transit*, 4 March 2019.

82. Colorado Department of Transportation, *Transit Buses in Colorado Get Cleaner Through VW Settlement*, 18 April 2019, archived at https://web.archive.org/web/20190920233048/https://www.codot.gov/news/2019/april/transit-buses-in-colorado-get-cleaner-through-vw-settlement.

83. Metro Magazine, *BYD Delivers 3 Electric Buses to Md. Transit Agency*, 20 April 2017, archived at https://web.archive.org/web/20190930222124/https://www.metro-magazine.com/sustainability/news/722078/byd-delivers-3-electric-buses-to-md-transit-agency; Samantha Hogan, “Maryland Invests in Electric Buses to Reduce Diesel Emissions,” *Government Technology*, 25 February 2019, accessed at https://www.govtech.com/fs/transportation/Maryland-Invests-in-Electric-Buses-to-Reduce-Diesel-Emissions.html.

84. Sustainable Bus, *U.S. Electric Bus Market to Grow 18.5% Yearly till 2024*, 28 February 2019, archived at https://web.archive.org/web/20190920233156/https://www.sustainable-bus.com/news/u-s-electric-bus-market-to-grow-18-5-yearly-till-2024/.

85. See note 11.

86. Susan Carpenter, “Can Electric School Buses Make the Grade?,” *Trucks.com*, 22 March 2019, archived at https://web.archive.org/web/20190920233235/https://www.trucks.com/2019/03/22/can-electric-school-buses-make-the-grade/.

87. Vermont Energy Investment Corporation, *Electric School Bus Pilot Project Evaluation*, 20 April 2018, archived at https://web.archive.org/web/20190920221318/https://www.mass.gov/files/documents/2018/04/30/Mass%20DOER%20EV%20school%20bus%20pilot%20final%20report_.pdf.

88. Frank Jossi, “Minnesota District to Get Midwest’s First Electric School Bus This Fall,” *Midwest Energy News,* 11 July 2017; “Electric School Bus Fleet in NY State. Lion Electric Buses Will Be Used Also as Power Storage Unit,” *Sustainable Bus*, 4 December 2018, archived at https://web.archive.org/web/20190920233312/https://www.sustainable-bus.com/news/electric-school-bus-fleet-in-ny-state-lion-electric-buses-will-be-used-also-as-power-storage-unit/.

89. Dominion Energy, *Dominion Energy Proposes Largest Electric School Bus Initiative in the Country* (press release), 29 August 2019

90. Julie Young, “It’s Not the Size of the City That Counts,” *The Municipal*, 15 April 2017, archived at http://www.themunicipal.com/2017/04/its-not-the-size-of-the-city-that-counts/; Mass Transit, *Proterra and City of Seneca. S.C. Showcase Zero-Emission All-Electric Transit System Plans*, 21 July 2012, available at https://www.masstransitmag.com/home/press-release/10753585/proterra-proterra-and-city-of-seneca-sc-showcase-zeroemission-allelectric-transit-system-plans.

91. See note 4.

92. Ibid.

93. Betsy Lillian, “Clemson Area Transit Brings on Board More Proterra Electric Buses,” *NGT News*, 6 September 2017, archived at https://web.archive.org/web/20181202221449/https://ngtnews.com/clemson-area-transit-brings-board-proterra-electric-buses.

94. See note 4.

95. Julie Young, “It’s Not the Size of the City That Counts,” *The Municipal*, 15 April 2017, archived at https://web.archive.org/web/20170423015611/http://www.themunicipal.com/2017/04/its-not-the-size-of-the-city-that-counts/, 23 April, 2017.

96. See note 4.

97. Ibid.

98. Ibid.

99. Ibid.

100. Ibid.

101. Ibid.

102. National Academies of Sciences, Engineering, and Medicine, *Battery Electric Buses State of the Practice*, (Washington, DC: The National Academies Press, 2018), p. 68, available at https://web.archive.org/web/20190920221705/https://www.plugincanada.ca/wp-content/uploads/2019/02/25061.pdf.

103. Sustainable Race, *Seneca Ready to Test Electric Buses in Passenger Service*, 20 August 2014, archived at https://web.archive.org/web/20190920233558/https://sustainablerace.com/seneca-ready-test-electric-buses-passenger-service/16211/.

104. See note 95.

105. Chicago Transit Authority, *CTA Expands Electric Bus Fleet*, 13 June 2018, archived at http://web.archive.org/web/20190920192555/https://www.transitchicago.com/cta-expands-electric-bus-fleet/; Jon Hilkevitch, “CTA Testing 2 All-Electric Buses,” *Chicago Tribune*, 29 October 2014.

106. Chicago Transit Authority, *Electric Buses*, archived at https://web.archive.org/web/20190920233910/https://www.transitchicago.com/electricbus/.

107. Chicago Transit Authority, *CTA to Acquire Two Electric Buses for Testing and Research* (press release), 13 June 2012, available at https://www.transitchicago.com/cta-to-acquire-two-electric-buses-for-testing-and-research/.

108. Ibid.; See note 106.

109. Chicago Transit Authority, *CTA Expands Electric Bus Fleet*, 13 June 2018, archived at http://web.archive.org/web/20190920192555/https://www.transitchicago.com/cta-expands-electric-bus-fleet/.

110. See note 106.

111. Use of onboard electric heaters requires around 20 percent of the energy stored in the bus battery, causing a 15-20 percent reduction in the vehicle’s range. While diesel-fueled heaters allow an electric bus to retain its full range, they are sometimes controversial since they also produce greenhouse gas emissions, albeit a negligible amount compared to a diesel-powered bus. Diesel heaters are used only in the winter months and at most consume around 4 percent of the diesel used to power diesel buses. The heaters used in trials conducted for a 2016 electric bus feasibility study by consulting firm MARCON for the city of Edmonton in Canada consumed an average of around half a gallon of diesel per 100km (62 miles). The electric bus saves approximately 10-13 gallons per 100km compared to a diesel combustion engine. The MACRON study found that replacing a diesel bus with a diesel-heated, BYD trickle-charged electric bus would lead to a reduction of the carbon footprint of 60 percent over 20 years, while replacing a diesel bus with a diesel-heated, *en route*-charged NFI electric bus would reduce the GHG footprint by 56 percent over the same period. The use of diesel in electric bus heating systems has generally been seen as an interim solution, however, and with improvements in battery technology, the use of diesel heaters is likely to be phased out altogether in the near future: MARCON, *Electric Bus Feasibility Study for the City of Edmonton*, 2016; Thoralf Knote, Fraunhofer IVI Institute for Transportation and Infrastructure Systems, quoted in “Are Buses with a Diesel-Powered Heater True Zero-Emission Buses?,” ELIPTIC: *Electrification of Public Transport in Cities*, http://www.eliptic-project.eu/news/are-buses-diesel-powered-heater-true-zero-emission-buses, accessed 17 Aug 2019.

112. See note 106.

113. Metro Magazine, *Chicago Transit Awards Proterra $32M Order for Battery-Electric Buses*, 14 June 2018, archived at https://web.archive.org/web/20190930223002/https://www.metro-magazine.com/technology/news/730133/chicago-transit-awards-proterra-32m-order-for-battery-electric-buses.

114. See note 109.

115. See note 106.

116. See note 109.

117. See note 6.

118. See note 109.

119. King County Metro, *Metro is Building a Zero-Emission Fleet*, archived at https://web.archive.org/web/20190920224609/https://kingcounty.gov/depts/transportation/metro/programs-projects/innovation-technology/zero-emission-fleet.aspx.

120. See note 7.

121. Ibid.

122. King County, *Implementation Plan for a Carbon Neutral King County Government*, February 2019, archived at https://web.archive.org/web/20190920224925/https://www.kingcounty.gov/~/media/services/environment/climate/documents/190228-operational-carbon-neutral-plan.ashx?la=en.

123. U.S. Department of Energy, *King County Metro Battery Electric Bus Demonstration— Preliminary Project Results*, May 2017, archived at https://web.archive.org/web/20190920225044/https://afdc.energy.gov/files/u/publication/king_county_be_bus_preliminary.pdf; King County Metro, *Metro to Test Battery-Electric Buses*, Summer 2015, archived at https://web.archive.org/web/20190920225016/https://metro.kingcounty.gov/am/vehicles/battery-bus/battery-bus-fact-sheet-081715.pdf.

124. U.S. Department of Energy, *King County Metro Battery Electric Bus Demonstration— Preliminary Project Results*, May 2017, archived at https://web.archive.org/web/20190920225044/https://afdc.energy.gov/files/u/publication/king_county_be_bus_preliminary.pdf.

125. See note 7.

126. Ibid.

127. Federal Transit Administration, *Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses*, February 2018, archived at https://web.archive.org/web/20190920225147/https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/115086/zero-emission-bus-evaluation-results-king-county-metro-battery-electric-buses-fta-report-no-0118.pdf. Seasonal variation in outside temperatures had an impact on the buses' fuel economy (in the 2016 tests, the fuel economy of the battery fleet varied from a high of 17.6 miles per diesel gallon equivalent [mpdge] in September to a low of 13.3 mpdge in December). Average fuel economy remains significantly higher than Metro's diesel buses at 15.9 mpdge, vs. the diesels' 5.3 mpdge.

128. During the test period, Metro paid an average of $1.60 per gallon for diesel and $0.20/kWh, or $7.66/diesel gallon equivalent, for electricity.

129. Federal Transit Administration, *Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses*, February 2018, archived at https://web.archive.org/web/20190920225147/https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/115086/zero-emission-bus-evaluation-results-king-county-metro-battery-electric-buses-fta-report-no-0118.pdf.

130. Danny Ilioiu, Zero-Emissions Fleet Strategic Planning Manager, King County Metro, personal communication, 14 July 2019.

131. See note 129.

132. See note 7.

133. See note 130.

134. This calculation includes the costs associated with air pollutants, greenhouse gas emissions and noise pollution over the life-cycle of a bus: King County Metro, *Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet,* March 2017, archived at: https://web.archive.org/web/20190920230137/https://kingcounty.gov/~/media/elected/executive/constantine/news/documents/Zero_Emission_Fleet.

135. Federal Transit Administration, *Albuquerque Rapid Transit Project*, archived at https://web.archive.org/web/20190920230254/https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/funding/grant-programs/capital-investments/69926/nm-albuquerque-rapid-transit-project-fy19-profile.pdf.

136. Alon Levy, "The Verdict's Still Out on Battery-Electric Buses," *CityLab*, 17 January 2019, archived at https://web.archive.org/web/20190920230911/https://www.citylab.com/transportation/2019/01/electric-bus-battery-recharge-new-flyer-byd-proterra-beb/577954/.

137. Dan McKay, "City to Use Electric Buses for Rapid Transit," *Albuquerque Journal*, 13 July 2016, archived at https://web.archive.org/web/20190925011225/https://www.abqjournal.com/806990/electric-buses-to-be-used-for-art.html.

138. City of Albuquerque, *ART Announces Plan for Electric Buses*, archived at https://web.archive.org/web/20190920230948/https://www.cabq.gov/transit/news-events/news/albuquerque-rapid-transit-art-announces-plan-for-electric-buses.

139. Steve Knight, "Mayor Pulls the Plug on Electric Bus Deal," *Albuquerque Journal*, 13 November 2018; Alon Levy, "The Verdict's Still Out on Battery-Electric Buses," *CityLab*, 17 January 2019, archived at https://web.archive.org/web/20190920230911/https://www.citylab.com/transportation/2019/01/electric-bus-battery-recharge-new-flyer-byd-proterra-beb/577954/.

140. Susan Orr, "IndyGo OK So Far with Electric Buses, Despite Albuquerque Woes," *Indianapolis Business Journal*, 21 November 2018.

141. T.J. Wilham, "On Way Out of Town, ART Bus Breaks Down," *KOAT Action News*, 29 November 2018, archived at https://web.archive.org/web/20190920234110/https://www.koat.com/article/electric-art-buses-split-for-california-one-had-to-stop-early/25337413.

142. See note 140.

143. Ibid.; Martin Salazar, "ART Project 'A Bit of a Lemon,' Mayor Says as Problems Mount," *Albuquerque Journal*, 9 January 2018; Steve Knight, "Albuquerque's Electric Buses Grounded After Malfunctions," *Government Technology*, 2 November 2018, accessed at http://www.govtech.com:80/fs/transportation/Albuquerques-Electric-Buses-Grounded-After-Malfunctions.html. Elliott Zaagman, "Briefing: Albuquerque Cancels Deal with BYD Over Bus Quality Issues," *Tech Node*, 19 November 2018, archived at https://web.archive.org/web/20190925014649/https://technode.com/2018/11/19/briefing-albuquerque-cancels-deal-with-byd-over-bus-quality-issues/.

144. Martin Salazar, "ART Project 'A Bit of a Lemon,' Mayor Says as Problems Mount," *Albuquerque Journal*, 9 January 2018.

145. See note 140.

146. Maddy Hayden, "City Sues BYD Over ART Buses," *Albuquerque Journal*, 7 December 2018.

147. Alon Levy, "The Verdict's Still Out on Battery-Electric Buses," *CityLab*, 17 January 2019, archived at https://web.archive.org/web/20190920230911/https://www.citylab.com/transportation/2019/01/electric-bus-battery-recharge-new-flyer-byd-proterra-beb/577954/.

148. The Center for Transportation and the Environment, *Assessment of BYD K11 Battery Electric Bus Operation on the Albuquerque Rapid Transit (ART) Service*, 7 November 2018.

149. Phil Dzikiy, "BYD Installing Wireless Charging in Indianapolis to Boost Disappointing Range of its Electric Buses," *Elektrek*, 24 May 2019, archived at http://web.archive.org/web/20190602210918/https://electrek.co/2019/05/24/byd-indianapolis-electric-bus-range/. See also: Paige St. John, "Stalls, Stops and Breakdowns: Problems Plague Push for Electric Buses," *Los Angeles Times*, 20 May 2018.

150. Steve Knight, "Mayor Pulls the Plug on Electric Bus Deal," *Albuquerque Journal*, 13 November 2018.

151. Ethan May and Kellie Hwang, "IndyGo Red Line Electric Buses Weren't Going Far Enough on a Charge, so They're Getting a Tech Fix," *IndyStar*, 23 May 2019.

152. Ibid.

153. "IndyGo Red Line Electric Bus Testing Results May Have Been Flawed," *CALL 6*, 13 March 2019, archived at https://web.archive.org/web/20190920231403/https://www.theindychannel.com/news/call-6-investigators/call-6-indygo-red-line-electric-bus-testing-results-may-have-been-flawed.

154. Jessica Dyer, "City, Maker of Electric ART Buses Settle Suit," *Albuquerque Journal*, 31 May 2019.

155. See note 146.

156. Ibid.

157. See note 9.

158. Twin Rivers Unified School District, *About*, archived at https://web.archive.org/web/20180930100902/http://www.twinriversusd.org/About/; Twin Rivers Unified School District, *Electric Vehicles*, archived at https://web.archive.org/web/20190920231520/http://www.twinriversusd.org/Students--Families/Transportation-Services/Electric-Vehicles-/index.html; Tim Shannon, Director of Transportation, Twin Rivers Unified School District, personal communication, 1 July 2019.

159. Tim Shannon, Director of Transportation, Twin Rivers Unified School District, personal communication, 1 July 2019.

160. These are electric eSeries buses from Type-A school bus manufacturer Trans Tech, powered by Motiv Power Systems' all-electric powertrains.

161. See note 159.

162. Ibid.

163. Ibid.

164. See note 11.

165. Matt Casale and Brendan Mahoney, U.S. PIRG Education Fund, *Paying for Electric Buses: Financing Tools for Cities and Agencies to Ditch Diesel*, Fall 2018, 16.

166. See note 159.

167. Ibid.

168. See note 11.

169. See note 159.

170. Ibid.

171. Ibid.

172. Ibid.

173. See note 87.

174. Ibid.

175. Ibid.

176. Ibid.

177. Ibid.