Transforming Transit, Realizing Opportunity:

How battery-electric buses can benefit the environment, the economy, and public transit

JOBS TO MOVE AMERICA

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Methodology

This report analyzes currently available data and literature on the operational, environmental, and economic implications of a large-scale shift to battery-electric buses by US public transit agencies. The report draws from information on transit operations, utility policy, public health, environmental justice, climate change, macroeconomics, labor economics, workforce policy, and social justice history; numerous interviews were also conducted with experienced practitioners in these fields. Employment projections were modeled using IMPLAN 2019 software. This report's goal is to discuss and illuminate the hurdles and opportunities facing transit agencies, communities, and workers in the context of transitioning to battery-electric buses.

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About Jobs to Move America

Jobs to Move America is a strategic policy center dedicated to building an equitable, sustainable society by creating good jobs for all. JMA research has been used by policymakers in cities and states across the country to ensure that public investment in infrastructure counters climate change, holds corporations accountable, and expands access to good, clean jobs for all working people. JMA has built powerful coalitions of labor, community, and environmental groups to advocate for equitable policy solutions that offer a roadmap to transforming our economy.

About the Political Economy Research Institute

The Political Economy Research Institute (PERI) at the University of Massachusetts, Amherst, promotes human and ecological well-being through its original research. PERI's approach is to develop workable policy proposals that are capable of improving life on our planet today and in the future. Since its founding in 1998, PERI has become a leading source of research and policy initiatives on issues of globalization, unemployment, central bank policy, living wages and decent work, and the economics of peace, development, and the environment.

Preface

The transportation sector is now the largest emitter of greenhouse gases. Furthermore, in many of our largest cities, transportation is the biggest contributor to poor air quality, the effects of which are disproportionately borne by poorer communities of color. Fortunately, recent rapid advancements in battery and electric-drive technologies afford us an opportunity to transition our national vehicle fleet to electric.

While all vehicle segments can and do need to transition to electric drive, the nation's urban buses are best poised for an early and fast transition of the fleet to battery electric. This report by Jobs to Move America finds that if city bus operators replace diesel and compressed natural gas buses with battery-electric buses (BEBs), they can potentially save tens of thousands of dollars in fuel and maintenance costs per bus each year, with greater savings likely in the future as more cheap solar and wind power enter our power system. More importantly, this increase in renewable power further reduces greenhouse gas emissions every year that a BEB continues to operate, beginning with an average of 40 percent reduction relative to a diesel bus today. Hence, BEBs can address climate change while saving public bus operators a substantial amount of money.

Importantly, electrifying urban buses will improve the public health outcomes of our poorest citizens, who rely most on bus services, while also creating millions of new green jobs in manufacturing. Hence, bus electrification can be an example of equitable and just transition to a decarbonized transportation sector. In pursuing the transition to BEBs and supporting the creation of direct and indirect green jobs, transit agencies can serve as a template for other government vehicle fleets to go electric.

As a philanthropic partner of Jobs to Move America committed to fighting climate change, we hope that this report will provide greater clarity to governments, transit agencies, unions, and environmental groups on the multiple benefits of transitioning the country's buses to battery-electric technology.

Dr. Anand R. Gopal
Program Officer, Environment Program
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Executive Summary

Battery-Electric Buses: State of the Industry and Operational Considerations

Public transit agencies in the United States are in the early stages of what agency experts and industry professionals expect will be a large-scale transition from diesel and compressed natural gas (CNG) buses to zero-emission, battery-powered electric buses. Although the number of battery-electric buses (BEBs) in the US is less than one percent of all BEBs worldwide, the number of BEBs in use or on order domestically has multiplied dramatically over the past decade. While BEB technology and design are still developing, BEBs are expected to have lower total costs of ownership than conventionally fueled buses, and are seen as an important step that cities can take to improve urban air quality and reduce greenhouse gas emissions.

Despite these anticipated benefits, BEBs are still new and comprehensive data on their reliability, maintenance needs, and battery life spans are not yet available. A handful of transit agencies that have established themselves as early adopters of BEB technology are actively gathering operational and maintenance data. However, the costs of BEB ownership will remain challenging to forecast for some time to come. In addition to the current uncertainties around operating costs, BEBs have a higher upfront purchase price than diesel and CNG buses, and require agencies to buy and install battery-charging equipment. That said, a growing number of funding programs exist to support the purchase of electric buses; increasingly, state- and city-level policies and regulations (especially those designed to reduce greenhouse gas emissions) are also helping agencies start BEB pilot programs and make long-term plans for BEB fleet conversion.

The complexities of deployment are similarly expressed in the considerations around BEB fuel use and charging. Fuel economy for BEBs are typically about three times higher than those for diesel and CNG buses, with the added benefit that electricity prices tend to be significantly more stable than fossil fuel prices. However, variability in utility rates and added demand charges mean that the cost of fueling BEBs can be comparable to, or sometimes higher than, diesel or CNG fuel costs. The cost of an agency's electricity use will in turn depend on what types of BEB chargers the agency decides to use: on-route chargers that buses use during their duty cycles, and plug-in chargers that buses typically use overnight, draw electricity from the grid at different rates and will result in different costs to the agency. Whether an agency relies more heavily on plug-in chargers or on-route chargers often depends on what real estate is available for the agency's use, as well as what kinds of routes will work with the driving ranges of their BEBs. While it will take time for transit agencies to develop the best practices to address these and other operational challenges, many agencies have already demonstrated strong commitments to incorporating BEBs into their bus fleets and to full fleet conversion over the next twenty to thirty years.

Environmental and Public Health Considerations

While deploying and operating BEB fleets requires complex preparation and planning, stakeholders at all levels have expressed widespread agreement about the substantial environmental and public health benefits that electric buses can provide. Agencies are clear on the value of achieving better air quality and reducing reliance on greenhouse gas-producing fossil fuels. Although BEBs are still a relatively small fraction of the global vehicle fleet, they are already significantly reducing demand for diesel fuel. The climate-related benefits of BEBs are also tied to the ongoing greening of the American electrical grid: over the course of their driving lifetimes, BEBs in the US currently have lower lifetime greenhouse gas (GHG) emissions than diesel or CNG buses. It is difficult to forecast the trajectory of renewable energy deployment, but it seems highly likely that GHG emissions for BEBs will diminish further as the prices of wind and solar power, which are already cost-competitive with fossil fuel-powered energy sources, continue to fall.

Reducing reliance on fossil fuel-powered buses also has the potential to substantially improve air quality and public health. The vehicle exhaust that is produced from burning diesel fuel contains nitrogen oxides (NO_x), ozone, and particulate matter (PM), and a large body of literature documents the extensive range of illnesses and diseases (including asthma, chronic obstructive pulmonary disease, cardiovascular disease, and multiple kinds of cancer) that are associated with these pollutants. In particular, a number of research articles describe the heightened health risks faced by bus operators, bus maintenance workers, and other people with occupational exposure to diesel exhaust.

Finding ways to improve air quality, especially in urban areas with high levels of heavy-duty vehicle traffic, is also an important factor in considering BEB deployment. The Environmental Protection Agency estimates that 15 percent of all Americans live near major traffic areas where exposure to vehicle exhaust is most pronounced; in urban areas, the estimate increases to 30 to 45 percent. Numerous studies discuss the high association between air pollution in low-income communities, communities of color, and the pollution-related health impacts suffered by those living there. These air quality findings echo the documentation on the disproportionate impact that extreme weather events associated with climate change have on disadvantaged communities that have the fewest resources available for response and adaptation. Several transit agencies, as well as public-private initiatives like the Zero-Emission Vehicle Challenge, are addressing these interconnected issues by developing BEB programs with an environmental justice focus and lowering the upfront costs of zero-emissions vehicle procurement by aggregating demand.

Economic and Workforce Considerations

In addition to examining the challenges that transit agencies must address with battery-electric buses, and the environmental and public health considerations that would result from a shift to BEBs, it is important to consider how a broad-scale BEB transition would affect the US economy and workforce. The largest impact that BEBs will have on job creation will be in the manufacturing sector—a part of the American economy that has been diminished for decades, but is now showing signs of post-recession improvement. Manufacturing contributes significantly to national gross domestic product, both in terms of gross output and value added. The manufacturing sector has also been consistently adding jobs since 2010, which is especially important because of the unique and valuable characteristics of manufacturing jobs. Careers in manufacturing can be accessible to workers with a wide range of abilities and educational backgrounds, and in particular to workers without college degrees. At the same time, manufacturing work requires notable levels of skill and in some cases pays better than other jobs that don't require advanced education. The historically higher rates of unionization in the manufacturing sector also contribute to the higher wages that manufacturing workers have earned. These are the kinds of jobs that could be created by a large-scale shift to BEBs that also includes a focus on ensuring the buses are manufactured in the US with good wages and benefits. Modeling studies by the Political Economy Research Institute at the University of Massachusetts Amherst show that for every $1 million invested in BEBs, about 5.7 US jobs would be created—a number that is comparable with the same amount of investment in diesel buses. When the jobs associated with the manufacture and installation of BEB charging stations and the necessary upgrades to bus depots are factored in, it becomes evident that a broad-scale transition to BEBs can have a positive impact on the job market if the transition is managed with good job creation in mind.

In considering this future job creation—especially in the tight labor market that currently exists in the US—it is important to understand the opportunities that exist for maximizing the economic impact of BEB deployment. For years, the American manufacturing workforce has been relatively homogeneous—roughly 70 percent male and 80 percent white. Given the high demand for workers, women and people of color are two of the most promising demographics for manufacturing sector recruitment. By focusing on these and other historically marginalized groups, manufacturing firms can realize their goals for workforce diversity and begin to correct for decades of hiring inequities. Because the lion's share of BEB purchases in future years will likely come from public transit agencies, these agencies can exercise their abilities as stewards of public resources not only to incentivize manufacturing firms to create good jobs with improved access for disadvantaged workers, but also to expand on-the-job training and access to pre-apprenticeships, which will be critical in growing the ranks of skilled job applicants. Agencies can also develop best practices around procurement that allow for training their in-house maintenance staff to keep BEB fleets in good repair. Underpinning these considerations is the critical role that transit agencies will play in creating predictable levels of demand for BEB original equipment manufacturers and supply chain companies: the stability of BEB-related manufacturing jobs will depend significantly on whether transit agencies have reliable access to the funds needed for future procurements.

Summary

The combined ways in which BEBs can improve public transit, public health, the environment, workforce, and economy present the kind of opportunity that only comes along once in several generations. The sum of BEBs' advantages is too great not to pursue, and a concerted effort to nurture the production of this new technology can result in strengthening an important part of America's emerging electric vehicles sector while improving air quality, transit services, and manufacturing jobs. Ultimately, capturing the combined upsides of BEBs can help America achieve an even more fundamental goal: expanding public transit availability across the country, so that people everywhere—especially those that need mobility most—can access transportation services that will expand their ability to connect with their jobs, schools, families, and communities, while improving the environment and creating better jobs for working Americans.

Policy Recommendations

The overall recommendation is for transit agencies to adopt comprehensive programs around transitioning to battery-electric bus fleets, with commitments to maximizing benefits to riders, taxpayers, workers, and communities:

Prepare for successful large-scale BEB deployment:

- Agencies should commit to ambitious targets for transitioning their bus fleets to BEBs over a specific period of time and create strategic transition plans for accomplishing these goals.
- In developing their transition plans, agencies should work closely with key stakeholders including their local government, current agency workers, and communities.

- All stakeholders should take whatever steps are necessary to create a constructive dialogue and a shared sense of mission between the transit agency and its utility.
- To increase the success of BEB deployment, policymakers and governing bodies that shape decisions at transit agencies should provide robust support for data gathering within the agency and sharing of best practices with peer agencies.
- Elected officials, agencies, and other groups should work together to create targeted funding streams and take any additional steps that are necessary to ensure that BEB procurements are funded and can progress on schedule.

Create community health and climate solutions:

- As part of their transition plans, agencies should identify the neighborhoods in their areas that are most impacted by air pollution and prioritize the deployment of BEBs in those neighborhoods.
- Agencies should also engage in dialogue with their utilities about options for on-site renewable energy generation to maximize greenhouse gas reductions.

Prioritize good jobs with equity and career growth:

- Large agencies should develop sustainable good jobs policies to ensure that BEB manufacturers are incentivized to create permanent jobs with family-supporting wages, benefits, and training in transferable skills.
- Agencies and manufacturers should coordinate with economic development programs to support technical skills training for BEB manufacturing workers.
- Agencies should consult bus operators and maintenance workers, and their unions, to determine what skills training is needed to ensure that bus maintenance can be performed by current agency workers.

Commit to transparency and accountability for the entire program:

- Agencies should encourage and create opportunities for large-scale stakeholder participation.
- Agencies should build re-evaluation into their transition plans over time, and commit to regular and open review of their BEB programs.

Introduction

Electric buses are coming: this is the comment one unfailingly hears when talking with public transportation officials about the future of bus transit. With their simpler, cleaner engines, higher fuel efficiencies, and lower projected maintenance costs, electric buses have tremendous potential for lowering the costs of public transit while improving transit service on multiple fronts.

It would be understandable to think that, for a transit agency, switching to electric buses would be as simple as a family swapping out their old station wagon for an electric car. Deploying a fleet of electric buses, however, is significantly more challenging: electric buses can cost close to twice as much upfront as conventionally fueled buses, even before the purchase of charging equipment and the cost of the necessary utility connections. Electric bus driving ranges depend on a combination of different factors, and their routes must be planned accordingly. There are also complex logistical questions about where a transit agency may be able to install the appropriate charging equipment to keep the bus running; closely tied to these considerations is the process of conferring with the local utility to understand the potential costs associated with battery charging. These are just some of the questions that a transit agency faces when starting their first electric bus pilot program; the challenges increase greatly when larger numbers of electric buses are deployed.

The term “electric buses” includes both battery-electric buses (BEBs) and hydrogen fuel cell electric buses. Although fuel-cell buses have their own unique challenges and benefits, BEBs are overwhelmingly the dominant type of electric bus on the market today, and will be the focus of this report. The greenhouse gas emissions from driving BEBs are substantially lower than for fossil fuel-powered buses, even after accounting for greenhouse gases associated with electricity generation. Transitioning to BEBs can therefore be an important part of a city or state's climate change mitigation policy. Battery-electric buses also have no tailpipe emissions,[1] and the improved air quality associated with BEBs is one of the major factors driving BEB deployment worldwide. From a public health standpoint, BEBs are especially important for low-income communities and communities of color. Although air pollution is a problem experienced by people from all backgrounds, low-income communities and communities of color tend to have greater exposure to air pollution, and are less likely to have the resources to cope with the associated health risks. Battery-electric buses also greatly reduce the lung-related, cancer-related, and cardiovascular problems that threaten the health of diesel bus operators and maintenance workers.

In addition to the ways in which BEBs will change transit operations and bring environmental improvements, battery-electric buses hold the promise of good American jobs. Economic modeling by the Political Economy Research Institute at the University of Massachusetts Amherst shows that about 5.7 jobs would be created for every $1 million invested in BEBs. A majority of these positions will be manufacturing jobs, which makes them more likely to pay a living wage and to require significant levels of technical skill, while also being available to job

5.7 jobs supported
for every $1 million invested in BEBs

6.6 jobs supported
for every $1 million spent on manufacturing and installation of charging equipment

9.6 jobs supported
for every $1 million spent on bus facility construction & upgrades

1 Vehicles that do not emit tailpipe exhaust are classified as zero-emission vehicles (ZEVs), a category that includes both battery-electric buses and hydrogen fuel-cell buses.

seekers without college degrees. Additionally, about 6.6 jobs would be supported for every $1 million spent on the manufacturing and installation of charging equipment, and about 9.6 jobs would be supported by each $1 million spent on bus facility construction and upgrades. Furthermore, because public transit agencies are likely to be largest purchasers of BEBs in the coming years, those agencies are uniquely positioned to set standards for bus performance characteristics. Agencies can also encourage the creation of BEB manufacturing jobs with the compensation, training, and equity that can provide real opportunity for American workers while helping companies up and down the BEB supply chain achieve greater success. More fundamentally, by creating steady demand for this new kind of transportation equipment, transit agencies will be energizing a part of the manufacturing sector that has exceptional leverage for strengthening the overall US economy.

Taken together, the benefits, challenges, and opportunities of battery-electric buses present a remarkable chance to create industrial policy that can achieve multiple civil, economic, and environmental objectives in one fell swoop. This report will show the pathways that transit agencies, policy makers, and citizen supporters can take to bring us there.

Photo courtesy Armando Aparicio

1 Financial and Operational Considerations for Battery-Electric Buses

Battery-electric buses (BEBs) present a remarkable and complex transit opportunity. On one hand, BEBs are substantially cleaner and better for the environment than diesel or compressed natural gas (CNG) buses: because all parts of the vehicle are powered by a battery rather than a combustion engine, BEBs have no tailpipe emissions. Life-cycle global warming emissions for BEBs (encompassing both tailpipe emissions and emissions associated with fuel production) are on the order of 75 percent less than lifetime greenhouse gas emissions for diesel and CNG buses.[2]

BEBs are becoming increasingly affordable, and thanks to their simpler engine structure, hold the promise of lower maintenance costs over the course of the buses' useful lives. BEB engines are quieter and more efficient than CNG and diesel engines, and BEB fuel economy is currently on the order of four times higher than those of CNG and diesel buses.[3]

At the same time, BEBs are still so new that comprehensive data on their reliability, maintenance needs, and battery lifespans are not yet available, making the total cost of BEB ownership challenging to forecast. Operational costs are also difficult to estimate, in part because BEB driving ranges depend more strongly on operator skill and training than is the case for diesel or CNG buses. Additionally, because BEB air conditioning and heating systems are powered by the same battery that

2 S. Chandler, J. Espino, and J. O'Dea, "Delivering Opportunity," Union of Concerned Scientists and the Greenlining Institute, October 2016 (updated May 2017), p. 3. https://www.ucsusa.org/clean-vehicles/electric-vehicles/freight-electrification#.W0y37dhKhYc

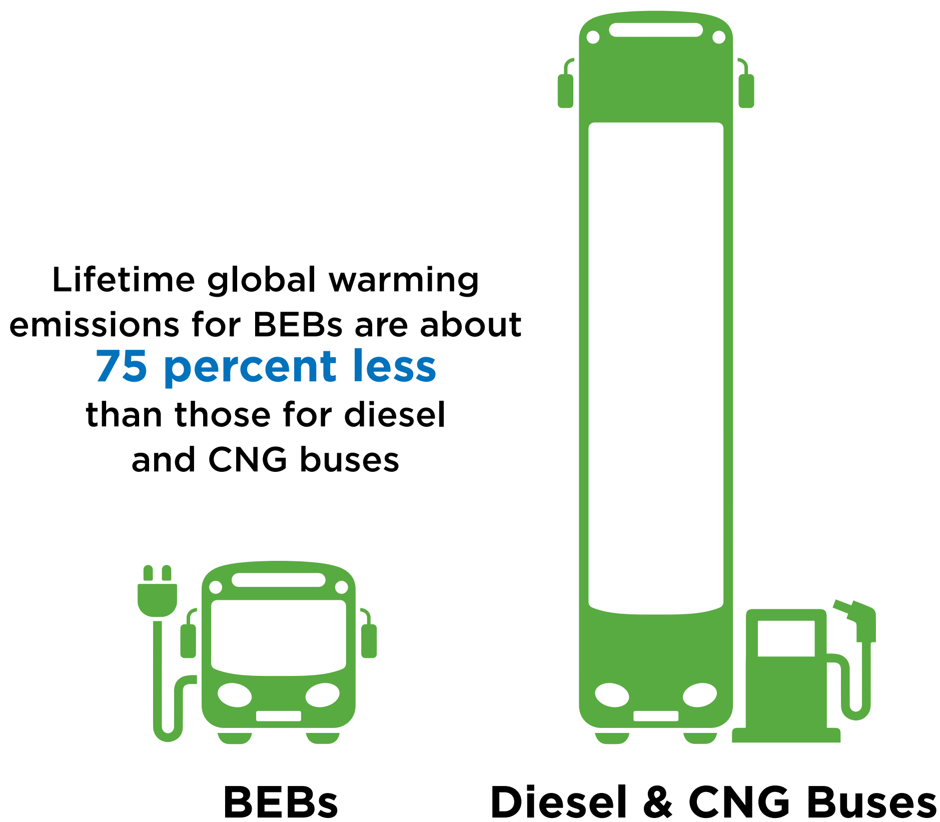
3 J. Hanlin, D. Reddaway, and J. Lane, "Battery Electric Buses—State of the Practice," National Academy of Sciences Transit Cooperative Research Program, 2018, p. 1-2.

propels the bus, seasonal temperature changes can have a substantial impact on driving range. Incorporating BEBs into an agency's bus fleet also requires a significant amount of advanced planning, in particular around the best choices for utility rates and charging infrastructure.

The complexity and newness of these considerations present challenges for transit agencies exploring the pathways to BEB fleet transition. Transit agencies that are considering introducing BEBs into their operations, or expanding their existing BEB fleets, have a strong interest in reviewing all available information and engaging with peers at other agencies to share best practices. This chapter will provide a review of the rapidly developing body of literature on BEB economics, planning, and operations, as well as information from interviews with transit agency staff. The material in this chapter should also be useful for state and local policymakers and community stakeholders who are looking to deepen their knowledge of the considerations involved in BEB fleet transition.

State of the Market

According to Bloomberg New Energy Finance's 2018 report *Electric Buses in Cities*, in 2017 roughly three million municipal buses were in use worldwide, and about 385,000 of those were electric buses—roughly 13 percent of the global fleet. About 99 percent of all BEBs worldwide are currently in use in China, where BEBs make



up 17 percent of the total bus fleet.[4] By comparison, in 2017 there were approximately 2,100 BEBs in use in Europe, and 360 BEBs in use by US transit agencies;[5] by 2018, the US number had increased to 520 BEBs,[6] with roughly 1,000 additional BEBs on order.[7] Given that the total US municipal bus fleet consists of roughly 70,000 buses, in 2018 BEBs comprised about 0.7 percent of the overall domestic fleet.

These relatively low numbers for US BEB deployment are not surprising given that the American market for BEBs is barely ten years old: in 2009, the total number of BEBs awarded, contracted, or sold in the US was 17; by 2016, that number had grown to 582 BEBs[8] (figure 1-1).

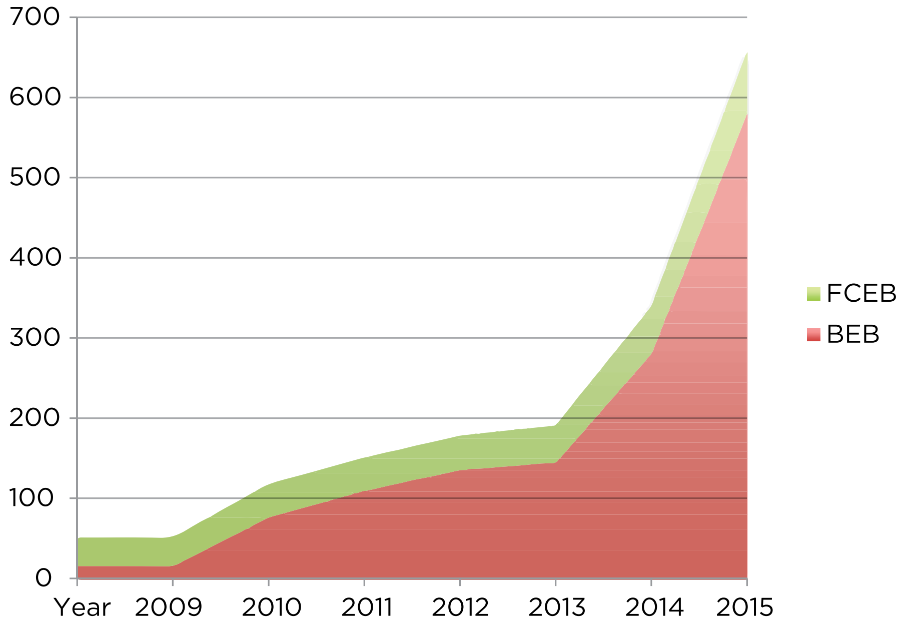


Figure 1-1: U.S. zero emission bus cumulative sales and awards. FCEB = fuel cell electric buses; BEB = battery-electric buses. Source: Hanlin et al. 2018

As of January 2019, 13 percent of US transit agencies had BEBs in service or on order.[9] And transit agency BEB use is poised for significant expansion: in 2017, the Los Angeles County Metropolitan Transportation Authority announced its plan to transition completely to BEBs by 2030, and in 2018 the New York City Metropolitan Transportation Authority made a similar commitment to convert to BEBs by 2040. More recently, in April 2019, the Chicago City Council approved a resolution to transition the Chicago Transit Authority's (CTA) bus fleet to

4 "Electric Buses in Cities," Bloomberg New Energy Finance, March 29, 2018.

5 Bloomberg, "Electric Buses in Cities."

6 "Electric Bus Industry Continues to Make Strides in 2018" (press release), EB START Consulting, January 31, 2019.

7 Elliott James Popel, "Breathing Easy: A Survey of Zero Emission Buses Across America," CALSTART, August 17, 2018.

8 Hanlin et al., "Battery Electric Buses," p. 8.

9 EB START, "Electric Bus Industry."

electric buses by 2040 as well.[10] In *Battery Electric Buses: State of the Practice* (one of the most comprehensive resources about BEBs currently available) by Jason Hanlin and colleagues, the authors note that in 2017, Seattle's King County Metro announced that its current fleet of three BEBs would be expanded to 120 BEBs over the next four years,[11] and also mentions that several mid-size California transit agencies have committed to transitioning their bus fleets entirely to BEBs.[12]

Currently, the BEB manufacturers with the greatest US sales are Proterra, an American company with facilities in South Carolina and California; Build Your Dreams (BYD), a Chinese firm whose US factory is located in California; and New Flyer, a Canadian multinational firm with facilities in Indiana, New York, Minnesota, Alabama, and Manitoba, Canada.

BEB Purchase Costs and Funding Support

Despite their environmental and operational advantages, the upfront price tag of BEBs relative to diesel and CNG buses presents a challenge for transit agencies. However, technological improvements and increasing economies of scale have allowed BEB prices to decline rapidly over the past decade. One example of this downward trend comes from Foothill Transit, a California agency whose experience with deploying BEBs is comprehensively documented in the National Renewable Energy Laboratory's 2016 report, *Foothill Transit Battery Electric Bus Demonstration Results*. From 2009 to 2015, Foothill Transit purchased a total of 30 BEBs; during that time, the agency's per bus purchase cost decreased from $1 million for a 35-foot bus to $789,000 for a 40-foot bus.[13] (Similarly, around 2014, the Antelope Valley Transit Authority (AVTA) paid $770,000 per bus for two 40-foot BEBs.[14] Prices in this ballpark are comparable to those reported by other agencies around the country.) Even with this drop in price, however, the cost in 2015 of adding a comparable CNG bus to Foothill Transit's fleet was $575,000—about 27 percent less than the cost of the agency's most recently purchased BEBs.[15] For diesel buses, the Bloomberg New Energy Finance (BNEF) report uses $450,000 (43 percent less than the cost of the newest Foothill Transit BEBs) as a reference price.

Another approach for illustrating trends in BEB prices is to look at the change over time in the cost of electric vehicle (EV) batteries. The BNEF report shows that from 2010 to 2017, the price per kWh for EV batteries decreased by a factor of five,

10 Mischa Wanek-Libman, "Chicago City Council approves transition to 100 percent renewable energy," Mass Transit, April 15, 2019.

11 "King County Executive Announces Purchases of Battery Buses, Challenges Industry to Build Next-Generation Transit" (press release), King County, January 2017.

12 Hanlin et al., "Battery Electric Buses," p.8.

13 L. Eudy, R. Prohaska, K. Kelly, and M. Post, "Foothill Battery Electric Bus Demonstration Results," NREL/TP-5400-65274, National Renewable Energy Laboratory, January 2016, p. 9.

14 Hanlin et al., "Battery Electric Buses," p. 61-62.

15 Hanlin et al., "Battery Electric Buses," p.8.

from approximately $1000/kWh to $200/kWh (figure 1-2). The BNEF research forecasts that continued improvements in battery manufacturing combined with growing demand for electric vehicles will allow the price of both batteries and BEBs to continue to decrease, hastening the point at which BEBs will reach cost parity with CNG and diesel buses.

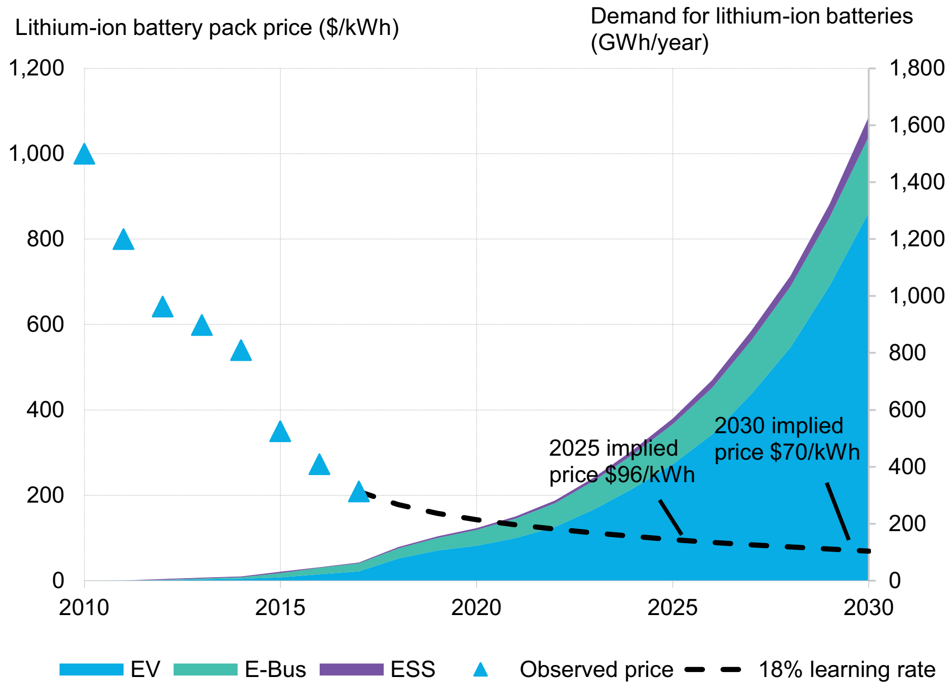


Figure 1-2: Lithium-ion battery pack price forecast. ESS = stationary energy storage applications. (Source: BNEF)

While ultimately these declining prices should facilitate BEB procurement, they can also turn accurate cost estimates into moving targets.[16] Even so, for the time being the price difference between BEBs and CNG or diesel buses is substantial enough that transit agencies must carefully consider the total cost of BEB ownership. Toward that end, in April 2019, Proterra announced that it was significantly scaling up its battery leasing program, which allows transit agencies and other customers to purchase a BEB separately from its battery and use operating funds to cover the cost of the battery lease over a twelve-year period.[17] While such battery leasing initiatives develop, other programs are already in place to facilitate public BEB deployment. A major source of support is the Federal Transit Administration (FTA), which provides grants designed to address the high upfront costs of BEBs and their charging infrastructure. These grants typically cover 80 to 90 percent of BEB purchase costs[18] and in the past were often sourced through the FTA's Transit Investments for Greenhouse Gas

16 In the 2018 BNEF report, city officials from eight large and mid-sized international cities at varying levels of economic development all cited falling battery prices as a barrier to launching BEB programs. Bloomberg, "Electric Buses in Cities."

17 Phil Dzikiy, "Proterra's $200M battery leasing program to accelerate electric bus adoption, take aim at diesel," electrek, April 16, 2019.

18 Hanlin et al., "Battery Electric Buses," p. 32.

and Energy Reduction (TIGGER) program. Transit agencies can currently receive federal support through FTA's Clean Fuels Grant program, which makes funds available both (a) to provide assistance for nonattainment and maintenance areas in achieving or maintaining the National Ambient Air Quality Standards for ozone and carbon monoxide, and (b) to support emerging clean fuel and advanced propulsion technologies for transit buses (and the markets for those technologies).[19]

The FTA also administers the Low or No Emission Vehicle (Low-No) Program, which "provides funding to state and local governmental authorities for the purchase or lease of zero-emission and low-emission transit buses as well as acquisition, construction, and leasing of required supporting facilities."[20] The Low-No Program was authorized under the 2015 FAST Act and awards grants on a competitive basis each year until fiscal year 2020; in 2019, the total funding is $85 million.[21] The FTA has reported that in Fiscal Year 2017, 47 transit agencies around the country received Low-No funding for the purchase of BEBs and supporting infrastructure.[22] In addition to these FTA programs, in April 2019, Representative Julia Brownley (D-CA) introduced the Green Bus Act, which if passed would mandate that all new buses purchased with federal funds be zero-emission by 2029. The bill increases funding for FTA bus programs and also for the Low-No Program, and would give funding preference to transit agencies that have completed full fleet transition plans.[23]

State-sponsored funding can also support BEB deployment, with California at the vanguard of state-level funding: the 2018 report by Hanlin and colleagues describes how, in addition to TIGGER funds, Foothill Transit also used funding from the California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project to expand its BEB fleet.[24] In 2016, AVTA committed to transitioning its bus fleet to BEB; as of June 2019, the agency was on target to convert its local fleet to BEBs by autumn of that year.[25] The new buses will be paid for with a combination of federal funds and grants from the California State Transportation Agency (CalSTA).[26]

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19 Federal Transit Administration, "Clean Fuels Grant Program (5308)," https://www.transit.dot.gov/funding/grants/clean-fuels-grant-program-5308.

20 Federal Transit Administration, "Low or No Emission Vehicle Program – 5339(c)," https://www.transit.dot.gov/funding/grants/lowno.

21 Solicitation of Project Proposals for the Low or No Emission (Low-No) Program Department of Transportation, FTA-2019-001-TPM-LOWNO, posted March 18, 2019. Available here: https://www.grants.gov/web/grants/view-opportunity.html?oppId=313967.

22 Hanlin et al., "Battery Electric Buses," p.33.

23 "Brownley Introduces Bill to Fight Climate Crisis by Helping Localities Convert to Clean Transit Systems, Requiring All New FTA-Funded Buses Be Zero-Emission by 2029" (press release), Congresswoman Julia Brownley, April 9, 2019.

24 Federal Transit Administration, "Fiscal Year 2017 Low or No-Emission (Low-No) Bus Program Projects" (Updated March 22, 2018), https://www.transit.dot.gov/funding/grants/fiscal-year-2017-low-or-no-emission-low-no-bus-program-projects.

25 Personal communication with Macy Neshati, Executive Director and CEO of Antelope Valley Transit Authority, June 4, 2019.

26 Antelope Valley Transit Authority, "Electric Bus Fleet Conversion" (January 2018), http://www.avta.com/index.aspx?page=482.

In 2018, states also began receiving funds from Volkswagen as a result of the 2016 federal court case in which the automotive manufacturer admitted to programming its diesel vehicles to perform at artificially low levels on emissions tests. The $2.8 billion that Volkswagen is required to pay will be used by states to lower diesel pollution: states will receive amounts ranging from $8 million to $423 million, depending on the number of diesel VW vehicles sold in each state. (Under a separate part of its court settlement, Volkswagen is providing states with $2 billion to build electric car charging stations, and will spend $10 billion on a diesel car buy-back program.[27]) So far Rhode Island has announced that it will spend most of its settlement funds on BEBs;[28] and New York,[29] Colorado,[30] Georgia,[31] and the city of Sacramento[32] have announced that a portion of their funds will go towards replacing part of their bus fleets with BEBs and other alternative-fuel buses.

Regulations that Impact BEB Deployment

Regulations can also play a motivating role in BEB deployment: Foothill Transit's BEB initiative was a response to the California Air Resources Board's Fleet Rule for Transit Agencies, which was adopted in 2000. The rule's objective is to reduce diesel particulate matter and nitrogen oxide emissions from urban buses and transit fleet vehicles. Transit agencies were required to comply either by retrofitting diesel buses with improved emissions controls or by purchasing or leasing alternative fuel vehicles. The 2018 Hanlin et al. report described the Fleet Rule for Transit Agencies as "one of the primary drivers for demonstration and deployment of advanced technology buses in the state of California."[33] In December 2018, the California Air Resources Board (CARB) strengthened the policies addressed in the Fleet Rule by passing the Innovative Clean Transit (ICT) regulation, which sets a statewide goal for public transit agencies to gradually transition California's fleet of about 12,000 buses to zero-emission buses (ZEBs) by 2040. While the ICT does allow for the purchase of hydrogen fuel-cell buses,

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27 Martha T. Moore, "Billions From VW Settlement Boost Push to Clean Vehicles," Pew Charitable Trusts (blog), January 4, 2018.

28 Alex Kuffner, "R.I. Agrees to Spend Volkswagen Settlement Money on Electric Buses and Charging Stations," Providence (RI) Journal, May 11, 2018.

29 "Governor Cuomo Announces New York to Invest $127.7 Million Volkswagen Settlement in Clean Vehicles" (press release), Office of Governor Andrew M. Cuomo, September 5, 2018.

30 Kieran Nicholson, "Colorado's plans for $68.7 million Volkswagen pollution settlement finalized," Denver Post, March 23, 2018.

31 "Beneficiary Mitigation Plan for the State of Georgia," Georgia Governor's Office of Planning and Budget, January 30, 2018.

32 Editorial Board, "Sacramento, make way for electric buses and cars. It's a good thing," Sacramento Bee, June 14, 2018.

33 Hanlin et al., "Battery Electric Buses," p.33.

the regulation is complemented by other state policies that encourage the use of electric vehicles. Utilities are also incenting a transition to BEBs by rolling out new electricity rate designs and investments in charging infrastructure.[34]

Regulations can also lower BEB life-cycle costs: CARB administers the Low Carbon Fuel Standard (LCFS), a trading system that allows the owners of alternatively fueled truck and bus fleets to earn credits for avoided greenhouse gas (GHG) emissions. Those credits can then be sold to oil refineries and producers that make and sell high-carbon fuels. In their 2016 report on electric buses and trucks, the Greenlining Institute and the Union of Concerned Scientists noted that at LCFS credit prices of $100 per ton of carbon dioxide equivalent, a zero-emissions transit bus traveling 40,000 miles per year can earn more than $9,000 in LCFS credits.[35] As a real-life example, in 2017, a BEB in Foothill Transit's fleet typically traveled about 23,000 miles per year.[36] As of June 2018, LCFS credits were trading at roughly $137 per metric ton of CO_2 equivalent.[37] Assuming a linear relationship between miles traveled and credits earned, Foothill Transit would be able to earn approximately $7,000 in LCFS credits for each of its BEBs.

BEB Fuel Economy

The distinguishing characteristics of BEB performance stem from the fundamentals of their engine design. In contrast to buses that use diesel or CNG to fuel an internal combustion engine, BEBs have an electric motor that is powered by a large battery pack.[38] What makes BEBs and other electric-drive vehicles unique is the efficiency with which they convert energy into forward motion. Buses powered by diesel or CNG require the extra step of combusting fuel to power the engine. A significant amount of energy is lost as heat during this process, resulting in energy conversion efficiencies of 35 to 45 percent.[39] Analysis done by the Environmental Protection Agency's Department of Energy Efficiency and Renewable Energy indicates that for conventional combustion-engine passenger vehicles, 12 to 30 percent of the energy from the gas in the tank is used to move the vehicle down the road, whereas 72 to 94 percent of the energy used to power all-electric passenger vehicles is converted into forward motion.[40]

34 "California transitioning to all-electric public bus fleet by 2040" (press release), California Air Resources Board, December 14, 2018.

35 Chandler et al., "Delivering Opportunity," p. 27.

36 Leslie Eudy and Matthew Jeffers, "Foothill Transit Agency Battery Electric Bus Progress Report," NREL/PR-5400-71292, National Renewable Energy Laboratory, May 2018, p. 13.

37 California Air Resources Board, "Data Dashboard: 2011-2017 Performance and Future Targets of the Low Carbon Fuel Standard," https://www.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm.

38 Hybrid electric vehicles (which use a combination of a combustion engine and a battery) and fuel-cell vehicles (which are typically fueled with compressed hydrogen gas) are also powered by electric motors, and, along with BEBs, are categorized as electric-drive vehicles.

39 Hanlin et al., "Battery Electric Buses," p. 5.

40 U.S. Department of Energy, "Where the Energy Goes: Hybrids," http://www.fueleconomy.gov/feg/atv-hev.shtml.

One of the most valuable sources of data on BEB performance is the Federal Transit Administration's Altoona Bus Research and Testing Center. The Center specializes in "providing an unbiased and accurate comparison of bus models through the use of an established set of test procedures," and has tested BEBs made by most major American manufacturers, including Proterra, BYD, and New Flyer. To provide an indication of the relative efficiencies of BEB, CNG, and diesel buses, figure 1-3 compares the fuel economy of New Flyer's Xcelsior 40-foot low floor bus, which can be equipped with an all-electric, CNG, diesel, or hybrid engine. The average fuel economy for the electric bus (20.5 miles per diesel gallon equivalent, or MPDGE[41]) is more than four times greater than the average CNG and diesel fuel economy (both 4.8 MPDGE) and more than three times greater than the average hybrid fuel economy (5.84 MPDGE).[42]

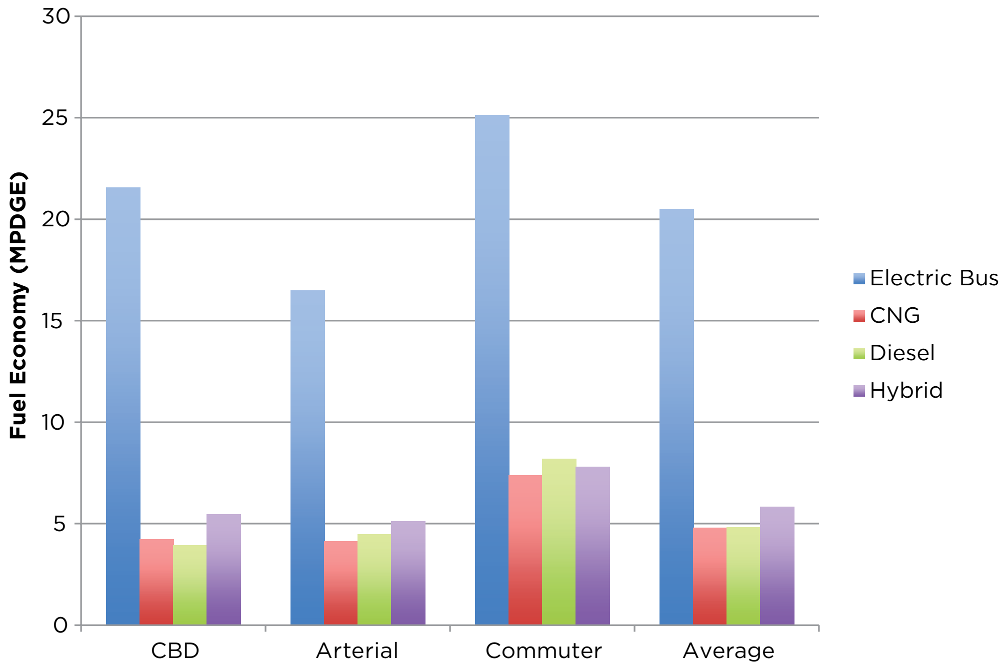


Figure 1-3: Altoona-measured fuel economy in miles per diesel gallon equivalent (MPDGE). CBD = central business district (Source: Hanlin et al.)

Analysis by Foothill Transit and the National Renewable Energy Laboratory (NREL) of the BEB and CNG vehicles in Foothill Transit's fleet shows similar results. In 2017, fuel economy was 17.24 MPDGE for Foothill's twelve 35-foot Proterra BEBs, and 16.99 MPDGE for the agency's two 40-foot Proterra BEBs. In contrast, fuel economy for Foothill's eight NABI 42-foot CNG buses was 4.15 MPDGE.[43]

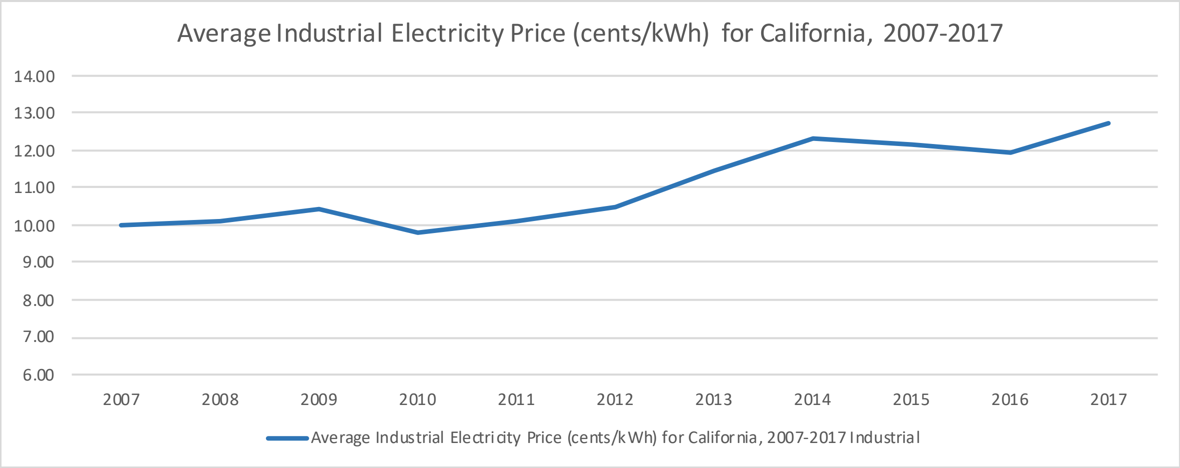
41 Miles per diesel gallon equivalent allows researchers to compare with how far a bus can travel on a quantity of electricity that contains the same amount of energy as a gallon of diesel fuel.

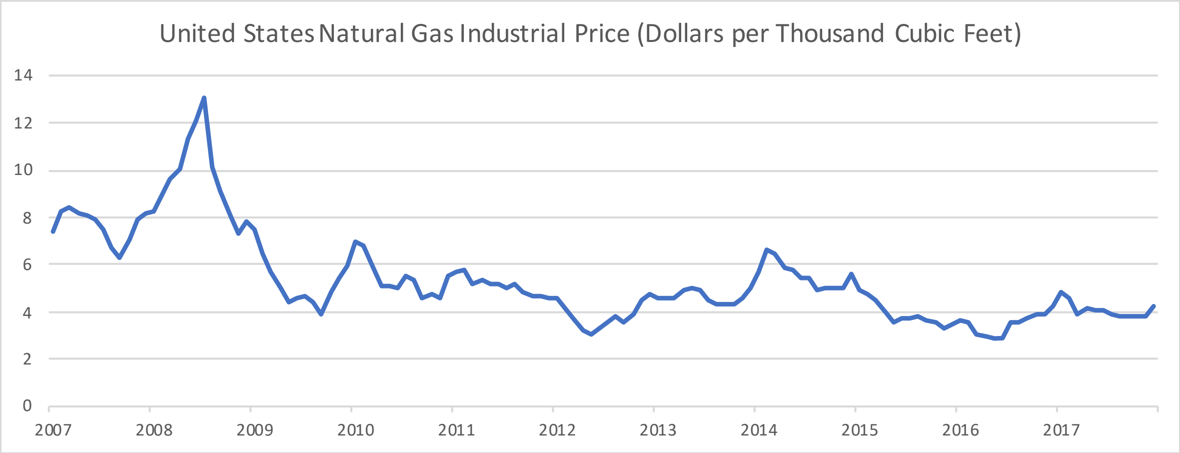
42 Hanlin et al., "Battery Electric Buses," p. 5-6.

43 Eudy and Jeffers, "Foothill Battery Electric Bus Progress Report," p. 4.

Evaluating a BEB's cost per mile, however, depends on the relative prices of electricity in a given region, as well as on the price of competing fuels, which can vary widely. To illustrate this variability, figure 1-4 shows the prices of natural gas, gasoline, and California electricity from 2007 to 2017. The plots illustrate the relative volatility of fossil fuel prices compared to electricity prices: between 2010 and 2012, natural gas prices fell 46 percent; similarly, between 2009 and 2012, the price of diesel rose by roughly 100 percent. In comparison, electricity on the California market has experienced lower and more stable price changes over a much longer period of time. In the case of Foothill Transit, the agency calculated the cost of fuel for CNG and BEB buses being driven on the same route and found that, during 2017, they were comparable, with the average cost of energy for BEB buses was $0.49/mile, while the average cost of fuel for CNG buses was slightly higher at $0.51/mile.[44]

44 Eudy and Jeffers, "Foothill Battery Electric Bus Progress Report," p. 4





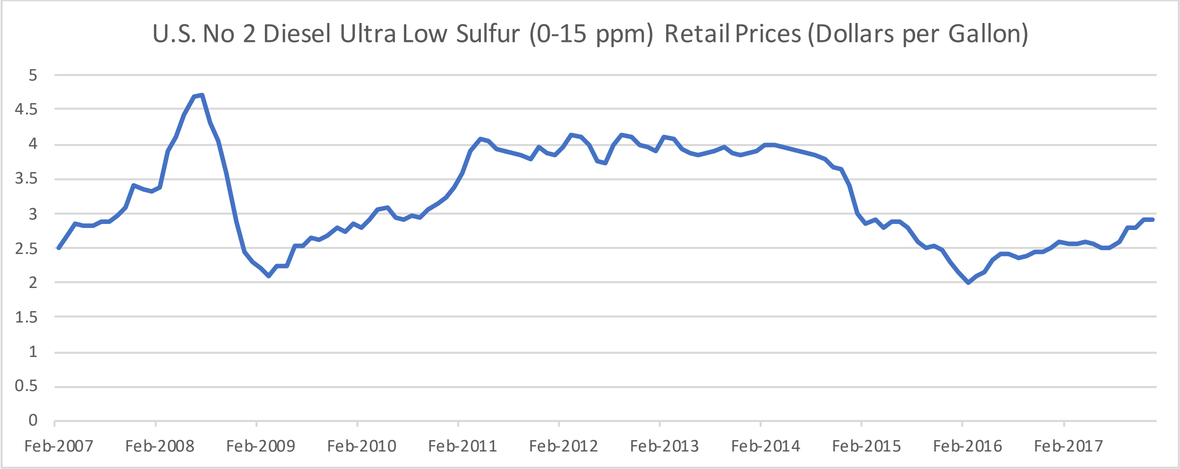


Figure 1-4: A comparison of the stability of electricity and fuel prices. (source: U.S. Energy Information Administration)

Operations and Maintenance Costs

Numerous sources[45] make the comment that the higher upfront cost of BEBs can be offset by the likelihood that BEB maintenance costs will be lower than those for diesel buses. Some initial reports are promising. The Chicago Transit Authority, which announced in June 2018 that it would be expanding its BEB fleet from two buses to 20 buses, described the savings that CTA has realized so far in its BEB pilot project: "In addition to lower emissions that benefit air quality, electric buses offer savings in fuel costs and maintenance costs. The two electric buses currently in operation have saved CTA more than $24,000 annually in fuel costs, and $30,000 annually in maintenance costs, when compared to diesel buses purchased in 2014."[46]

NREL's 2016 report on Foothill Transit also provided early data on maintenance, showing reduced costs for BEBs: Foothill calculated the cost per mile as $0.08/mile for scheduled BEB maintenance and $0.09/mile for unscheduled BEB maintenance. In contrast, for Foothill's CNG buses, the cost per mile was calculated to be $0.14/mile for scheduled maintenance and $0.04/mile for unscheduled maintenance. Cumulatively, the BEBs had a maintenance cost per mile that was 11 percent lower than that of the CNG buses.[47] The report notes that maintenance costs were low for both CNG and electric buses since all buses were still under warranty at the time.

While initial results like these are encouraging, BEB deployment is still in its nascent stages: operations data are limited in scope and do not yet cover time periods that approach the 12-year working life of an electric bus. More recent data on maintenance costs from NREL and Foothill Transit provide an illustration of these kinds of uncertainties. In NREL's 2018 report on Foothill Transit's BEB program, the 2017 maintenance costs for Foothill's buses were calculated to be $0.41/mile for the 35-foot BEBs, $0.32/mi for the 40-foot BEBs, and $0.27/mile for the CNG buses.

The higher maintenance cost for Foothill's 35-foot BEBs is partly due to the fact that the warranty on some of the components for those buses expired, resulting in greater spending on parts. Foothill Transit also changed contractors at one of its maintenance facilities; in addition to cost differences associated with that transition, Proterra was working to train the new maintenance staff, which added to labor costs.[48] Also, during the latter half of 2017, problems arose with the low-voltage battery on the BEBs, and the process of finding reliable replacement batteries wound up being longer and more costly than expected. As the report notes, because the low-voltage battery issue "is not related to the BEB system and is not expected to re-occur,

45 Bloomberg, "Electric Buses in Cities." F. Tong, C. Hendrickson, A. Biehler, P. Jaramillo, and S. Seki, "Life cycle ownership cost and environmental externality of alternative fuel options for transit buses," Transportation Research Part D: Transport and Environment, 65, December 2017, p. 287-302. Dan Welch, "Electrified Transportation for All: How Electrification can Benefit Low-Income Communities" Center for Climate and Energy Solutions, November 2017.

46 "CTA Expands Electric Bus Fleet" (press release), Chicago Transit Authority, June 13, 2018.

47 Eudy et al. "Foothill Battery Electric Bus," p. 23-24.

48 Eudy and Jeffers, "Foothill Battery Electric Bus Progress Report," p. 6.

NREL has provided the maintenance costs with and without the low-voltage battery replacement costs. Total maintenance cost without low-voltage battery costs was $0.35/mi for the BEB 35FC buses and $0.21/mi for the BEB 40FC buses."[49]

Another perspective on BEB maintenance costs is described in Hanlin et al., which includes the results of an extensive survey of transit agency BEB practices. Of the 21 agencies with BEB programs that were invited to participate in the survey, 18 submitted information. One of the survey questions addressed the differences in capital costs, operations and maintenance (O&M) costs, and life-cycle costs between BEBs and diesel or CNG buses. The findings are summarized in figure 1-5: for the majority of respondents (about 45 percent), BEB O&M costs were lower than those for diesel or CNG buses, however more than 20 percent of respondents indicated that BEB O&M costs were higher, and more than 30 percent of respondents were unsure. On a related note, 46 percent of the agencies surveyed indicated that spare parts inventories for BEBs were comparable to those for diesel buses, and 46 percent of agencies found inventories to be lower—most likely because BEB motors have fewer components and some BEB parts need replacing less frequently than conventional buses. The report by Hanlin et al. notes, though, that "parts availability and long lead times have been problematic due to the relatively small scale of BEB deployments and the lack of a mature supply chain."[50]

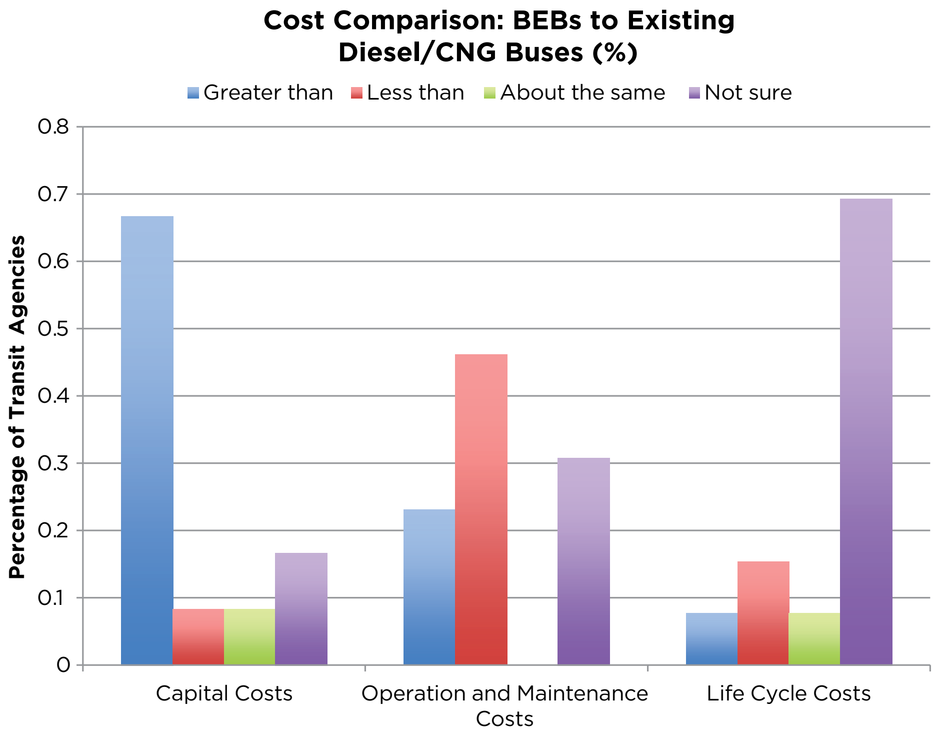


Figure 1-5: Battery-electric buses cost versus existing diesel/CNG buses cost (%). (sources: Hanlin et al. and Center for Transportation and the Environment)

49 Eudy and Jeffers, "Foothill Battery Electric Bus Progress Report," p. 7.

50 Hanlin et al., "Battery Electric Buses," p. 57.

The maintenance cost data shared by Foothill Transit and the information provided in Hanlin et al. provide examples of the variability and considerations (both expected and unexpected) that transit agencies may face when implementing equipment and technology associated with a new mode of transport. The NREL reports are valuable in allowing members of the transit community to learn firsthand about the kinds of challenges that Foothill Transit has faced as its peer agencies develop their own BEB deployment plans. Even with the reported variability and uncertainty in O&M costs, the agencies surveyed in Hanlin et al. cited "very little maintenance issues and liked the relative simplicity of the vehicles. The challenges that agencies have encountered with BEB maintenance center on the learning curve associated with the new technology, which can be addressed with robust training programs and, ultimately, experience."[51]

Charging and Infrastructure Considerations

There is broad agreement across BEB literature about the importance of an agency's planning efforts around charging infrastructure and electricity costs. Many aspects of electricity use and BEB charging interconnect in ways that make designing BEB deployment uniquely challenging. This section looks at some of the primary facets of charging technology and electricity use that agencies must consider.

Charging Equipment

There are numerous factors that transit agencies must take into account when planning BEB charging locations. As discussed in research by Alexander Kunith and colleagues,[52] decisions about charging infrastructure can be considered in terms of (a) the best locations along the bus's route for replenishing a bus's consumed energy; (b) the limitations and opportunities of local and institutional structures to accommodate charging infrastructure, and (c) the degree to which different bus lines can access a particular charger. Kunith et al. also describe how the "optimal distribution of charging points is the end result from a number of prior considerations: the grid power, battery type, and battery [state of charge] affect the schedule, which in turn affects the dwell (charging) time, which then affects the level of replenishment of the energy consumption."[53] Weighing these factors to determine the best charging options is a complex balancing act. Another important consideration is the interoperability of charging infrastructure with buses made by different manufacturers; to streamline this part of the planning process, the Society for Automotive Engineers (SAE) International is currently leading the ongoing effort to develop uniform standards for charging equipment.

51 Hanlin et al., "Battery Electric Buses," p. 57.

52 A. Kunith, D. Goehlich, and R. Mendelevitch, "Planning and Optimization of a Fast-Charging Infrastructure for Electric Urban Bus Systems," Conference Paper, International Conference on Traffic and Transport, November 2014.

53 Hanlin et al., "Battery Electric Buses," p. 20-21.

One potential starting point is the question of how an agency's BEBs will be charged. Currently there are three options for BEB charging, each with its own pros and cons:

- **Plug-in charging** is usually done at the bus depot and typically takes place overnight when electricity tends to be less expensive. Buses must be plugged in and unplugged manually. While plug-in charging replenishes the battery at a slower rate than other charging options and limits the amount of time that the bus can be available for repair and maintenance, it also lowers electricity costs by reducing demand charges (these are discussed in greater detail later in this section). Because buses can be charged overnight, BEBs that are equipped for plug-in charging can carry a larger battery, which can considerably extend a bus's driving range. However, larger batteries also make buses heavier and may reduce the amount of space available for passengers. An agency must also determine whether its facilities have the space and the utility connections that are necessary to accommodate BEBs for overnight charging, and whether the local utility can provide enough electricity to charge multiple buses at once.

- **Overhead on-route charging** (also called conductive charging) involves parking the BEB under or next to a charging device that connects with the top or the side of the bus. The on-route charger is typically located along the bus route. On-route charging can recharge a battery much faster than plug-in charging: instead of four to five hours of plug-in charging, on-route charging can fully charge a BEB battery in approximately ten minutes or less. Thanks to this shorter charge time, on-route charging can allow a BEB to proceed along its route with minimal disturbance to customers.[54] Agencies planning to use on-route charging must consider the ways in which faster charge times will increase demand charges, especially given that BEBs will frequently need to recharge during the day, when electricity prices are higher. On the upside, however, BEBs designed for on-route charging can use smaller batteries, which can reduce purchase costs and may allow for more passenger space on the bus.

- **Wireless charging** (also called inductive charging) requires the charging equipment to be embedded in the roadway beneath the bus. As with on-route charging, wireless charging can allow the bus to charge more frequently and for shorter periods of time: this brings with it the same kinds of benefits for reducing battery size, and similar expenses associated with charging at faster rates during peak daytime grid use. Building the charging equipment into the pavement reduces the infrastructure's visual impact,[55] but would likely make repairing or replacing the charging equipment more difficult and costly. As

54 Research led by the Society for Automotive Engineers (SAE) has highlighted the need for even faster on-route charging times. In response, in early 2019 SAE plans to release a recommended practice for heavy-duty on-route charging infrastructure that is interoperable for all makes of BEBs. Known as J3105, the recommended practice will describe two types of roof-mounted bus charging (as well as side-mounted charging, which certain truck companies are beginning to use and which can be used with buses as well). See: Jennifer Shuttleworth, "Conductive Automotive Charging Recommended Practice nears completion," Automotive Engineering, June 2018.

55 J.B. Gallo, T. Bloch-Rubin, and J. Tomic, "Peak Demand Charges and Electric Transit Buses," CALSTART, October 1, 2014, p. 32.

also noted in a comprehensive report on electricity use by BEBs prepared by CALSTART, "Inductive charging is generally less efficient that conductive charging and can vary significantly depending on the distance between the charging device and the vehicle and how well the vehicle is positioned over the inductive charger."[56] Currently, wireless charging is the least used of the three charging options: in Hanlin et al., of the 18 agencies that provided data in the BEB survey, only two agencies reported using wireless charging.[57]

The survey response information contained in Hanlin et al. is probably the most comprehensive collection of data currently available on how BEB operations work in practice, including the choices that transit agencies make around charging infrastructure. Seventeen of the 18 agencies reported using plug-in charging at their depot facilities, and nine of the agencies reported using overhead on-route charging.[58] Some important considerations relating to on-route charging are summarized in the following passage:

> *On-route charging can be extremely useful because it can enable BEBs to meet extended range and duty cycle requirements ... However, [agencies] ... stated that it can be risky for the agency to rely solely or primarily on on-route chargers because if one charger goes down, service is affected. Even with multiple chargers at the same location for redundancy, power outages will affect service. Many agencies plan for such risks by having multiple buses charging at the depot or deploying backup diesel or CNG buses. The general consensus of agencies is that on-route charging works well as long as there is adequate planning, testing, training, and practice docking ... Most agencies using on-route charging reported that 90 to 95% of charges attempted were successfully made. The lowest reported successful connection rate was 75% of the time. Charges were missed due to a variety of reasons, including mechanical malfunction of chargers, buses behind schedule, misalignment, loss of power to chargers, and blocked paths.*[59]

Hanlin et al.'s survey data on the ways that agencies have combined the use of different battery sizes and types of charging infrastructure is shown in figure 1-6: agencies have primarily used depot charging for their large-battery buses, but also use on-route charging for both small- and large-battery BEBs. On-route charging is also the preferred method for charging BEBs with larger maximum daily ranges.[60] The range of battery size/charging type configurations shown in the survey data suggest that there is no one-size-fits-all solution for BEB deployment, and that the range of possible solutions represent the diverse needs and constraints that different agencies must accommodate.

56 Gallo et al., "Peak Demand Charges."

57 Hanlin et al., "Battery Electric Buses," p. 43.

58 Hanlin et al., "Battery Electric Buses," p. 44.

59 Hanlin et al., "Battery Electric Buses," p. 55-56.

60 Hanlin et al., "Battery Electric Buses," p. 43.

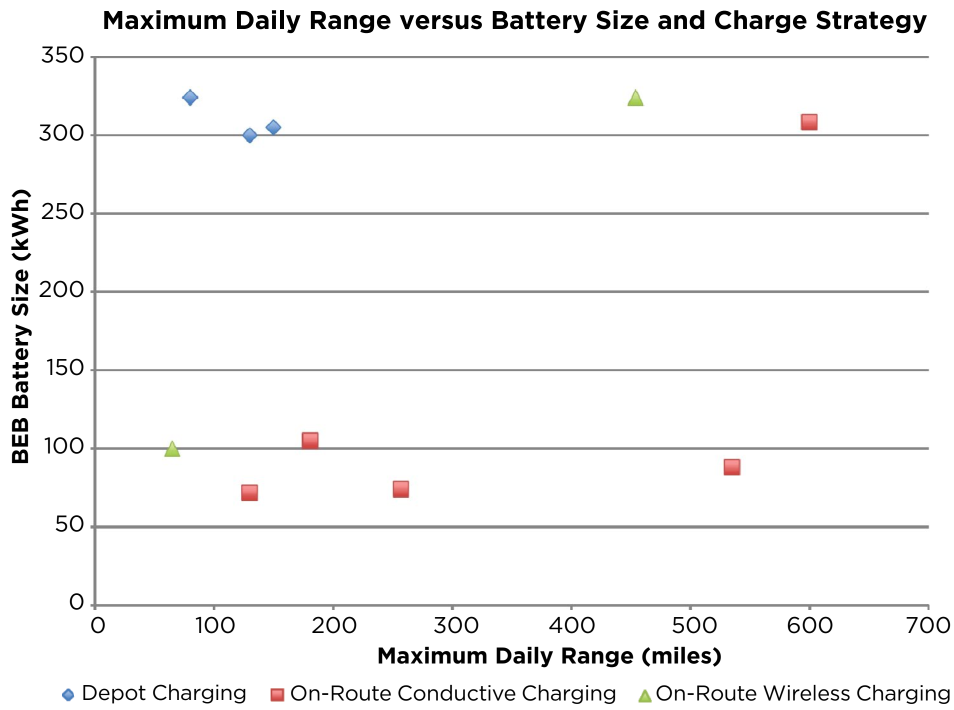


Figure 1-6: Survey results showing bus range in relation to BEB battery size and charging strategy (sources: Hanlin et al. and Center for Transportation and the Environment)

Utility Rate Charges

Since BEBs are fueled with electricity, understanding the utility rates associated with BEB use is a central part of an agency's planning process. As discussed earlier in this chapter, electricity rates in a given part of the country can remain relatively stable over time compared to fossil fuel prices. However, the cost of electricity varies widely around the country: in April 2018, data from the Energy Information Administration (EIA) showed average commercial utility rates ranging by more than a factor of two, from $0.071/kWh in Arkansas to $0.167/kWh in Connecticut (Alaska, at $0.185/kWh, and Hawaii, at $0.288/kWh, have higher rates than the rest of the country.)[61] Additionally, the size of an agency's utility bill can vary substantially depending on the type of BEB charging equipment that the agency uses, as well as the times of day when most charging takes place.

Foothill Transit's BEB deployment, which has been comprehensively documented in NREL reports, provided the impetus for separate research on BEB-related electricity charges, which Foothill Transit cited early on as a significant barrier to BEB deployment.[62] The resulting 2014 report by CALSTART (*Peak Demand Charges and Electric Transit Buses*) provides a detailed look at the costs associated with BEB electricity use, including research on rate schedules for 26 major electric

61 "Electric Power Monthly with Data for February 2018," U.S. Energy Information Administration, April 2019. Available here: https://www.eia.gov/electricity/monthly/current_month/epm.pdf.

62 Gallo et al., "Peak Demand Charges," p. 5.

utilities in Arizona, California, Colorado, Florida, Georgia, Illinois, New York, Oregon, Texas, and Washington.[63] For readers who may not be familiar with electricity generation practices, the CALSTART report provides a helpful primer:

> Electricity demand fluctuates depending on the time of day, day of the week (weekends or weekdays) and seasonally. To meet this demand, electric utilities build their electricity generation infrastructure in order to meet the highest peak demand plus a reserve margin for contingency. Every day, electric utilities dispatch power plants to meet total demand in the most economical way. Power plants are categorized in three groups:
>
> - **Baseload** power plants (for example nuclear and coal power plants) are expensive to build but cheap to operate. As a result, they should be operated continuously.
> - **Peaking** power plants (for example natural gas and oil power plants) are cheaper to build but more expensive to operate. Thus, they are generally operated only during periods of highest demand.
> - **Intermediate** power plants (for example natural gas power plants) are in between baseload and peaking power plants and are generally operated during the day and as necessary to follow demand.[64]

Utilities charge their customers for the total amount of energy used. Most utilities also bill commercial and industrial customers for what are called demand charges: a demand charge is an extra fee associated with what it costs the utility to use the more expensive peaking power plants to provide larger amounts of power on short notice. In this way, demand charges can motivate commercial and industrial customers to "even out" their electricity use (by minimizing spikes in power demand), and also to shift electricity use from times of high grid use (generally during the middle of the day) to times of low grid use (during nighttime). In CALSTART's research, 24 of the 26 utilities studied included direct or indirect peak demand charges in their commercial and industrial electricity rates, leading the authors to comment that "transit agencies around the country are bound to experience the impact of peak demand charges."[65]

Demand charges are typically calculated based on the largest amount of electricity used during a 15-minute interval in a given month. (The CALSTART report notes that some utilities will only levy demand charges if a commercial or industrial customer's energy use rises above a certain threshold, however that threshold can vary significantly from utility to utility.)[66] What is remarkable about demand charges is the way in which they can be disproportionately expensive when a transit agency is operating just one or two BEBs as opposed to a larger number

63 Gallo et al., "Peak Demand Charges."

64 Gallo et al., "Peak Demand Charges," p. 20.

65 Gallo et al., "Peak Demand Charges," p. 6.

66 Gallo et al., "Peak Demand Charges," p. 21.

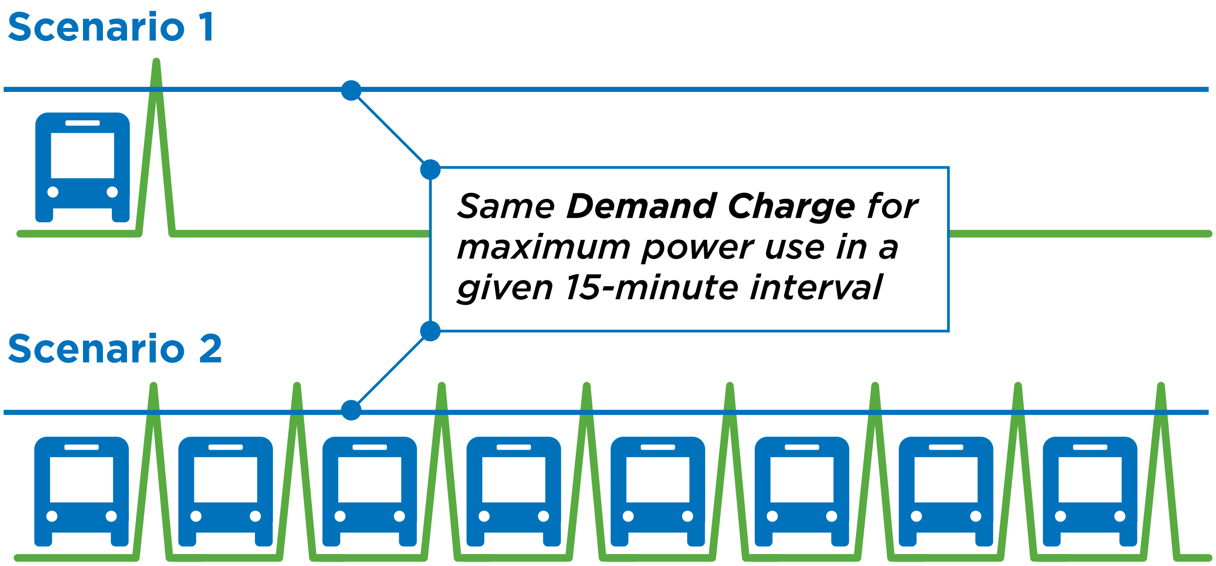
of BEBs. For example: Imagine Scenario 1, in which a transit agency has one BEB which it charges with an on-route charger. The BEB only needs to charge for several minutes at a time, but uses a large amount of electricity while charging. The resulting monthly demand charge is $2800.

In contrast, imagine Scenario 2, where a transit agency operates eight BEBs, all of which share the same on-route charger over the course of a given day. The eight BEBs all charge for the same amount of time as the single BEB in the first scenario, but the maximum power use in a given 15-minute interval remains the same. As a result, the transit agency's monthly demand charge is still $2800. The relative costs of these two scenarios (as well as similar examples for BEB fleets of two and four buses) are shown in table 1-1:

	1 bus	2 buses	4 buses	8 buses
Total Energy Charges	$750	$1500	$3000	$6000
Total Demand Charges	$2800	$2800	$2800	$2800
Total Charges	$3550	$4300	$5800	$8800
Per bus	***$3550***	***$2150***	***$1450***	***$1100***
Per mile	***$1.18***	***$0.72***	***$0.48***	***$0.37***

Table 1-1: Operating costs for fast-charging electric bus fleets of different sizes (source: Gallo et al.)

The greater the number of buses per on-route charger, the lower the energy cost per bus. Practically speaking, though, there is a limit on how many buses can use a given on-route charger during the day: the length of the bus's route, the time each bus needs to charge, and the number of buses whose routes intersect with the charger will contribute to determining how many buses a given charger can accommodate.



The CALSTART report provides a similar example to illustrate the difference in demand charges between on-route charging and overnight plug-in charging. Imagine Scenario 3, in which a transit agency has eight BEBs, all of which it charges overnight with plug-in chargers. Each plug-in charger uses electricity at a lower rate than an on-route charger (so the "spike" in demand created by each bus is lower). However because all eight buses are being charged at the same time, each additional bus increases the total amount of electricity being used—and as a result, the demand charge increases with each additional bus. (This is in contrast to Scenario 2, in which additional buses did not increase the demand charge.) The changes in electricity demand for Scenario 2 and Scenario 3 are shown in table 1-2: as the size of the BEB fleet increases to 8 buses, the peak electricity use for on-route charging and overnight charging become comparable:

	On-route	Overnight
Nominal Power	450 kW	40 kW
Average Peak Demand (1 bus)	150 kW	40 kW
Average Peak Demand (4 bus)	280 kW	160 kW
Average Peak Demand (6 bus)	330 kW	240 kW
Average Peak Demand (8 bus)	380 kW	320 kW

Table 1-2: Comparison of peak demand for on-route charging vs. overnight charging (source: Gallo et al.)

To give a sense of the relative cost of demand charges, the CALSTART report compares fuel cost per mile for diesel, CNG, and electric buses. Figures 1-7 and 1-8 show these cost comparisons for low and high demand charges. Readers should note that these estimated costs are based on a set of assumptions about the costs of fuel and electricity, as well as how much electricity each bus uses and how many miles each bus travels per year.[67] In describing CALSTART's research, Hanlin et al. note that all of these assumed values can vary greatly over time and from region to region, and point out that as of early 2018, many transit agencies were paying less than $2/gallon for diesel, which is less than half of the $4/gallon value used in the CALSTART analysis.[68] That being said, the CALSTART cost estimates clearly illustrate the non-trivial expense that demand charges may add to an agency's BEB operating budget.

67 "We assume each bus drives 40,000 miles per year. The diesel bus has a fuel economy of 4 MPG and diesel is priced at $4.00 per gallon. The CNG bus has a fuel economy of 3.5 MPDGE and CNG is priced at $2.00 per DGE. The electric transit buses have an efficiency of 2.5 AC kWh / mile and electricity is priced at $0.10/kWh. One electric bus charging on-route draws 150 kW from the grid, 4 draw 280 kW, 6 draw 330 kW and 8 draw 380 kW. The electric bus charging overnight draws 40 kW from the grid." Gallo et al., "Peak Demand Charges," p. 26, footnote 25.

68 Hanlin et al., "Battery Electric Buses," p. 25.

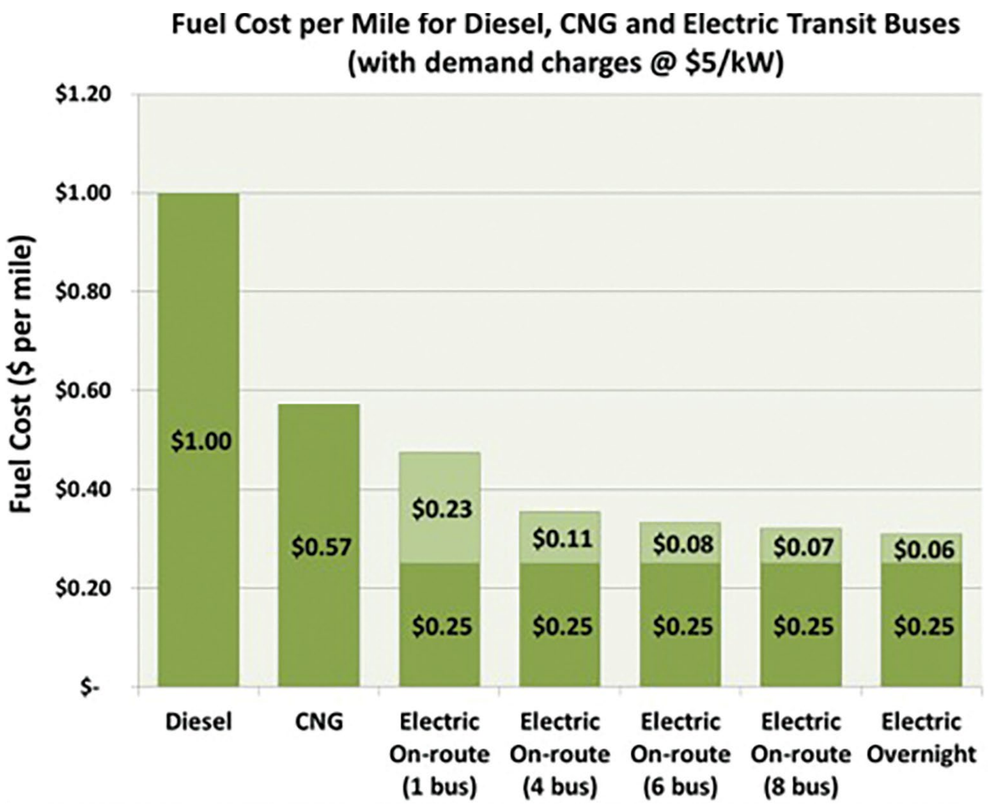


Figure 1-7: Fuel costs per mile for different buses, with demand charges (indicated in light green) at $5/kW (source: Gallo et al.)

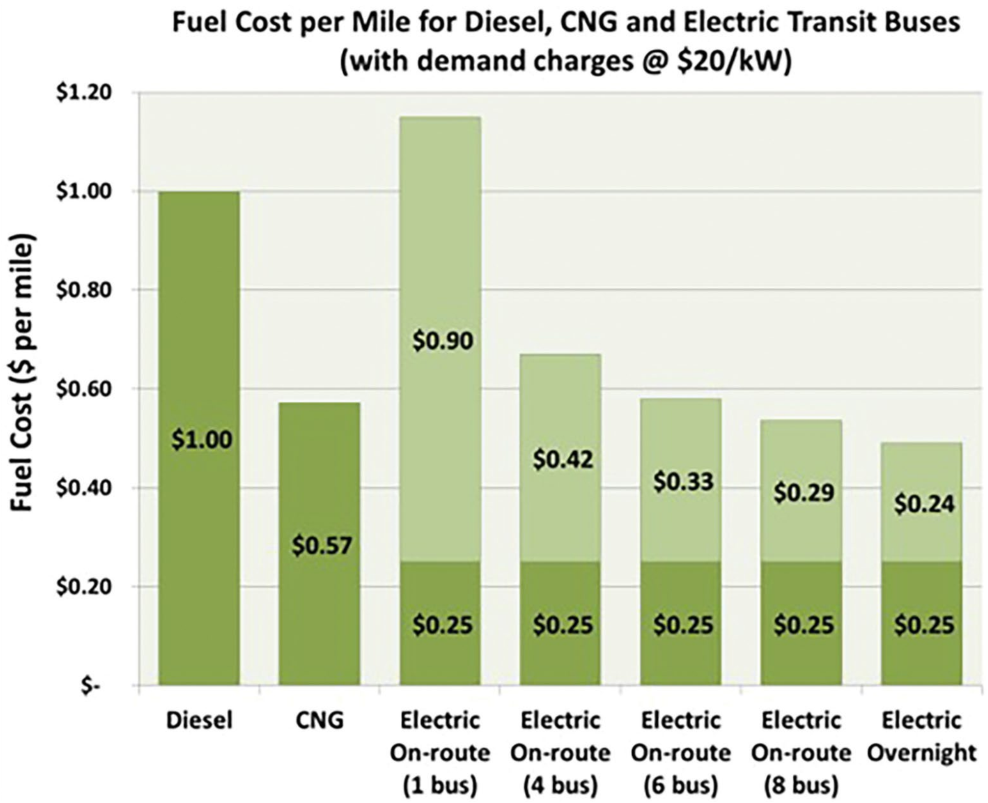


Figure 1-8: Fuel costs per mile for different buses, with demand charges (indicated in light green) at $20/kW (source: Gallo et al.)

As mentioned earlier, electricity charges also vary according to the time of day: at night, utilities usually can rely mostly on their baseload power plants to cheaply meet the low demand for power. However during the middle of the day, when much more electricity is being used, the cost of electricity goes up significantly as utilities use their more expensive intermediate and peaking power plants to meet demand. Similarly, electricity prices can vary seasonally, depending on the needs for air conditioning and heating in different parts of the country. These different price factors also need to be taken into consideration when transit agencies are mapping out long-term BEB costs.

The literature on BEBs in public transit repeatedly emphasizes how important it is for agencies to work with their local utility early in the BEB planning process. The survey data collected in Hanlin et al. showed that "[m]ost of the transit agencies reported that they involved the local utility early in the process when making procurement decisions (78 percent) and when making installation decisions (83 percent)"[69] and "[a]ll of the transit agencies that responded ... believe there is a need for development of a utility rate specifically suited to the needs of BEB fleets."[70] In California, where the Fleet Rule and the Innovative Clean Transit regulation are expediting the statewide transition of public bus fleets to ZEBs, utilities are developing comprehensive programs designed to support transit agencies and lower the barriers to BEB deployment. One such example is Southern California Edison's Charge Ready program[71], in which participating agencies work with Southern California Edison (SCE) to map out plans for managing fleet conversion. The agency and SCE work together to maximize the use of existing infrastructure that can help meet the agency's near-term charging needs, and to create a plan for a phased build-out that will accommodate the projected growth of the agency's BEB fleet while allowing for future technological improvements.

Through the Charge Ready program, the transit agency pays for the vehicles and the charging infrastructure and SCE covers all costs associated with designing and installing the necessary utility connections. The agency also works with SCE to decide the number and types of chargers that will allow the agency to power its BEBs while keeping overall electricity use below a reasonable threshold—a practice known as load-side management. There is an emerging market of load-side management software products that transit agencies are starting to utilize.

69 Hanlin et al., "Battery Electric Buses," p. 46.

70 Hanlin et al., "Battery Electric Buses," p. 51.

71 "SCE Charge Ready: Transit Bus Program Fact Sheet," Southern California Edison, no date.

These products integrate the agency's bus dispatch systems and bus charging systems with the local electric grid to allow each BEB in the fleet to charge at the optimal time and for the necessary duration while keeping overall electricity use at a level that won't incur demand charges. Early data on managed fueling by electric school bus operators indicates that the software's use can result in potentially significant cost savings.[72] Load-side management products are becoming an increasingly integral aspect of transit fleet BEB deployment, and programs like Charge Ready will likely become more widely available as utilities in other parts of the US work with the growing numbers of agencies that are planning to increase their BEB fleets.

72 Nicole Schlosser, "Electric School Buses Take to the Road: Real-World Results," School Bus Fleet, May 15, 2018.

Additional Considerations and Looking Ahead

Another notable characteristic of BEBs is how quietly they run: in the early and mid 2000s, when hybrid passenger cars were becoming more widely available, car owners would frequently remark on how different it felt to drive a car with an almost silent engine. Relative to other bus types, BEBs are establishing new levels of quiet: According to Altoona testing of New Flyer's diesel, CNG, hybrid, and battery-electric buses, BEBs had the lowest exterior and interior noise levels in every test case, with the one exception of interior noise levels in the driver's seat, where engine noise was roughly the same for both battery-electric and diesel buses.[73] Agency professionals frequently praise the quietness of BEBs, and it would be surprising if communities along BEB transit routes failed to notice the lower levels of traffic noise as BEBs are increasingly deployed in the months and years to come.

Indeed, the development of public perceptions around BEBs will be important to observe on many levels. In an interview for this report, one agency professional who described how some of his transit customers would forgo riding the first, and possibly second bus to arrive at the bus stop, preferring instead to wait to board one of the agency's BEBs. Another professional described riding along on one of his agency's pilot BEBs in the first week of its deployment: despite outfitting the new bus with an eye-catching exterior, morning commuters seemed mostly unaware that they were being transported by a pioneering form of transit. These two anecdotes provide an interesting complement to each other: on one hand, agencies would certainly be gratified to see that the public is excited about the new technology, especially considering all the planning preceding its implementation. And in another sense, a highly positive outcome is for BEBs to integrate into an agency's transit system so seamlessly that the complexities surrounding their deployment are never even perceived.

Directly related to these future scenarios, however, is the question of how agencies can plan for the scalability of their BEB fleets. This issue comes up consistently in discussions, conference talks, and interviews with agency professionals. Regardless of an agency's size or geographic location, staff tasked with BEB planning share a strong motivation to structure their work in a way that will allow their BEB fleets to grow as smoothly, efficiently, and affordably as possible. For most agencies, achieving scalability will be highly challenging: constraints around the real estate needed for depot or on-route charging, access to utility connections, and negotiating electricity rates—combined with the logistical

73 Hanlin et al., "Battery Electric Buses," p.33-34.

necessity of growing a bus fleet over time with successive procurements—are some of the main challenges for designing scalable BEB deployment. The agencies that are already in the process of transitioning their fleets to BEBs will have the advantage of establishing their leadership and expertise with the new technology; through their procurements, they can also play a role in shaping the development of the technology itself. Agencies that take on BEB transition further in the future will have the benefit of learning from the experiences of first-mover agencies, and may benefit from lower purchase prices, but their maintenance staff and bus operators will still need to master the BEB learning curve. In addition to planning and operational challenges, however, a large-scale transition from diesel and CNG buses to BEBs includes important environmental and economic considerations—to be discussed in the following chapters—that will powerfully impact both the communities each agency serves and the country as a whole.

2 Environmental and Public Health Considerations

While deploying and operating BEB fleets requires complex preparation and planning, stakeholders at all levels have expressed widespread agreement about the substantial environmental and public health benefits that electric buses can provide. Agencies are clear on the value of achieving better air quality and reducing reliance on greenhouse-gas producing fossil fuels.

For Bloomberg New Energy Finance's 2018 report, researchers interviewed officials from an international collection of large and mid-sized cities at varying levels of economic development to learn about the role that BEBs could play for a range of different municipalities. The BNEF researchers found that "[r]egardless of the archetype, all cities mentioned environmental outcomes as one of the major reasons for considering electric buses."[74] This chapter will provide more detailed background on those outcomes as they relate to climate, air quality, and health for both the general public—especially low-income and environmental justice communities—and transit workers.

Fossil Fuel Use and Greenhouse Gas Emissions

Battery-electric buses are still a relatively small fraction of the global bus fleet—and an even smaller fraction of the US fleet. However, recent reporting gives a sense of the impact that continued BEB deployment could have on worldwide petroleum use. Even though the number of BEBs currently in use is small relative to other vehicles, the large amounts of diesel that buses use (relative to cars) allows them to have a disproportionate impact on fuel consumption. According to calculations from Bloomberg New Energy Finance, putting 1,000 BEBs on the road has the

74 Bloomberg, "Electric Buses in Cities," p. 48.

effect of reducing diesel fuel use by 500 barrels per day. In March 2019, Bloomberg researchers forecast that in the coming year, about "270,000 barrels a day of diesel demand will have been displaced by electric buses,"[75] most of which are located in China (figure 2-1). The amount of diesel that will be avoided through the use of electric buses is roughly equivalent to Greece's oil consumption.

Cumulative global fuel displacement by e-buses and passenger EVs

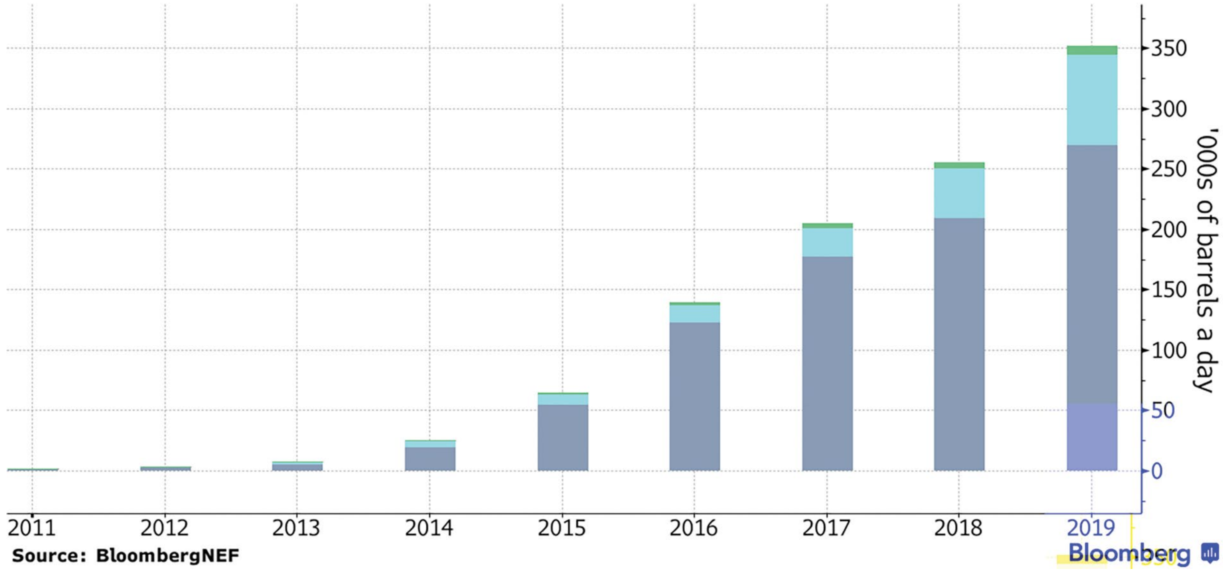


Figure 2-1: Cumulative global fuel displacement by e-buses and passenger EVs. Violet = diesel displaced by electric buses; turquoise = gasoline displaced by passenger EVs; green = diesel displaced by passenger EVs. (Source: Bloomberg New Energy Finance)

This reduction in diesel use is all the more noteworthy considering that substantial room exists for BEB use to expand, both in the US and worldwide. A full conversion of the US transit bus fleet would enlarge the global BEB count by about 70,000 vehicles, reducing the amount of diesel fuel needed by 35,000 barrels per day—an additional 13 percent relative to the BNEF calculation.

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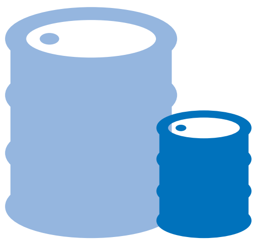

75 Alaric Nightingale, "Forget Tesla, It's China's E-Buses That Are Denting Oil Demand," Bloomberg, March 19, 2019.

Another way to look at BEB-related fuel use and greenhouse gas (GHG) emissions is to compare those BEB characteristics to GHG emissions for diesel and CNG buses. As mentioned in Chapter 1, analysis by the Union of Concerned Scientists (UCS) and the Greenlining Institute based on data for 40-foot diesel, CNG, fuel-cell, and battery-electric buses show that BEBs have the lowest lifetime GHG emissions of all bus types (figure 2-2). Making calculations based on the different sources of electricity in California in 2016, lifetime GHG emissions for a BEB powered on the California grid would be 74 percent lower than emissions for a conventional diesel bus. For a BEB connected to a grid powered with 50 percent renewable energy and 50 percent natural gas, lifetime GHG emissions would be 80 percent lower than the diesel bus. (The UCS/Greenlining report calculated California electricity emissions based on a mix of roughly 25 percent renewable energy, 8 percent large-scale hydropower, 10 percent nuclear power, 7 percent coal, and 50 percent natural gas.[76]) For comparison, CNG buses and fuel-cell buses have lifetime GHG emissions that are 9 percent lower and 59 percent lower, respectively, than diesel buses.[77]

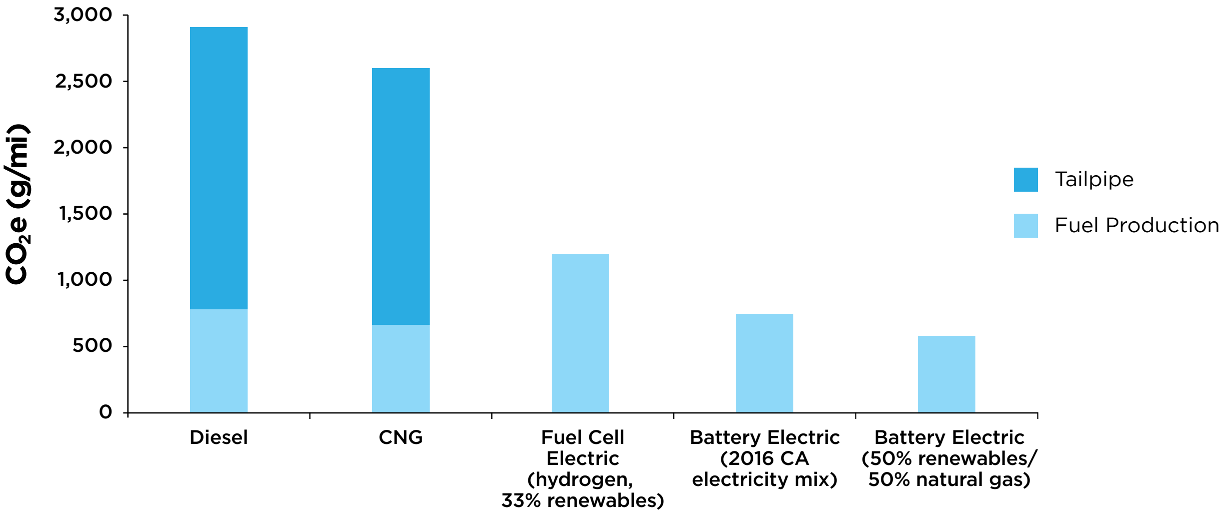

Figure 2-2: Lifetime greenhouse gas emissions for different bus types. Global warming emissions from diesel and CNG buses are far higher than those from fuel-cell electric buses (fueled by hydrogen gas) or BEBs. Comparison based on emissions from 40-foot transit buses. CO_2e stands for carbon dioxide equivalent. (Source: Chandler et al.)

The Union of Concerned Scientists released additional research in July 2018 showing that, despite the range of electricity mixes across the United States, BEBs have lower lifetime GHG emissions than diesel, natural gas, and diesel-hybrid buses (figure 2-3). Lifetime GHG emissions for diesel buses can be anywhere from 1.4 to 7.7 times the lifetime emissions for BEBs, depending on region.[78]

76 Chandler et al., “Delivering Opportunity,” p. 15.

77 Chandler et al., “Delivering Opportunity.”

78 Jimmy O’Dea, “Electric vs. Diesel vs. Natural Gas: Which Bus is Best for the Climate?,” Union of Concerned Scientists (blog), July 19, 2018.

Life cycle global warming emissions from different types of transit buses

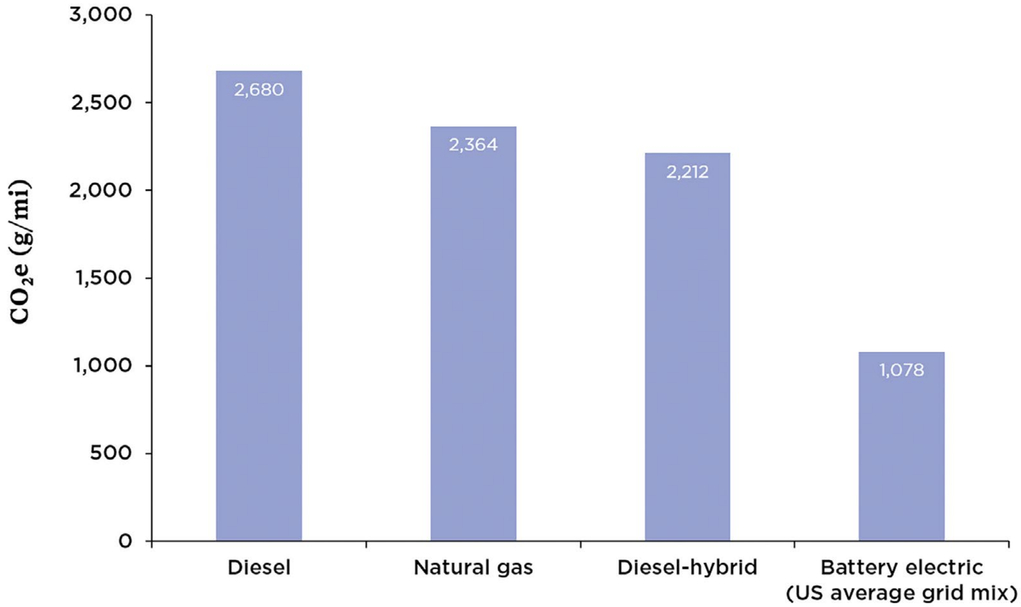

Figure 2-3: Lifetime global warming emissions for different types of transit buses in terms of grams of CO_2-equivalent emissions per mile. Charged with the national electricity mix, an electric bus produces 60 percent less CO_2e per mile compared to a diesel bus. (Source: Union of Concerned Scientists)

The GHG emissions that can be avoided by switching to BEBs are therefore a significant step that agencies and municipalities can take to mitigate the impacts (and economic consequences) of climate change. Those impacts are already being felt around the country in the form of higher seasonal temperatures,[79] increased sea level rise,[80] shorter snow season and reduced snow cover,[81] longer and more frequent fire seasons,[82] and changing fisheries,[83] to name a few.

Especially notable is the increase in frequency and intensity of severe weather events, which in many ways have become the bellwether for climate change's future economic cost. According to the Bulletin of the American Meteorological Society's *The State of the Climate in 2016*,

79 A. Mekonnen, J. A. Renwick, and A. Sánchez-Lugo, "State of the Climate in 2016: Regional Climates," Bulletin of the American Meteorological Society, August 2017, p. S93-S128.

80 Environmental Protection Agency, "Climate Change Indicators: Sea Level," https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level.

81 Noah Knowles, "Trends in Snow Cover and Related Quantities at Weather Stations in the Conterminous United States," Journal of Climate, 28, October 1, 2015.

82 M. W.. Jolly, M. A. Cochrane, P. H. Freeborn, Z. A. Holden, T. J. Brown, G. J. Williamson, and D. M. J. S. Bowman, "Climate-induced variations in global wildfire danger from 1979 to 2013," Nature Communications, 6, July 14, 2015.

83 National Oceanic and Atmospheric Administration Fisheries, "Understanding Our Changing Climate" (June 19, 2017), https://www.fisheries.noaa.gov/insight/climate.

> *There were 15 weather and climate events with losses (insured and uninsured) exceeding $1 billion (U.S. dollars) each across the United States ... in 2016, including drought, wildfire, four inland flood events, eight severe storm events, and a tropical cyclone event (Hurricane Matthew). The 2016 total was the second highest annual number of U.S. billion dollar disasters (adjusted for inflation) since records began in 1980, behind the 16 events that occurred in 2011. Cumulatively, these 15 events led to 138 fatalities and caused $46.0 billion (U.S. dollars) in total, direct costs. The four billion-dollar non-tropical inland flood events during 2016 doubled the previous record, as no more than two such costly inland flood events have occurred in a single year since at least 1980.*[84]

Even though cars and trucks contribute significantly more to US GHG emissions than buses,[85] given the potential severity of present-day and future climate change impacts, BEB-associated GHG reductions are still important (especially so if increased public transit can raise the proportion of total passenger miles traveled by bus relative to cars). Mitigating future climate change is especially critical given the disproportionate impact that climate change is and will continue to have on poor and historically marginalized communities.[86] People living in low-income communities are more likely to live in substandard housing (increasing their vulnerability to weather damage) and are less likely to have the financial resources to rebuild or relocate after hurricanes or major storms.[87] People living in poverty or social isolation are more at risk for health problems in extreme heat events, due to their lack of access to or inability to afford air conditioning.[88] Marginalized communities are also more likely than other populations to experience water contamination, delays in medical treatment, disruption of educational services, and damage to infrastructure as a result of severe weather. Events have repeatedly played out this way in the US, most recently in the case of Hurricane Maria's impact on Puerto Rico in 2017.[89] These considerations are especially relevant given the public health and air quality impacts that diesel buses have on low-income communities, which this chapter will discuss in greater detail.

In thinking about the future GHG-related benefits of switching from fossil fuel buses to BEBs, it's worth considering how America's energy-generation mix is likely to change in coming decades. What would the emissions trade-off be in a future United States where a greater number of buses were powered by the grid instead of by diesel and natural gas? The growing number of American cities and counties (as well as Hawaii, California, New Mexico, and Puerto Rico) that are committed to, or

84 Mekonnen et al., "State of the Climate."

85 "Facts Facts: U.S.Transportation Sector Greenhouse Gas Emissions 1990-2016," U.S. Environmental Protection Agency, July 2018.

86 Barry S. Levy and Jonathan A. Patz, "Climate Change, Human Rights, and Social Justice," Annals of Global Health, 81:3, May-June 2015, p 310-322.

87 Tracey Ross, "A Disaster in the Making: Addressing the Vulnerability of Low-Income Communities to Extreme Weather," Center for American Progress, August 2013.

88 "Excessive Heat Events Guidebook," EPA 430-B-16-001, U.S. Environmental Protection Agency, June 2006.

89 "Climate Change & Human Rights: A Primer," Center for International Environmental Law, 2011.

already powered by, 100 percent renewable energy[90] are one indication that lifetime GHG emissions from BEBs and other electric vehicles may continue decreasing in the coming decades. A detailed discussion of forecasted renewables deployment is beyond the scope of this report, however recent trends in energy markets provide strong indications that renewable energy generation will increase as prices for wind and solar energy (which are already competitive with combined-cycle natural gas plants) continue to drop.[91] The US Energy Information Administration regularly reports on the levelized cost of energy, which can be considered as the average price of a unit of energy from a given source. Their analysis from February 2019 (table 2-1) shows that, even without consideration of environmental and public health benefits, the costs for wind power and photovoltaic solar energy are comparable with electricity from combined-cycle natural gas plants (currently the cheapest form of fossil fuel electricity available). This price parity, combined with the public's strong support for renewable energy,[92] indicate the likelihood that the future US electric grid will be increasingly powered by renewable sources without GHG or particulate emissions.

90 Sierra Club, "100% Commitments in Cities, Counties, & States," https://www.sierraclub.org/ready-for-100/commitments.

91 David Roberts, "Clean energy is catching up to natural gas," Vox, July 13, 2018.

92 Pew Research Center, "2. Public opinion on renewables and other energy sources," http://www.pewinternet.org/2016/10/04/public-opinion-on-renewables-and-other-energy-sources/.

Plant type	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit	Total LCOE including tax credit
Dispatchable technologies							
Coal with 30% CCS	61.3	9.7	32.2	1.1	104.3	NA	104.3
Coal with 90% CCS	50.2	11.2	36.0	1.1	98.6	NA	98.6
Conventional CC	9.3	1.5	34.4	1.1	46.3	NA	46.3
Advanced CC	7.3	1.4	31.5	1.1	41.2	NA	41.2
Advanced CC with CCS	19.4	4.5	42.5	1.1	67.5	NA	67.5
Conventional CT	28.7	6.9	50.5	3.2	89.3	NA	89.3
Advanced CT	17.6	2.7	54.2	3.2	77.7	NA	77.7
Advanced nuclear	53.8	13.1	9.5	1.0	77.5	NA	77.5
Geothermal	26.7	12.9	0.0	1.4	41.0	-2.7	38.3
Biomass	36.3	15.7	39.0	1.2	92.2	NA	92.2
Non-dispatchable technologies							
Wind, onshore	39.8	13.7	0.0	2.5	55.9	-6.1	49.8
Wind, offshore	107.7	20.3	0.0	2.3	130.4	-12.9	117.5
Solar PV	47.8	8.9	0.0	3.4	60.0	-14.3	45.7
Solar thermal	119.6	33.3	0.0	4.2	157.1	-35.9	121.2
Hydroelectric	29.9	6.2	1.4	1.6	39.1	NA	39.1

Table 2-1: Estimated levelized cost of electricity (unweighted average) for new generation resources entering service in 2023 (2018 $/MWh). CCS=carbon capture and sequestration. CC=combined-cycle (natural gas). CT=combustion turbine. PV=photovoltaic. The tax credit component is based on targeted federal tax credits such as the PTC or ITC available for some technologies. It reflects tax credits available only for plants entering service in 2023 and the substantial phase out of both the PTC and ITC as scheduled under current law. Technologies not eligible for PTC or ITC are indicated as NA or not available. The results are based on a regional model, and state or local incentives are not included in LCOE calculations. See text box on page 2 for details on how the tax credits are represented in the model. (Source: US Energy Information Administration, Annual Energy Outlook 2019)

BEBs, Air Quality, and Health Impacts

Reducing reliance on fossil fuel-powered buses has the potential to substantially improve air quality and public health. The vehicle exhaust that is produced from burning diesel and gasoline contains numerous substances that cause poor health, disease, and shortened lifespan. A major category of pollutants from vehicle exhaust includes nitrogen oxide (NO) and nitrogen dioxide (NO_2), which are generally referred to collectively as NO_x (figure 2-4). Exposure to NO_x irritates the human respiratory system: short-term exposure can exacerbate asthma and other respiratory diseases, resulting in the need for medical care. Long-term exposure can contribute to the development of asthma and heighten susceptibility to other respiratory illnesses.

In addition to causing health problems on its own, exposure to sunlight causes NO_x to react with atmospheric oxygen (O_2) and other pollutants to create ozone (O_3). Ozone is the main component of smog; like NO_x, breathing ozone can irritate human airways, causing chest pain, coughing, and sore throat; and can exacerbate other respiratory conditions like emphysema, asthma, and bronchitis.

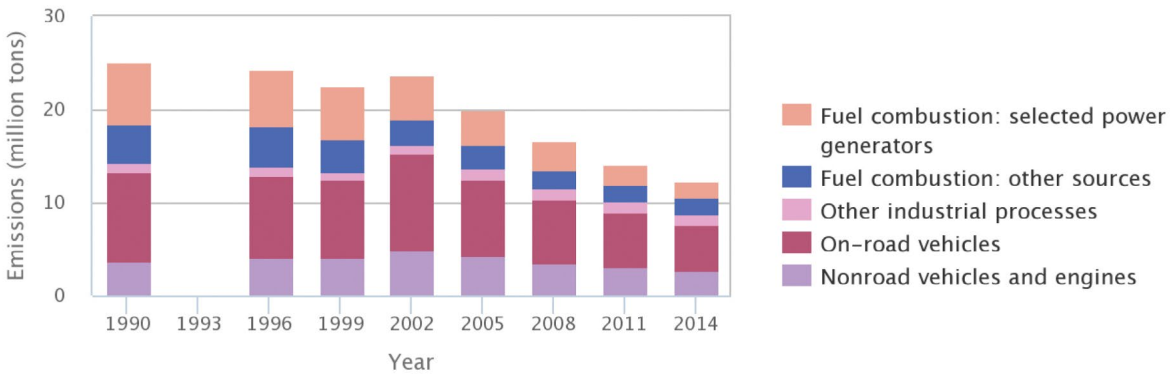

Figure 2-4: Anthropogenic NO_x emissions in the US by source category, 1990-2011. (Source: EPA)

Particulate matter (PM), which is the third major pollutant from vehicle exhaust, consists of tiny solid particles (like soot and dust) or liquid droplets. Particulate matter from diesel exhaust is especially dangerous because it contains benzene, formaldehyde, and other harmful substances. As a result, the World Health Organization has classified diesel exhaust PM as a carcinogen,[93] and CARB has classified it as a toxic air contaminant. According to a 2008 paper from Douglas Houston and colleagues, diesel exhaust PM has also been associated with approximately 70 percent of the known potential cancer risk from exposure to air toxics in Southern California.[94] Levels of PM pollution can also be increased by NO_x, which reacts with other chemicals in the air to create additional PM.

93 Chandler et al., "Delivering Opportunity," p. 9.

94 D. Houston, M. Krudysz, and A. Winer, "Diesel Truck Traffic in Low-Income and Minority Communities Adjacent to Ports," Journal of the Transportation Research Board, 2067:1, January 1, 2008, p. 38-46. "Multiple Air Toxics Exposure Study in the South Coast Air Basin (MATES-II)," South Coast Air Quality Management District, March 2000.

There are two main types of particulate matter: PM_{10} (made up of particles that are about 10 micrometers or smaller) and $PM_{2.5}$ (particles that are generally 2.5 micrometers or smaller). Both types of PM are inhalable, however $PM_{2.5}$ is considered to be more harmful because it can penetrate deeper into the lungs and, in some cases, into the bloodstream as well. The health impacts of PM exposure are extensive, and scientific studies have shown links between PM and aggravated asthma, irregular heartbeat, decreased lung function, nonfatal heart attacks, premature death in people with heart or lung disease,[95] shorter life expectancies, and an increased risk of death from stroke.[96]

In addition to the specific harms caused by ozone, NO_x, and PM, research shows that air pollution is generally linked to a wide range of health impacts including premature death,[97] cardiovascular disease,[98] increased risk of multiple kinds of cancer,[99] pregnancy complications,[100] decreased cognitive ability,[101] and impaired lung function in children[102] and adults.[103]

95 Environmental Protection Agency, "Health and Environmental Effects of Particulate Matter (PM)," https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm.

96 "Counties with dirtier air have more stroke deaths" (press release), American Heart Association: January 30, 2019.

97 J. Lelieveld, J.S. Evans, M. Fnais, D. Giannadaki, and A. Pozzer, "The contribution of outdoor air pollution sources to premature mortality on a global scale," Nature, 525, September 17, 2015, p. 367-371.

98 J. O. Anderson, J.G. Thundiyil, and A. Stolbach. "Clearing the Air: A Review of the Effects of Particulate Matter Air Pollution on Human Health," Journal of Medical Toxicology, June 2012, p. 166-175.

99 C.M. Wong, H. Tsang, H.K. Lai, G. N. Thomas, K.B. Lam, K.P. Chan, Q. Zheng, J.G. Ayres, S.Y. Lee, T.H. Lam, and T.Q. Thach. "Cancer mortality risks from long-term exposure to ambient fine particle," Cancer Epidemiology, Biomarkers and Prevention, p. 1-7.

100 J. Wu, C. Ren, R.J. Delfino, J. Chung, M. Wilhelm, B. Ritz, "Association between local traffic-generated air pollution and preeclampsia and preterm delivery in the south coast air basin of California," Environmental Health Perspectives, November 2009, p. 1773-1779.

101 M.C. Power, M.G. Weisskopf, A.E. Stacey, B.A. Coull, A. Spiro, and J. Schwartz, "Traffic-related air pollution and cognitive function in a cohort of older men," Environmental Health Perspectives, 119:5, May 2011, p. 682-687.

102 R. Urman, R. McConnell, T. Islam, E.L. Avol, F.W. Lurmann, H. Vora, W.S. Linn, E.B. Rappaport, F.D. Gilliland, and W.J. Gauderman, "Associations of children's lung function with ambient air pollution: joint effects of regional and near-roadway pollutants," Thorax, 69:6, June 2014, p. 540-547.

103 Anderson et al., "Clearing the Air."

Occupational Impacts

Transit workers with occupational exposure to exhaust from diesel buses are one of the first groups of people who would benefit from a transition to BEBs. A substantial and growing body of published research attests to the health risks of jobs that involve occupational exposure to heavy-duty vehicle emissions. Many of these studies have been conducted in Denmark and Sweden, owing to the longstanding tradition of employee record keeping in those countries. A study by Tüchsen and Hannerz looked at records for Danish workers across a wide range of occupations from 1981 to 1991, and found that taxi and bus drivers were included in the group of workers for whom chronic obstructive pulmonary disease (COPD) hospitalization rates increased over time.[104] Another Danish study of urban bus drivers and tramway workers from 1900 to 1994 found that bus drivers and tramway workers had an increased risk of developing multiple cancers, especially lung cancer.[105] Similarly, a Swedish study by Gustavsson and colleagues assessed the health impacts of diesel exhaust by analyzing the records of men who had worked in bus garages for at least six months between 1945 and 1970. The researchers found that lung cancer risk grew with increased cumulative exposure to bus diesel exhaust.[106] Another study of men working in a range of occupations in Sweden showed that the incidence of coronary heart disease in bus and tram drivers was nearly three times as high as that of the other men in the study.[107]

While the body of research on emissions-related health risks for frontline transit workers appears to be smaller in the US than in Europe, a recent article on American trucking industry workers found that long-haul drivers, who have high levels of exposure to diesel exhaust relative to other professions, had increased risk of dying from heart disease.[108] A 2017 study by Zhang and colleagues also showed that for diesel engine testing workers, long-term exposure to diesel exhaust resulted in lung function decline, and that this decreased lung function was associated with elevated indications of genomic instability (a precursor to tissue damage and cancer formation).[109] Also in 2017, the California Department of Public Health held

104 F. Tüchsen and H. Hannerz, "Social and occupational differences in chronic obstructive lung disease in Denmark 1981-1993," American Journal of Industrial Medicine, 37:3, March 2000, p. 300-306.

105 H. Soll-Johanning, E. Bach, J.H. Olsen, and F. Tüchsen, "Cancer incidence in urban bus drivers and tramway employees: a retrospective cohort study," Occupational and Environmental Medicine, 55:5. September 1998, p. 594-598.

106 P. Gustavsson, N. Plato, E.B. Lidström, and C. Hogstedt, "Lung cancer and exposure to diesel exhaust among bus garage workers." Scandinavian Journal of Work, Environment and Health, 16:5, October 1990, p. 348-354.

107 A. Rosengren, K. Anderson, and L. Wilhelmsen, "Risk of coronary heart disease in middle-aged male bus and tram drivers compared to men in other occupations: a prospective study," International Journal of Epidemiology, 20:1, March 1991, p. 82-7.

108 J.E. Hart, E. Garshick, T.J. Smith, M.E. Davis, and F. Laden, "Ischemic heart disease mortality and years of work in trucking industry workers." Occupational and Environmental Medicine, 70:8, August 2013, p. 523-528.

109 L.P. Zhang, X. Zhang, H.W. Duan, T. Meng, Y. Niu, C.F. Huang, W.M. Gao, S.F. Yu, and Y.X. Zheng, "Long-term exposure to diesel engine exhaust induced lung function decline in a cross sectional study," Industrial Health, 55:1, February 2017, p. 13-26.

focus groups with bus operators in San Mateo, Long Beach, and San Jose as part of the Department's Work-Related Asthma Prevention Program. Breathing issues and vehicle exhaust were consistently cited as problems by the participating bus operators. The focus groups were initiated as a result of the Department's ongoing research, which consistently showed "Local Transit" as the industry sector with the highest rate of work-related asthma statewide, and with bus operators experiencing work-related asthma at a rate that was 2.5 times higher than that of all occupations combined.[110] In light of these and other studies, it is difficult to deny that shifting to zero-emission electric engines would substantially improve long-term health prospects and reduce medical costs for the transit staff who operate, maintain, or perform other hands-on work with conventionally fueled buses.

Air Pollution Impacts on Vulnerable Communities

Another important characteristic of air pollution is the heightened risk that localized pollution hotspots—such as bus depots, ports, and heavily traveled roads—pose to certain communities. Air pollution levels—and the resulting health risks—typically increase the closer one lives or works to major highways, railroads, airports, or similar facilities. In 2009, the EPA reported that about 15 percent of Americans lived near major traffic areas;[111] in urban areas, 30 to 45 percent of the local populations are estimated to live in high traffic areas.[112]

Compounding the risks associated with tailpipe pollution for people living in high traffic areas is the heightened exposure that low-income and minority populations have to air pollution. A large body of research literature has documented the disproportionate pollutant exposure these communities face. The correlation between poverty level, ethnic background, and vehicle emissions has been discussed in numerous publications. However the UCS/Greenlining report provides a vivid depiction of these three related factors by using EPA data to show the overlap between low-income populations, communities of color, and diesel PM pollution in the Los Angeles area (figure 2-5).

110 Personal communication with Ed Watt, Amalgamated Transit Union, and Jennifer Flattery, California Department of Public Health, Occupational Health Branch, February 2019.

111 "Near Roadway Air Pollution and Health: Frequently Asked Questions," Environmental Protection Agency, August 2014.

112 "Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects," Health Effects Institute, January 2010.

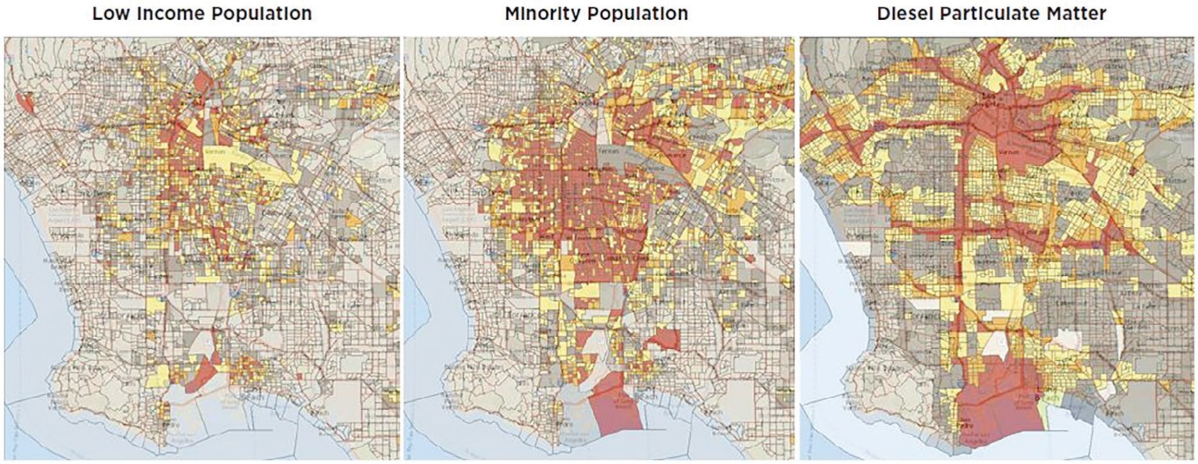

Figure 2-5: Maps of the Los Angeles area using 2016 EPA data showing correlations between diesel particulate air pollution, income, and race. (Source: Chandler et al., 2016)

The race-income-pollution relationship is also discussed in the analysis of US Census data by Lara Clark and colleagues. Their research shows that, nationwide, ground-level NO_2 concentrations are 38 percent higher for nonwhites than for whites; 10 percent higher for people below the poverty line compared to people above the poverty line; and 27 percent higher for lower-income nonwhites than for higher-income whites.[113] Additional research by Gregory Rowangould shows that, on average, the portion of the US population that lives closer to roads with high traffic volume is disproportionately composed of non-white residents with household income below the local median.[114]

In New York City, a dense urban environment with significant road traffic and heavily used bus and subway systems, the city's Department of Health and Mental Hygiene published a 2003 report that showed asthma-related hospitalization rates that were on the order of four times higher for children from low-income zip codes than from high-income zip codes.[115] Similar results were also included in a follow-up report that Iyad Kheirbek and other contributors wrote in 2011.[116] In 2013, Kheirbek and colleagues reported on a strong association between air pollutant-attributable health impacts and neighborhood poverty. The results discussed in Kheirbek et al's 2013 paper showed that $PM_{2.5}$- and ozone-attributable asthma emergency department visit rates were 4.5 and 3.9 times higher, respectively,

113 L.P. Clark, D.B. Millet, and J.D. Marshall, "National patterns in environmental injustice and inequality: Outdoor NO2 air pollution in the United States," PLoS ONE, April 15, 2014.

114 Gregory M. Rowangould, "A census of the U.S. near-roadway population: Public health and environmental justice considerations," Transportation Research Part D: Transport and Environment, December 2013, p. 59-67.

115 "Asthma Facts, Second Edition," New York City Department of Health and Mental Hygiene, 2003.

116 "Air Pollution and the Health of New Yorkers: The Impact of Fine Particles and Ozone," New York City Department of Health and Mental Hygiene, no date.

in high-poverty neighborhoods compared to low-poverty neighborhoods.[117] Numerous other studies demonstrate the association between air pollution in low-income and/or minority communities and the pollution-related health impacts suffered by those living there.[118,119,120,121] Furthermore, people of color (who, due to systemic barriers, are also more likely to be poor) are less likely to have access to healthcare and good-quality housing, making them more susceptible to asthma, bronchitis, cancer, and other illnesses related to poor air quality.[122]

Assessing the Impacts of Bus Emissions on Public Health

Buses contribute significantly to air pollution, especially in densely settled urban areas with large bus fleets. According to the analysis in the UCS/Greenlining report, lifecycle NO_x emissions for diesel buses were about 70 percent higher than emissions for BEBs powered on the 2016 California grid. Another way to consider the impacts of bus-related air pollution is described in the 2016 study by Judah Aber ("Electric Bus Analysis for New York City Transit"), which used the EPA's Diesel Emissions Quantifier (DEQ) to estimate the health care cost savings associated with eliminating diesel-fueled transit buses in New York City. The DEQ estimates the cost of hospitalization, emergency room visits, absence from work, and other health-related consequences of PM exposure. Using moderate assumptions for average miles traveled and fuel economy, the healthcare cost savings calculated by the DEQ ranged from $87,000 to $150,000 per bus per year, depending on which New York boroughs the buses drove in most.[123] (If ozone, NO_x, and other exhaust pollutants were taken into account, the DEQ's cost savings would arguably be higher.) The Chicago Transit Authority performed a similar analysis as part of their own electric bus initiative, and calculated a savings of $55,000 per bus per year.[124] Using Aber's high-end estimate, healthcare-related cost savings associated with the avoided New York City diesel emissions would be on the order of $100 per New York City resident per year.[125]

117 I. Kheirbek, K. Wheeler, S. Walters, D. Kass, and T. Matte, "PM2.5 and ozone health impacts and disparities in New York City: sensitivity to spatial and temporal resolution," Air Quality, Atmosphere and Health, 6:2, June 2013, p. 473-486.

118 T.S. Lena, V. Ochieng, M. Carter, J. Holguín-Veras, and P. L. Kinney. "Elemental Carbon and PM2.5 Levels in an Urban Community Heavily Impacted by Truck Traffic," Environmental Health Perspectives, October 2002, p. 1009-1015.

119 D. Houston, J. Wu, P. Ong, and A. Winer. "Structural disparities of urban traffic in Southern California: implications for vehicle-related air pollution exposure in minority and high-poverty neighborhoods, Journal of Urban Affairs, 5, November 12, 2004, p. 565-592.

120 R. Gunier, A. Hertz, J. Von Behren, and P. Reynolds, "Traffic density in California: Socioeconomic and ethnic differences among potentially exposed children," Journal of Exposure Analysis and Environmental Epidemiology, 13, 240-246.

121 "Counties with dirtier air have more stroke deaths" (press release), American Heart Association: January 30, 2019.

122 Lisa Schweitzer and Abel Valenzuela Jr., "Environmental Injustice and Transportation: The Claims and the Evidence," Journal of Planning Literature, 18:4, May 2004.

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

124 Chicago Transit Authority, "Electric Buses," https://www.transitchicago.com/electricbus/.

125 Aber, "Electric Bus Analysis," 2016.

City-level Strategies for Environmental Justice and Climate Goals

A focused approach on climate and air-quality-related environmental justice issues is already at the forefront of BEB initiatives that are in development around the country. One of the first cities to realize the potential of BEB-related air-quality benefits was the city of Seattle and its transit agency, King County Metro. In January 2017, King County Metro announced plans to purchase 120 BEBs by 2020 as part of the agency's ongoing efforts to "move people quietly and cleanly while helping meet our climate goals."[126] Later that year, the agency stated that it would purchase only zero-emission buses starting in 2020, and that its transition to a zero-emission fleet was expected to be completed by 2040, if not earlier. In March 2017, the agency released a report titled "Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet" which provided a comprehensive analysis of GHG emissions, air quality considerations, and noise pollution associated with transitioning the agency's fleet to zero-emission buses.

The report highlighted that "transitioning to a zero-emissions fleet would advance the goals and policy priorities of King County's 2015 Strategic Climate Action Plan by directly reducing transportation-related GHG emissions."[127] The report also included equity-focused analysis intended to guide King County Metro in using "the air pollution benefits of zero-emission technology [to] advance social equity by first serving communities most vulnerable to air pollution."[128] Using research on local traffic density, demographics, and environmental equity that had been commissioned by the King County Equity and Social Justice Initiative, the report assessed the air pollution vulnerability of different areas and bus routes in King County. The county's bus routes and census blocks were then scored on (1) air quality, (2) health conditions of local residents that could be caused or exacerbated by poor air quality, and (3) social factors (like poverty) that would suggest challenges in dealing with pollution-related health impacts. The resulting analysis provides guidance to the agency on how the BEB routes "can be distributed in a way that first benefits those who are most vulnerable to the effects of poor air quality and can then be distributed"[129] to other parts of Seattle over time.

Similar work is underway in Los Angeles: in July 2017, the LA Metro Board unanimously adopted a motion endorsing a comprehensive plan to transition the agency's 2,240-bus fleet to 100 percent zero-emission vehicles by 2030. The plan, which was created in response to a 2016 request from the Board that the agency develop a zero-emission initiative, is contingent on continuous advancements in electric bus technology (including range, bus weight, charging times, and

126 "King County Executive announces purchases of battery buses, challenges industry to build next-generation transit" (press release), King County (Washington), January 10, 2017.

127 "Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet," King County Metro Transit, March 2017, p. 2.

128 King County Metro, "Feasibility of Achieving," p. 57.

129 King County Metro, "Feasibility of Achieving," p. 63.

battery life) as well as future reductions in BEB prices.[130] Air quality, public health, and improved environmental outcomes were at the forefront of the agency's announcement: Los Angeles Mayor Eric Garcetti emphasized that "We're making bold investments in new technology because Metro is serious about making our air cleaner and communities healthier."[131] These sentiments were echoed by Metro Board and L.A. City Council Member Mike Bonin: "Electric buses are a game-changer because they help move more people to where they need to go, without adding harmful fossil fuel pollution to our air."[132]

Supporting those statements was language contained in the motion recommending that LA Metro's BEB plan include an equity threshold for priority BEB deployment in underserved communities, consistent with the 1964 Civil Rights Act.[133] This recommendation is in line with the agency's own civil rights policy, which includes an environmental justice commitment to preventing communities of color and low-income communities from being subject to disproportionately adverse environmental effects.

In August 2017, soon after LA Metro endorsed the creation of its comprehensive BEB plan, the San Joaquin Rapid Transit District (RTD) in Stockton, CA, announced the creation of its first all-electric bus rapid transit (BRT) route, running north-south from central Stockton to the Stockton Metropolitan Airport.[134] At the same time that the BRT route went all-electric, RTD also extended the route to service a greater area. According to CalEnviroScreen 3.0 data released earlier in 2017, the BRT route travels through an industrial corridor that ranks in the 96th percentile of California's most environmentally vulnerable communities. Providing zero-emission, low-noise transit service to residents in communities along the BRT route was one of the main objectives behind the choice to electrify that part of RTD's service area.[135] As of the writing of this report, San Joaquin Rapid Transit District was also planning to electrify a second, east-west BRT route, which traverses an economically disadvantaged part of Stockton; the possibility of extending the second BRT route (similar to the first BRT route) is also being considered. In 2017, RTD's board also approved a resolution to electrify all bus service within Stockton city limits by 2025. Fulfilling the resolution will result in upgrading about 100 of RTD's 125-bus fleet (mostly diesel-hybrid vehicles) to electric.

130 "Metro Leads the Nation in Setting Ambitious 2030 Zero Emission Bus Goal; Takes First Step with Purchase of 100 Electric Buses" (press release), Los Angeles County Metropolitan Transportation Authority, August 2, 2018.

131 L.A. Metro, "Metro Leads the Nation."

132 L.A. Metro, "Metro Leads the Nation."

133 Los Angeles County Metropolitan Transportation Authority Agenda, July 27, 2017. See item number 50 (File No. 2017-0524).

134 "San Joaquin Regional Transit District Opens First 100 Percent Electric, Zero-Emissions Bus Rapid Transit Route in the U.S." (press release), San Joaquin Regional Transit District, August 18, 2017.

135 Personal communication with Terry Williams, San Joaquin Regional Transit District Public Information Officer, August 22, 2018.

Climate change is also becoming a significant motivator for larger-scale transitions to electric vehicle fleets. In July 2018, an international coalition of states, cities, and businesses announced their participation in the Zero-Emission Vehicle Challenge, a campaign led by The Climate Group to increase the number of zero-emission vehicles (ZEVs) in their fleets and to encourage automakers to commit ZEV sales goals by 2025.[136] The ZEV Challenge campaign builds on a formal Request for Information (RFI) that Los Angeles, San Francisco, Seattle, and Portland, OR, opened to automakers to combine the purchasing power of city governments to substantially increase the number of EVs in their municipal fleets with the aim of lowering GHG emissions, improving air quality, and reducing fuel and maintenance costs.[137] This multi-city EV RFI demonstrated demand for nearly 115,000 vehicles of all classes, including buses, trash trucks, street sweepers, and shuttles, and received 40 responses from manufacturers across all vehicle segments.[138]

136 The Climate Group, "The Zero-Emission Vehicle (ZEV) Challenge," https://www.theclimategroup.org/project/zev-challenge.

137 Anne C. Mulkern, "Cities unite to seek 'record breaking' electric fleet," E&E News, January 10, 2017.

138 Climate Mayors, "Electric Vehicle Request for Information (EV RFI)," http://climatemayors.org/actions/initiatives/.

Conclusion

By providing a transit solution that completely eliminates tailpipe pollution, and whose fuel—electricity—is on a strong trajectory towards increasingly clean renewable generation, transitioning to BEBs presents the opportunity for substantial benefits to public health. The complete absence of tailpipe emissions also eliminates exposure to pollutants that have been associated with significant health risks for bus operators, bus maintenance workers, and others whose occupations expose them to bus exhaust. Given the strong correlation between ethnicity, poverty, and exposure to high-traffic areas, switching from diesel and CNG buses to BEBs can be an important step for improving health and reducing disease among specific segments of the US population that are the most at risk—and, often, the least equipped—to manage the economic, medical, and professional costs of air-pollution-related illness. Initial estimates of the healthcare savings associated with a full conversion to BEBs are on the order of $50,000 to $100,000 per bus per year. As the initiatives underway at LA Metro, Seattle's King County Metro, and San Joaquin RTD show, BEB deployment can be strategically planned to maximize environmental justice outcomes in communities of color and low-income neighborhoods. In addition to the public health benefits associated with BEBs, electric buses and other zero-emission vehicles are a key factor being considered by the growing number of cities in the US, and globally, that are adopting strategies to reduce their GHG emissions.

Photo courtesy Deanne Fitzmaurice

3 Economic and Workforce Considerations

In addition to examining the challenges that transit agencies must address with battery-electric buses, and also the environmental and public health considerations that would result from a shift to BEBs, it's important to consider the impact that a broad-scale BEB transition would have on the manufacturing sector and the US workforce.

The 2018 BNEF report *Electric Buses in Cities* cites the "opportunity to build a domestic industry around the electrification of transport," and the accompanying job creation and supply-chain growth, as a major selling point for municipalities that are switching to electric buses.[139] Such a moment as this—when a new branch of infrastructure manufacturing begins to develop—holds tremendous economic potential, which policymakers and agencies should consider carefully. A large part of this potential stems from the role that manufacturing plays in maintaining national-level economic health. To describe that role in the broadest strokes: manufacturing can provide relatively well-paying jobs that strengthen other parts of the economy. Producing manufactured goods helps balance trade with other countries and results in the creation of greater numbers of domestic jobs. Robust investment in manufacturing also keeps the US industrially competitive with other countries, which allows the manufacturing sector to continue growing.

In a 2012 Brookings Institution report written with Timothy Krueger and Howard Wial, Susan Helper (who would go on to become US Department of Commerce's Chief Economist) characterized transportation equipment in particular as one of four industries within the manufacturing sector that make the greatest contributions to the American economy in terms of high-wage jobs, commercial innovation, and deficit reduction.[140] This chapter looks into those contributions

139 Bloomberg, "Electric Buses in Cities."

140 S. Helper, T. Krueger, and H. Wial, "Why Does Manufacturing Matter? Which Manufacturing Matters? A Policy Framework," Metropolitan Policy Program at Brookings, February 2012.

in greater detail, and examines job creation potential associated with a comprehensive transition to BEBs. This chapter also discusses the linked issues of historical inequities in the manufacturing workforce and the sector's future hiring needs, and the role that public procurement processes can play in capturing the full economic benefits of a transition to BEBs.

Manufacturing and the US Economy

The largest impact that battery-electric buses will have on job creation will be in the manufacturing sector—a part of the economy, as Robert Pollin and colleagues describe in their 2015 paper *Strengthening U.S. Manufacturing Through Public Procurement Policies*, whose decline has been alarming economists and policymakers for two generations.[141] Perhaps the clearest indicator of the weakening of American manufacturing is job loss. In the 1950s, manufacturing jobs comprised more than 30 percent of all employment—a now almost inconceivable share of the US job market. As figure 3-1 shows, between then and now, manufacturing jobs steadily declined to 8.5 percent in 2018. The manufacturing workforce also shrank in absolute terms: figure 3-2 shows the change in the total number of US manufacturing jobs over the same time interval. After a relatively stable period between 1970-2000, the number of manufacturing jobs fell steeply, with further losses during the Great Recession.

Photo courtesy Armando Aparicio

141 R. Pollin, J. Heintz, and J. Wicks-Lim, "Strengthening U.S. Manufacturing Through Public Procurement Policies," University of Massachusetts-Amherst Department of Economics and Political Economy Research Institute, December 2015.

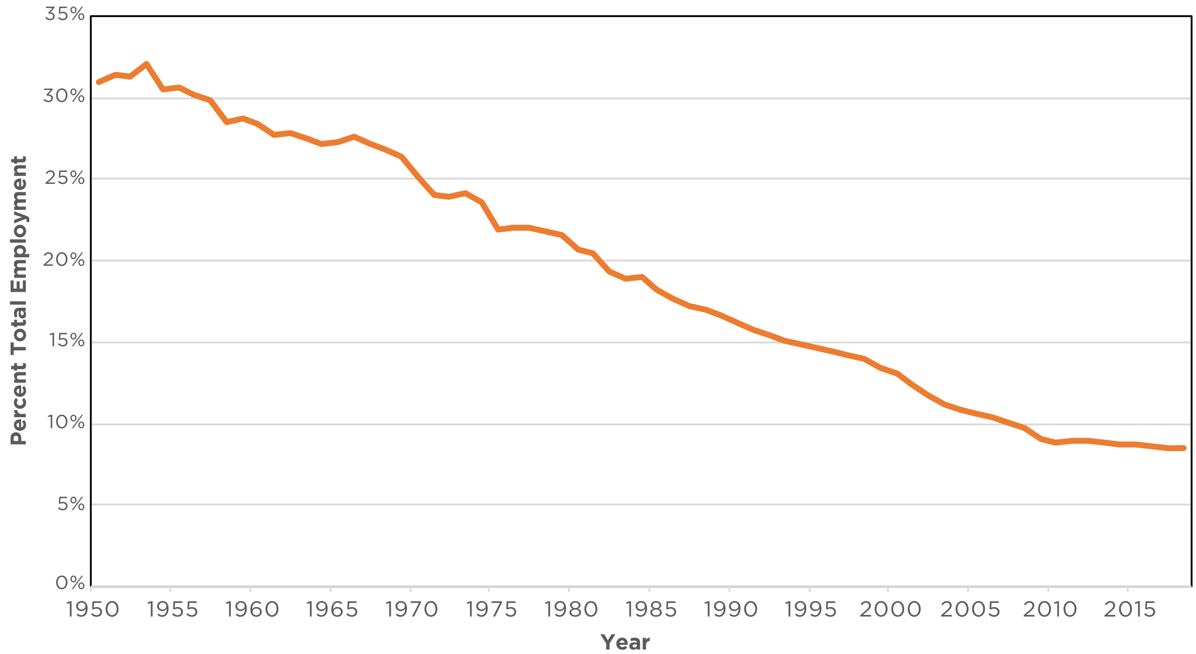

Figure 3-1: Manufacturing employment as a percentage of total US employment. (Source: US Bureau of Labor Statistics)

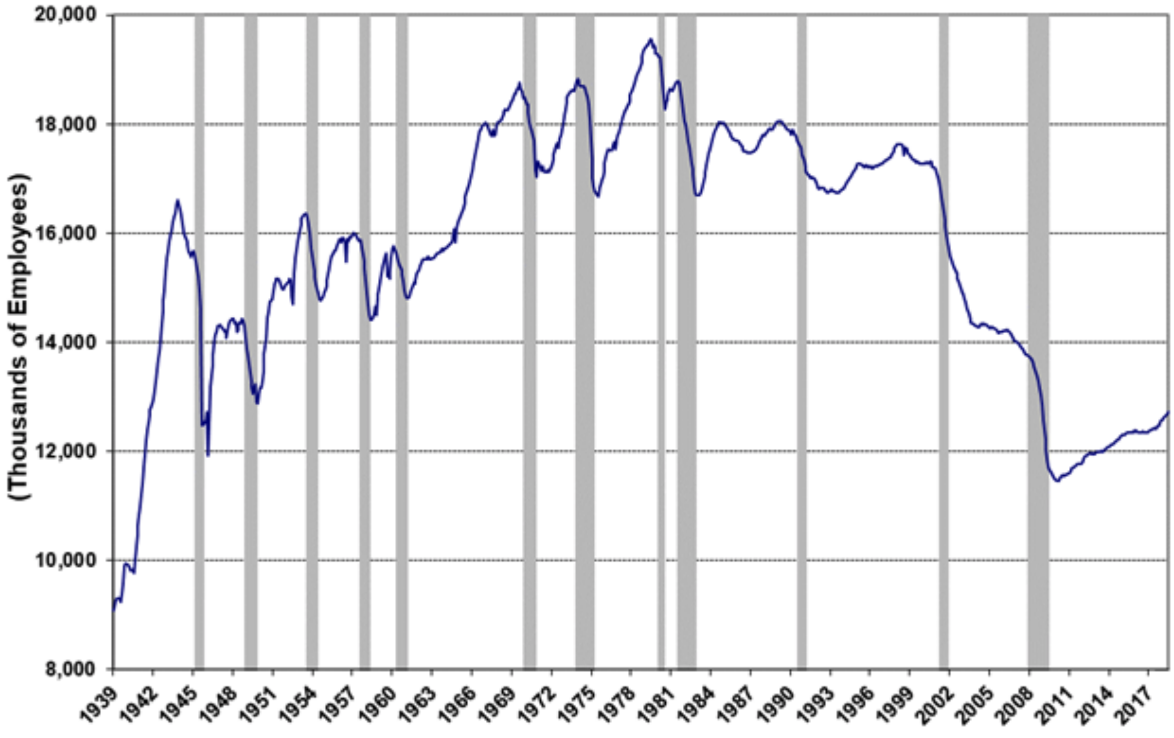

Figure 3-2: Total number (in thousands) of US manufacturing jobs over time. Shaded areas indicate US recessions. (Source: US Bureau of Economic Analysis and Plunkett Research Ltd.)

The dominant cause of manufacturing job loss between the late 1990s and mid-2000s was most likely the concurrent growth of offshoring. The detrimental effect that offshoring and outsourcing have had on the US economy is still debated in some economic circles, however there is little debate about offshoring's negative impact on the American workforce. In their 2013 book *Outsourcing Economics: Global Value Chains in Capitalist Development,* William Milberg and Deborah Winkler examined the characteristics of offshoring in 33 manufacturing and service sectors from 1998 to 2006 and concluded that offshoring during those years resulted in the loss of roughly 3.5 million full-time equivalent US jobs.[142] Pollin and colleagues also connect the rise in offshoring with reduced bargaining power on the part of US workers,[143] whose employers could relocate production to low- and middle-income countries where labor was significantly cheaper. This undermining of bargaining power was exacerbated by a dramatic increase in temporary hiring during the same time period. Research by Matthew Dey and colleagues on manufacturers' use of temporary workers shows that "whereas the staffing industry added 2.3 percent to manufacturing employment in 1989, it increased manufacturing employment by 8.7 percent in 2004. Although measured employment in manufacturing shrank by 4.1 percent from 1989 to 2000, including staffing workers who are assigned to manufacturing and who typically work alongside regular manufacturing employees, employment in the manufacturing sector actually rose by an estimated 1.4 percent over that period."[144] Alan Greenspan, who was chairman of the Federal Reserve Bank at the time, described in his 1997 testimony to Congress how workers were "too worried about keeping their jobs to push for higher wages" despite the fact that productivity was high and the unemployment rate was relatively low (a little over five percent)[145]. Greenspan's comment is corroborated by data from the Bureau of Labor Statistics showing that wages for US manufacturing workers in non-supervisory roles have in fact remained essentially flat for the past 30 years (figure 3-3). Since 2007, manufacturing wages have increasingly lagged below average wages for the private sector overall, and around 2015, average total private sector wages surpassed manufacturing's durable goods sector.

142 William Milberg and Deborah Winkler, Outsourcing Economics: Global Value Chains in Capitalist Development (New York, NY: Cambridge University Press, 2013).

143 Pollin et al., "Strengthening U.S. Manufacturing."

144 M. Dey, S.N. Houseman, and A.E. Polivka, "Manufacturers' Outsourcing to Employment Services," W.E. Upjohn Institute for Employment Research, 2006.

145 Louis Uchitelle, "Job Insecurity of Workers Is a Big Factor in Fed Policy," New York Times, February 27, 1997.

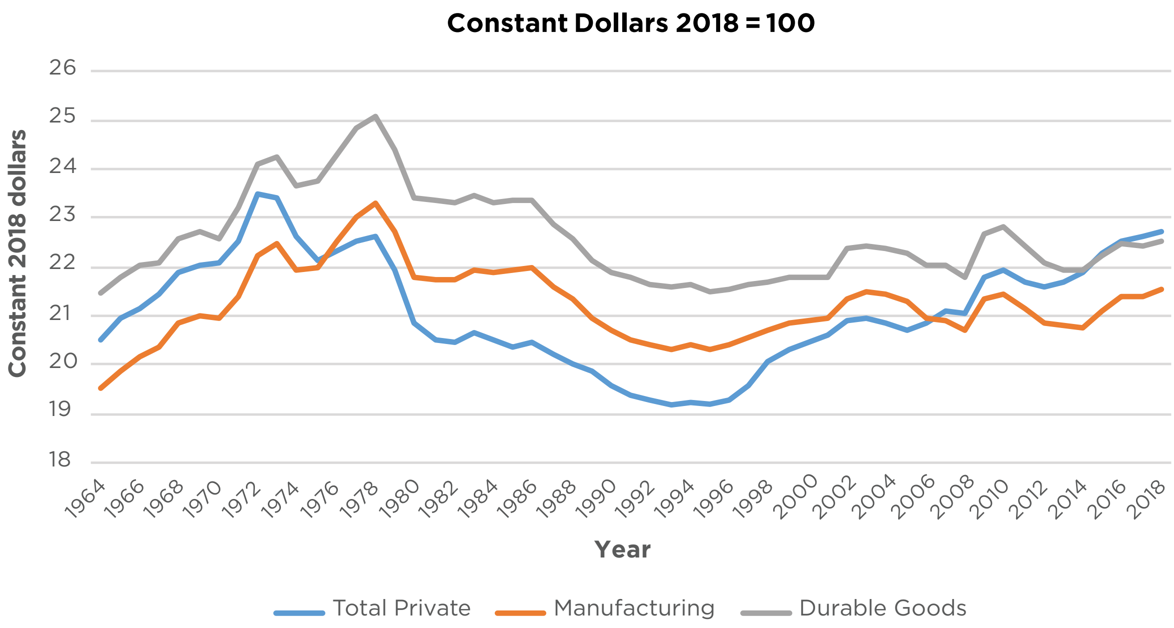

Figure 3-3: Average hourly earnings for production and nonsupervisory employees. Note that all dollar amounts are shown in 2018 constant dollars. (Source: US Bureau Labor Statistics)

Manufacturing Jobs in Greater Detail

Despite these persistent and ongoing challenges, both for the sector overall and for its workers, manufacturing still contributes significantly to the US economy. In recent years, the number of manufacturing jobs has been gradually increasing, from about 11.5 million jobs in January 2010 to 12.8 million jobs in January 2019.[146] Manufacturing also continues to be a large contributor to national gross domestic product (GDP): manufacturing represented 17 percent of gross output[147] in 2018, and 11.4 percent of value added.[148] Manufacturing gross output has largely mirrored the growth of all US private industry output, increasing from $3.9 trillion in 1997 to $5.9 trillion in 2017. The manufacturing sector also produced about 56 percent of all US exports in 2018.[149]

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146 U.S. Department of Labor Bureau of Labor Statistics, "Employment, Hours, and Earnings from the Current Employment Statistics survey (National): All employees, thousands, manufacturing, seasonally adjusted.

147 As a measure of economic activity, gross output is the total revenue from all products a manufacturer sells. Value added can be thought of as the difference between the price a manufacturer pays for raw materials and the total sales revenue of the final product sold by the manufacturer.

148 Manufacturing was second only to finance, insurance, and real estate (FIRE) in gross output, and third in value added (behind FIRE and Government).

149 U.S. Bureau of Economic Analysis, "Gross Output by Industry," https://www.bea.gov/data/industries/gross-output-by-industry.

What's arguably just as important as manufacturing's significant macroeconomic contributions are the characteristics of manufacturing-sector jobs. Manufacturing careers are accessible to workers with a wide range of skills and educational backgrounds, and in particular to workers without college degrees. As economist Robert Scott and others have noted,[150] workers with a high-school degree or less hold a larger share of manufacturing jobs than they do in the economy overall (47.7 percent in manufacturing vs. 37.6 percent in all industries, using data from 2009-2011[151]). Scott also clarifies that "while many manufacturing jobs may not require a college education, they are not 'unskilled.'"[152] As evidence, Scott points to the manufacturing wage premium, which is the difference between the average wages of manufacturing workers and the average wages of comparable workers in other parts of the economy. Nationally, for workers without a college degree, manufacturing employees earned 10.9 percent more ($1.78 per hour) than non-manufacturing workers in 2012-2013. Furthermore, in states like Montana, Michigan, New Mexico, and Louisiana that produce larger amounts of high-tech, capital-intensive goods, the manufacturing wage premium doubles, ranging from 19.6 percent to 24.4 percent.[153] Unionization also contributes to higher manufacturing wages: in 2018, about 9.7 percent of manufacturing workers were represented by unions, relative to 7.2 percent of private sector workers overall.[154] The 2018 median weekly earnings of full-time wage and salary workers were 9.2 percent higher for manufacturing workers who were represented by a union compared to manufacturing workers who lacked union representation.[155]

With their above-average wages, technical skill requirements, and accessibility to workers with different levels of academic achievement, manufacturing jobs present a strong value proposition for the larger US economy. However in some important ways, the decline of American manufacturing is due to overlapping vicious cycles at both micro- and macroeconomic levels: People are more likely to look for work in a particular sector if they can "see themselves in the job."[156] Unlike careers such as IT, retail, or healthcare, many people can't easily visualize what manufacturing

150 Louis Uchitelle, Making It: Why Manufacturing Still Matters (New York, NY: The New Press, 2017.) Robert E. Scott, "The Manufacturing Footprint and the Importance of U.S. Manufacturing Jobs," Briefing Paper #388, Economic Policy Institute, January 22, 2015.

151 Robert E. Scott, "Trading Away the Manufacturing Advantage: China Trade Drives Down U.S. Wages and Benefits and Eliminates Good Jobs for U.S. Workers," Briefing Paper #367, Economic Policy Institute, September 30, 2013,

152 Scott, "The Manufacturing Footprint."

153 Scott, "The Manufacturing Footprint."

154 U.S. Bureau of Labor Statistics, "Table 3. Union affiliation of employed wage and salary workers by occupation and industry, 2017-2018," https://www.bls.gov/news.release/union2.t03.htm.

155 U.S. Bureau of Labor Statistics, "Table 4. Median weekly earnings of full-time wage and salary workers by union affiliation, occupation, and industry, 2017-2018," https://www.bls.gov/news.release/union2.t04.htm.

156 Numerous workforce development programs around the United States reference this idea. A 2018 publication from National Alliance for Partnerships in Equity provides a detailed illustration of its application by the Ohio Department of Education: Ben Williams, "The Power of Micromessages in Marketing, Recruitment and Success in CTE," Association for Career and Technical Education, February 2018.

work is like. As the manufacturing workforce has shrunk and aged,[157] it has effectively become easier for new and younger workers to overlook manufacturing as a promising career option—a phenomenon that contributes to the current manufacturing employment gap.[158] Simultaneously, as the US has relinquished manufacturing market share to other countries, the motivation for robust domestic investment in technical innovation has waned as well.[159] This loss of competitiveness has been accompanied by a growing manufacturing trade deficit as the United States imports increasing amounts of manufactured goods from other countries,[160] and in doing so, effectively supports the creation of manufacturing jobs abroad while reducing the availability of manufacturing work at home.

Future BEB Jobs in the US

The advent of a large-scale transition to electric buses presents the opportunity to support the growth of this new technology—and the manufacturing jobs that it will bring—in the United States. Employment projections using IMPLAN 2019 software provide an approximate sense of the jobs that will be associated with investment in BEBs and their related infrastructure. These jobs can be categorized into three groups:

- **Direct jobs** are jobs that are associated with designing the buses and producing bus components, as well as final assembly of the buses.
- **Indirect jobs** are associated with the products and materials made by suppliers that become part of the finished buses.
- **Induced jobs** are created when people employed in direct or indirect jobs spend their earnings on other goods and services in other sectors of the economy.

Direct and indirect jobs are the most salient categories for this analysis, since induced jobs are created regardless of the type of bus produced.[161] Modeling

157 "Women in Manufacturing," U.S. Congress Joint Economic Committee, May 2013.

158 "2018 Deloitte and The Manufacturing Institute skills gap and future of work study," Deloitte and The Manufacturing Institute, 2018.

159 S. Kota, J. Talbot-Zorn, and T. Mahoney, "How the U.S. Can Rebuild Its Capacity to Innovate." Harvard Business Review, October 23, 2018. Helper et al. "Why Does Manufacturing Matter?" "OECD Science, Technology, and Industry Scoreboard 2011," Organisation for Economic Cooperation and Development, 2011.

160 Pollin et al., "Strengthening U.S. Manufacturing."

161 Induced jobs represent the spending of labor income by the employees working in the indirectly-impacted industries, under the assumption that the more income households earn, the more money those households spend. Note that IMPLAN does not assume that 100 percent of this labor income is spent, nor that it is spent locally. IMPLAN removes payroll taxes, personal income taxes, savings, in-commuter income, and non-local purchases before spending the rest locally.

performed by the Political Economy Research Institute[162] (PERI) at the University of Massachusetts Amherst (summarized in table 3-1) shows that every $1 million spent on BEBs would result in 2.3 direct and 3.4 indirect jobs, for a total of 5.7 jobs.[163] This estimate is similar to the number of jobs that would result from the same investment in diesel buses (6.1 jobs—a difference of 0.4 percentage points) and is consistent with analysis by Robert Scott showing that each US manufacturing job indirectly supports about 1.4 jobs elsewhere in the economy.[164]

Additionally, given that the current "early mover" transit agencies are planning to convert their fleets from diesel and CNG buses to BEBs by 2040 or 2050, BEB purchases will need to be accompanied by investments in charging stations, and also on renovating bus depots (or building new ones) to accommodate BEB charging equipment. Since it's likely that other transit agencies that are interested in BEBs will take longer to complete their fleet conversions, it would be reasonable to expect that substantial investment in charging equipment and bus depot upgrades would continue until at least 2060, and further into the future as charging technology continues to improve.

Job type	BEBs	Charging stations		Bus depots		Diesel buses
		Scen. A	Scen. B	Scen. C	Scen. D	
Direct	2.3	3.5	4.0	6.4	6.3	1.8
Indirect	3.4	2.9	2.8	3.2	3.3	4.3
Total	5.7	6.4	6.8	9.6	9.6	6.1
Induced	4.1	4.7	4.9	5.6	5.5	4.3
Total + induced	9.9	11.1	11.7	15.2	15.1	10.4

Table 3-1: Modeled job creation numbers for BEBs, BEB-related infrastructure, and diesel buses, per $1M of investment. (Source: Political Economy Research Institute)

Modeling was also performed to estimate the number of jobs associated with these infrastructure changes. Because the type of infrastructure needed will vary widely from agency to agency, two investment scenarios were modeled both for charging stations and bus depots. For charging stations, results are shown for the case in which more substantial construction work would be needed to connect an agency's charging equipment to the local electric grid (Scenario A), and also for the case in which connection to the grid would be easier, allowing more funds to be spent on the chargers themselves (Scenario B). For bus depots, Scenario C describes the case in which an agency invests more in new bus depot construction than in renovating existing structures; Scenario D describes the jobs created when a transit agency

162 For a full description of the modeling methodology used, please see the Appendices 2 and 3 of PERI's 2019 report: R. Pollin, J. Wicks-Lim, S. Chakraborty, and T. Hansen, "A Green Growth Program for Colorado," Political Economy Research Institute, April 4, 2019.

163 PERI's modeling estimates the jobs based on the current domestic content requirements (65 percent).

164 Scott, "The Manufacturing Footprint."

can upgrade more of its existing depot facilities to accommodate BEBs and as a result spends less on new construction.

As shown in table 3-1, for charging stations, Scenario A and Scenario B result in about 6.4 and 6.8 direct and indirect jobs, respectively, for an average about 6.6 jobs per $1 million of investment. For both bus depot scenarios, about 9.6 jobs would be created per $1 million of investment. Given these estimates, it is likely that the combined investment in BEBs, charging infrastructure, and bus depot upgrades that would be required for large-scale transition to BEBs would result in a greater number of direct and indirect jobs than would be the case if agencies continued to use mainly diesel and CNG buses—and, just as importantly, the environmental and operational benefits of BEBs will not come at a cost to manufacturing jobs.

To give a rough sense of what a strong nationwide commitment to transitioning to BEBs would mean in terms of employment, consider that total US public transportation expenditures on capital investment in 2016 were $19.9 billion.[165] Of that $19.9 billion, $5.08 billion was spent on rolling stock, and 57 percent of those rolling stock investments ($2.89 billion) were made on buses. If $2.89 billion was spent on BEBs, that investment would support about 16,700 direct and indirect jobs. Given that, realistically, some portion of the $2.89 billion would need to be spent on charging infrastructure, and that additional facility funds would be spent on bus depot upgrades, a conservative estimate for the number of jobs would likely be about 20,000[166]—an amount that approaches the total number of US manufacturing jobs for conventional buses.[167] While 20,000 jobs is an approximate figure (and some portion of those jobs would replace positions associated with diesel and CNG bus manufacturing), it provides a useful illustration of the potential that BEB technology holds for maintaining economic activity in US manufacturing and providing jobs for a key segment of the workforce, while also growing investment in the electric-vehicle technologies that will play a major role in American transportation.[168]

One additional scenario that is also worth considering is the possible future in which the full cost-saving potential of BEBs is realized, and allows transit agencies

165 "2018 Public Transportation Factbook," American Public Transportation Association, December 2018.

166 For this example, one can conservatively estimate that 90% of the $2.89B investment ($2.6B) is spent on BEBs and 10% ($289M) is spent on charging infrastructure. Multiplying $2.6B by 5.7 direct and indirect jobs per $1M results in 14,825 jobs. Multiplying $289M by 6.6 direct and indirect jobs results in 1,907 jobs. The APTA Factbook indicates that in 2016, transit agencies spent $11.93B on facilities; of that amount, 11% ($1.31B) was spent on maintenance facilities. Assume that 25% of the maintenance facilities budget ($327M) goes to BEB-related bus depot rehabilitation. Multiplying $327M by 9.6 direct and indirect jobs results in 3,139 jobs. The total of these BEB, charging infrastructure, and depot-related estimates is 19,871 jobs.

167 Marcy Lowe, "Value Chain Analysis of the U.S. Transit Bus Industry: Key Findings presented to the President's Council on Environmental Quality," Center on Globalization, Governance and Competitiveness, Duke University, February 25, 2010.

168 It is important to note that these job estimates are dependent on full compliance with Buy America requirements as stipulated for materials purchased with Federal Transit Administration funds.

to increase bus service while lowering fares. The benefits of such an outcome are discussed in detail in the comprehensive 2014 report "Green Growth: A U.S. Program for Controlling Climate Change and Expanding Job Opportunities" by Robert Pollin and colleagues. In such a future, if bus ridership could be increased through improved service and lower fares, overall energy use and greenhouse gas emissions would be significantly reduced, with the added benefits of less traffic congestion, lower household expenditures on transportation (especially for low-income communities), and increased manufacturing employment (assuming that new buses would be produced by US firms).[169] It is this combined collection of economic, civic, and environmental improvements that make the future of BEBs important to keep in sight.

Equity in the Manufacturing Workforce

Research by Deloitte and The Manufacturing Institute predicts that increased customer demand, the retirement of an aging cohort of workers, and other factors will create substantial hiring needs in the manufacturing sector between 2018 and 2028. Even after accounting for job losses associated with automation, the report forecasts that during the coming decade, there will be roughly 2.4 million manufacturing jobs that employers may struggle to fill.[170] Where can manufacturers look to find these future employees? With a workforce that for years has been highly homogeneous—roughly 70 percent male and 80 percent white[171]—women and people of color are two of the most promising options for recruitment to the manufacturing sector. Increasingly, corporate executives are prioritizing efforts to find and retain workers from demographics that have been historically underutilized in manufacturing: recruiting from these groups is seen as an essential strategy in tight labor markets (especially as people of color are projected to comprise half of the US workforce by 2045).[172] Employers also recognize that their diversity and inclusion efforts can strengthen their firms' competitive advantage by creating teams with greater breadth of experience, ability to innovate, and profit-growing potential.[173,174,175,176]

169 R. Pollin, H. Garrett-Peltier, J. Heintz, and B. Hendricks, "Green Growth: A U.S. Program for Controlling Climate Change and Expanding Job Opportunities," Political Economy Research Institute, September 2014.

170 Deloitte et al., "2018 Deloitte and The Manufacturing Institute Skills Gap."

171 "The Disappointing Truth About Diversity and Inclusion for U.S. Manufacturers," Manufacturers Alliance for Productivity and Innovation, September 21, 2016.

172 "All in: Shaping tomorrow's manufacturing workforce through diversity and inclusion," PwC and The Manufacturing Institute, 2018.

173 PwC and The Manufacturing Institute, "All in."

174 Paul Gompers and Silpa Kovvali, "The Other Diversity Dividend," Harvard Business Review, July-August 2018.

175 C. Hsieh, E. Hurst, C.I. Jones, and P.J. Klenow, "The Allocation of Talent and U.S. Economic Growth," National Bureau of Economic Research, April 26, 2019.

176 Cedrick Herring, "Does diversity pay?: Race, gender, and the business case for diversity," American Sociological Review, 74:2, p. 208-224.

Especially in the context of manufacturing that is financed with public dollars—as is the case with transit infrastructure—there is the opportunity to address historical hiring inequities. Since 1954 (the year when robust unemployment data first became available), unemployment rates for Black workers have been greater—typically twice as high—than those for white workers,[177] although in some cases the disparities have been much higher. In *The Dispossessed,* Jacqueline Jones describes the strong preference in the South for white workers during World War II; a study conducted in Atlanta at that time revealed that the unemployment rate for blacks was almost nine times that of whites (43 percent vs. 5 percent).[178] These disproportionate impacts on black workers, especially resulting from economic shifts away from manufacturing, are comprehensively documented William Julius Wilson's book *When Work Disappears*. Wilson describes data from the Chicago Urban Poverty and Family Life Survey showing the substantial drop in manufacturing jobs among Black men in Chicago during the second half of the 20th century:

> *Fifty-seven percent of Chicago's employed inner-city black fathers (aged 15 and over and without undergraduate degrees) who were born between 1950 and 1955 worked in manufacturing and construction industries in 1974. By 1987, industrial employment in this group had fallen to 31 percent. Of those born between 1956 and 1960, 52 percent worked in these industries as late as 1978. But again, by 1987 industrial employment in this group fell to 28 percent. No other male ethnic group in the inner city experienced such an overall precipitous drop in manufacturing employment … As a result, young black males have turned increasingly to the low-wage service sector and unskilled laboring jobs for employment, or have gone jobless.*[179]

The work of Jacqueline Jones, Michael Keith Honey,[180] and other social historians also document the myriad ways in which systemic racism in the South, Midwest, and Northeast kept Black workers relegated to lower-skilled, lower-paying manufacturing jobs from the 1920s onward. The legacy of these practices has not yet gone away: Pollin and colleagues' 2015 paper showed that while 34.7 percent of the American workforce was comprised of nonwhite and/or Latino people, workers from these groups make up only 30.9 percent of employees in the manufacturing sector. For people in low educational credentialed jobs, the disparity was greater, with nonwhite and/or Latino workers making up 37.4 percent of the workforce compared to 43.8 across the economy.

177 Gerald D. Taylor, "Unmade in America Industrial Flight and the Decline of Black Communities," Alliance for American Manufacturing, October 2016.Drew Desilver, "Black unemployment rate is consistently twice that of whites," Pew Research Center, August 21, 2013.

178 Jacqueline Jones, The Dispossessed: America's Underclasses from the Civil War to the Present (New York, NY: BasicBooks, 1992).

179 William Julius Wilson, "When Work Disappears: New Implications for Race and Urban Poverty in the Global Economy," Journal of Ethnic and Racial Studies, 22, 1999, p. 479-499.

180 Michael Keith Honey, Black Workers Remember: An Oral History of Segregation, Unionism, and the Freedom Struggle (Berkeley, CA: University of California Press, 1999).

The limited opportunities for workers of color in the manufacturing sector have been exacerbated by economy-wide racial wage gaps. An extensive body of research has sought to explain the persistence of race-based income disparities, despite decades of anti-discrimination policies.[181] Wage comparisons over the past decade consistently show that Black workers earn on the order of 25 percent less than comparable white workers.[182] Field experiments have demonstrated that racial discrimination against people of color exists for both low- and high-wage workers.[183] Other research shows that job closure (the tendency for better jobs to be reserved for white or otherwise privileged applicants) and differences in levels of education and training (which themselves often reflect historical patterns of discrimination) can have a significant impact on wage disparities.[184]

Numerous studies also document the gaps in wages and opportunities for working women, both in the manufacturing sector and across the US economy. Research published in 2016 by Ariane Hegewisch and colleagues shows that women comprise about 83 percent of workers in middle-skill jobs paying less than $30,000 per year, but only 36 percent of workers in middle-skill jobs paying more than $35,000 per year.[185] Although women make up 47 percent of the total US workforce, they fill only 29 percent of manufacturing jobs,[186] and women were hired for a mere 7 percent of the 650,000 manufacturing jobs that were created in the US between 2010 and 2014.[187] Similar disparities are described in a report by Manuel Pastor and Jared Sanchez from the University of Southern California's Program for Environmental and Regional Equity. Figure 3-4 shows their comparison of earnings for women and men in different types of jobs: manufacturing is one of the economic sectors where the wage gap is especially large, with women generally earning less than 75 percent as much as men.[188] This disparity is arguably partly due to the related fact that

181 Patrick Bayer and Kerwin Kofi Charles, "Divergent Paths: A New Perspective on Earnings Differences Between Black and White Men Since 1940," Working Paper No. 2018-45, Becker Friedman Institute, July 5, 2018. Valerie Wilson and William M. Rodgers III, "Black-white wage gaps expand with rising wage inequality," Economic Policy Institute, September 20, 2016.

182 Wilson and Rodgers, "Black-white wage gaps." Eileen Patton, "Racial, gender wage gaps persist in U.S. despite some progress," Pew Research Center (blog), July 1, 2016. D. Hamilton, A. Austin, and W. Darity Jr., "Whiter jobs, higher wages: Occupational segregation and the lower wages of black men," Briefing Paper #288, Economic Policy Institute, February 25, 2011.

183 D. Pager, B. Bonikowski, and B. Western, "Discrimination in a Low-Wage Labor Market: A Field Experiment," American Sociological Review, 74:5, October 1, 2009. S. Michael Gaddis, "Discrimination in the Credential Society: An Audit Study of Race and College Selectivity in the Labor Market," Social Forces, 93:4, June 2015, p. 1451-1479.

184 Donald Tomaskovic-Devey, "The Gender and Race Composition of Jobs and the Male/Female, White/Black Pay Gaps." Social Forces, 72:1, September 1993, p 45-76.

185 A. Hegewisch, M. Phil., M. Baldwin, B. Gault, and H. Hartmann, "Pathways to Equity: Narrowing the Wage Gap by Improving Women's Access to Good Middle-Skill Jobs," Institute for Women's Policy Research, March 2016.

186 U.S. Department of Labor, Bureau of Labor Statistics, "Labor Force Statistics from the Current Population Survey: Table 18. Employed persons by detailed industry, sex, race, and Hispanic or Latino ethnicity," https://www.bls.gov/cps/cpsaat18.htm.

187 Hegewisch et al., "Pathways to Equity."

188 Manuel Pastor and Jared Sanchez, "#WomenCanBuild: Including women in the resurgence of good U.S. manufacturing jobs," University of Southern California Program for Environmental and Regional Equity, 2015.

women in manufacturing tend to work in lower-paying, more clerical positions[189]—a perhaps unexpected state of affairs, considering that American women are more likely than men to have finished high school; to have some level of postsecondary education; or to have a two- or four-year degree.[190] Despite these inequities, there is evidence to show that women enjoy manufacturing work: in a 2012 survey of more than 600 women, over 75 percent described their manufacturing careers as rewarding and interesting, citing good pay and opportunities for challenging assignments as key factors for staying in the industry.[191]

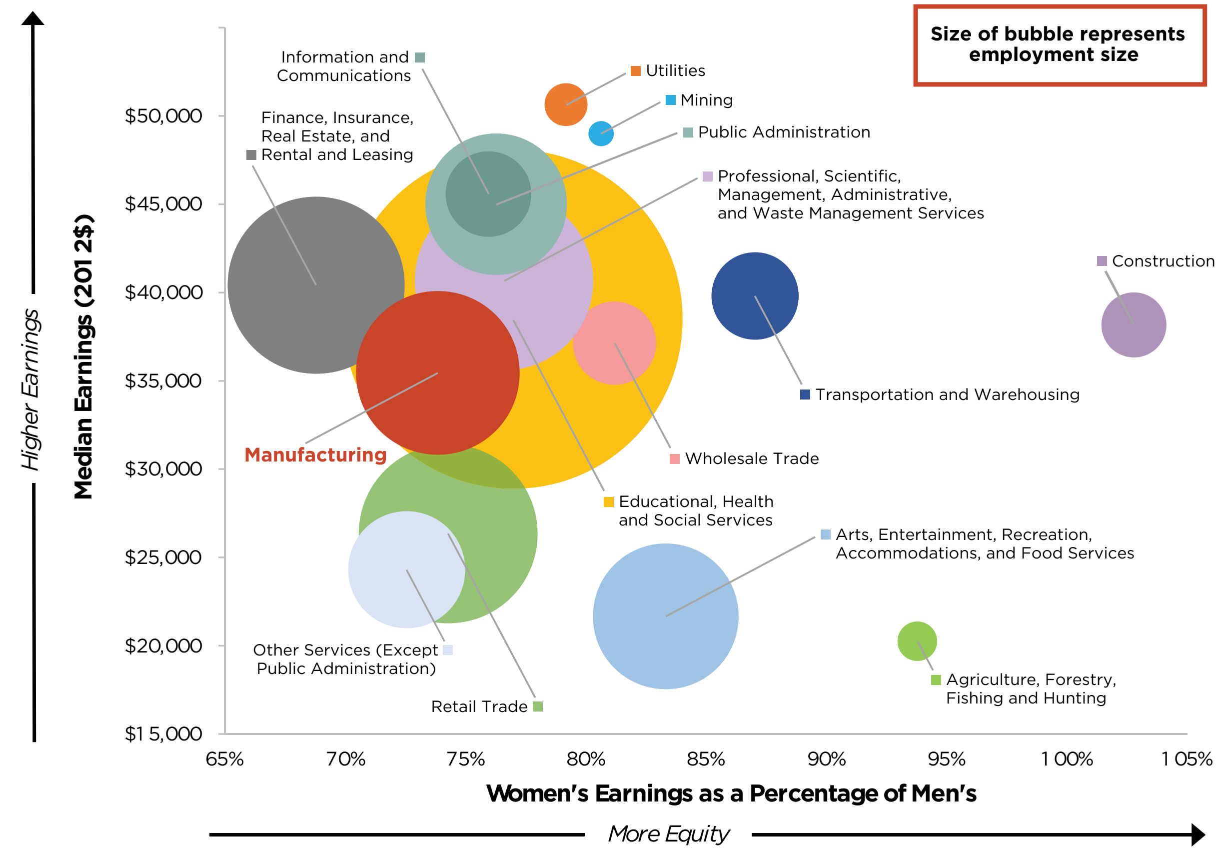

Figure 3-4: Disparities between male and female earnings for American workers. (Source: Pastor and Sanchez, 2015)

A Role for Public Procurement

Given these slow rates of diversity growth, and the substantial upsurge in hiring needs projected for the coming decade by Deloitte and the Manufacturing Institute, new strategies are needed to bring more—and more diverse—job seekers into the manufacturing workforce. Public procurements are a unique opportunity for

189 Pastor and Sanchez, "#WomenCanBuild."

190 Hegewisch et al., "Pathways to Equity."

191 Craig Giffi and Jennifer McNelly, "Untapped Resource: How manufacturers can attract, retain, and advance talented women," Deloitte and The Manufacturing Institute, 2013

agencies to maximize the value of taxpayer dollars by recognizing the full range of economic opportunities embedded in public purchasing. Through government purchasing processes, agencies can incentivize manufacturing firms to create good jobs with improved access for women, people of color, and other groups that are disadvantaged in the labor market—a practice known as inclusive procurement. One approach that agencies can take to reach inclusive procurement goals is to form partnerships with key stakeholders in their region: in 2014, the Chicago Transit Authority announced a joint initiative with the City of Chicago and the Chicago Federation of Labor to "reward global manufacturing companies that train and hire disadvantaged workers such as veterans, women, and residents of low-income neighborhoods, and those that create U.S. jobs, and build American factories."[192]

Agencies can also pursue inclusive procurement through the use of US Employment Plan policies. Developed by a team of experts from Jobs to Move America, the Brookings Institution, the University of Southern California's Program for Environmental and Regional Equity, and PERI, and approved by the US Department of Transportation,[193] the US Employment Plan (USEP) is language that agencies can include in their requests for proposals to bus and railcar manufacturers, allowing them the option of voluntarily committing to create a certain number of permanent, full-time US jobs if they are awarded the contract. The details of a USEP can be customized by the transit agency, and USEPs typically encourage bidders to provide information on (a) targeted hiring goals for people of color, women, and other workers who face barriers to employment; (b) the wages and benefits for which workers will be eligible, and (c) the level of training and projected career skills to which workers will have access, thus ensuring that their jobs provide transferable workforce skills. The agency will award extra credit to bids that include USEPs, however submitting a USEP is voluntary and bids that omit a USEP are not considered unresponsive. It is important to note that research by the UCLA School of Law has found that including USEP hiring goals typically add minimal or zero cost to manufacturers' bids,[194] thereby allowing significant workforce benefits to be achieved without extra cost to taxpayers. Versions of the USEP have been used by the Chicago Transit Authority, Los Angeles County Metropolitan Transportation Authority, Massachusetts Bay Transportation Authority, Metropolitan Atlanta Rapid Transit Authority, and MTA New York City Transit[195] to create jobs with meaningful career potential and family-supporting wages through bus and railcar procurements.

192 Rachele Huennekens, "IL: Chicago Transit Authority Restarts $2 Billion Rail Car Procurement with Strong Manufacturing Job-Creating Approach," Mass Transit, July 25, 2014.

193 U.S. Department of Transportation, "Letter from U.S. Transportation Secretary Anthony Foxx – U.S. Employment Plan," https://www.transit.dot.gov/funding/procurement/letter-us-transportation-secretary-anthony-foxx-%E2%80%93-us-employment-plan.

194 Letter from Scott Cummings, Robert Henigson Professor of Legal Ethics, to Molly Moran, Acting General Counsel at the US DOT, December 7, 2016. Available here: https://jobstomoveamerica.org/wp-content/uploads/2018/04/Cummings_Moran_Memos.pdf.

195 Jobs to Move America, "U.S. Employment Plan Resources," https://jobstomoveamerica.org/resources/us-employment-plan-resources-2/.

Utilizing policies like the US Employment Plan is an important part of maximizing the economic benefits of BEB manufacturing because of several trends that have degraded the quality of American manufacturing jobs. Research by Catherine Ruckelshaus and Sarah Leberstein at the National Employment Law Project shows evidence that the upsurge in temporary manufacturing hiring that took place during the late 1990s and early 2000s has continued. According to Ruckelshaus and Leberstein, "the number of temporary Team Assemblers[196] across all industries has grown from 57,520 (5.0 percent of all team assemblers) in 2002, to 176,590 (16.7 percent) in 2013."[197] This growth in temporary team assembler staffing took place while the overall number of team assemblers across all industries decreased by 7.1 percent, indicating the growing proportion of temporary staff among team assemblers.[198] Although it is understandable for people to be grateful for a job, the terms of temporary positions often require workers to pay a bitter price: wages can be as little as half of what permanent staff earn, and healthcare and other benefits—including the ability to take time off—are typically not available. While US Department of Labor regulations exist to prevent companies from hiring temporary workers to indefinitely perform the same work as permanent employees, reporting suggest that DOL oversight on this front is not adequate.[199]

Another factor that is lowering the quality of manufacturing jobs is the increasing tendency of companies to locate their facilities in the southern US. Although research on this phenomenon is still in its early phases, articles published[200] over the past several years depict the lack of organized labor in southern right-to-work states as highly compelling for manufacturing firms (and other businesses as well). In a notable example from 2012, Alabama Governor Robert Bentley specifically touted this characteristic in describing the recent announcement by European aerospace manufacturer Airbus to build a new factory in Mobile, AL: "'The cost of doing business in Alabama is low,' the Republican governor said, adding later: 'I think being a right-to work state is the reason many international companies look at Alabama and the other right-to-work states.'"[201] Allan McArtor, Airbus's American chairman, expressed similar views.[202] Data from the Bureau of Labor Statistics' "Union Members—2018" News Release shows that the percentage of workers represented by unions in Alabama, Arkansas, Georgia, Mississippi,

196 Also known as assembly line workers

197 Catherine Ruckelshaus and Sarah Leberstein, "Manufacturing Low Pay: Declining Wages in the Jobs That Built America's Middle Class," National Employment Law Project, November 2014.

198 Ruckelshaus and Leberstein, "Manufacturing Low Pay."

199 Jonathan Weisman, "Permanent Job Proves an Elusive Dream," Washington Post, October 11, 2004.

200 Good Jobs First, "Case Study of Foreign Auto Assembly Plants," https://www.goodjobsfirst.org/corporate-subsidy-watch/foreign-auto-plants. Brad Plumer, "Is U.S. manufacturing making a comeback—or is it just hype?", Washington Post, May 1, 2013.

201 Sean Higgins, "Alabama governor on how they snagged Airbus: We're a right to work state", Washington Examiner, July 2, 2012.

202 The same article noted that such acknowledgements were surprising given that Boeing, another large aerospace company, was issued a complaint by the National Labor Relations Board in 2011 for locating a new plant in South Carolina, which is also a right-to-work state.

North Carolina, and South Carolina ranges from four to eight percent. In contrast, California, Connecticut, Illinois, Massachusetts, Michigan, New Jersey, and Pennsylvania have union representation ranging from 13 to 18 percent; Washington and New York have 20 and 25 percent representation, respectively.[203]

The lack of trade union representation in Southern states is, unfortunately, matched by other factors that disadvantage workers: except for Arkansas and West Virginia, southern states pay their workers the lowest possible minimum wage: $7.25 per hour, as set by the federal government (in Alabama, Louisiana, Mississippi, South Carolina, and Tennessee, no minimum wage is required, so the federal wage is used by default).[204] Additionally, many southern states rank poorly on workplace safety. Findings from the US Department of Labor's Occupational Safety and Health Administration show that from 2011 to 2016, Alabama, Arkansas, Louisiana, Mississippi, Tennessee, and West Virginia all had annual fatality rates that were substantially above the national average; South Carolina's fatality rates were low as well.[205] Due to the prevalence of low wages and poor working conditions, transit agency procurements that result in the creation of US manufacturing jobs do not ensure that workers in those jobs will earn living wages, have a voice on the job, or have a safe place to work. These criteria, however, can be incorporated through the use of policies like the US Employment Plan.

By using USEPs or similar good-jobs policies, agencies can spur the creation of permanent jobs with benefits and family-supporting wages while improving equitable access to manufacturing sector employment, and encouraging domestic BEB manufacturing capability. Stakeholders can further support the realization of these goals by encouraging OEMs to negotiate community benefits agreements (CBAs) with local community groups. While CBAs were originally a method for ensuring that real estate developers provided certain amenities to the communities in which they constructed new facilities, Jobs to Move America has pioneered the use of CBAs between manufacturers and communities to create inclusive workforce practices for historically excluded populations, such as women and people of color. Community benefits agreements, which can include economic development, environmental justice, community, faith, labor, and civil rights groups, provide an opportunity to collectively create accountability mechanisms around corporate hiring commitments. As an example, the 2017 CBA created by electric bus manufacturer BYD with Jobs to Move America and SMART Local 105 established that the three organizations would collaborate to recruit and hire women, African Americans, reentry workers, veterans, and other people whose access to manufacturing jobs has been historically limited.

203 "Union Members—2018" (press release), U.S. Department of Labor Bureau of Labor Statistics, January 18, 2019.

204 U.S. Department of Labor, Wage and Hour Division, "Consolidated Minimum Wage Table," https://www.dol.gov/whd/minwage/mw-consolidated.htm.

205 "Death on the Job: The Toll of Neglect," 27th Edition, AFL-CIO, April 2018.

BYD committed to having at least 40 percent of its eventual workforce composed of workers in one or more of these groups, and also promised to address additional worker challenges by providing shuttles, ride-sharing programs, and other services to help employees with commuting due to limited public transportation.[206]

Another workforce hurdle that agencies can address through good jobs policies is on-the-job training. Literature on manufacturing workforce needs constantly comes back to the importance of creating training pipelines. Quality training programs for workers at all stages of their careers is also frequently cited by economists when discussing the remarkable success that Germany has had in maintaining a strong manufacturing sector that manages to be globally competitive while paying its employees high wages relative to workers in other advanced economies.[207] However in the US, robust training and apprenticeship programs for manufacturing jobs are only available to a small number of participants, despite manufacturers' increasing need for skilled workers.[208] As a representative example, a study done in Pennsylvania in 2010 found that the number of people enrolled in apprenticeship programs for precision machining and industrial maintenance occupations were only enough to fill about 10 percent of the annual job openings in those fields.[209] Good jobs policies can help address the skills gap by supporting the expansion of manufacturing training programs: agency requests for proposals that include USEPs typically ask manufacturers bidding on rolling stock contracts to describe the ways in which they will coordinate with workforce development programs and incorporate trainings or apprenticeships into the onboarding that will be provided to employees. A manufacturer's bid could include a plan for a program that combines classroom and hands-on training— in coordination with relevant existing apprenticeship programs— that will give employees nationally recognized and portable industry credentials, and the skills to meet quality and performance standards. Training objectives can also be achieved through CBAs: as part of its 2017 CBA, BYD is working with Jobs to Move America and SMART Local 105 to create the first pre-apprenticeship training program for BEB production jobs for women, Black workers, second-chance job seekers, veterans, and other groups facing barriers to employment.

In addition to helping set constructive benchmarks for job access and job quality, public procurement plays an essential role in how manufacturers invest in their workforce and maintain the health of their companies. In the Mineta Transportation Institute's 2016 report on the US transit bus industry, both agency staff and manufacturers described how predictable levels of funding over multi-year time periods is centrally important for maintaining a well-functioning

206 Jobs to Move America, "Labor and Community Groups Sign Landmark Agreement with Electric Bus Manufacturer BYD in Los Angeles" (July 17, 2017), https://jobstomoveamerica.org/labor-community-groups-sign-landmark-agreement-electric-bus-manufacturer-byd-los-angeles/.

207 Pollin et al., "Strengthening U.S. Manufacturing." Helper et al. "Why Does Manufacturing Matter?"

208 Deloitte et al., "2018 Deloitte and The Manufacturing Institute Skills Gap."

209 "Critical Shortages of Precision Machining and Industrial Maintenance Occupations in Pennsylvania's Manufacturing Sector," Pennsylvania Center for Advanced Manufacturing Careers, December 2010.

bus fleet and for manufacturers to plan for future production.[210] Stable markets with long-term horizons are broadly recognized as a vital component of industrial development,[211] and such market conditions are arguably even more important for developing technologies like BEBs. As the 2016 Mineta report pointed out, however, between 1995 and 2014, annual spending on buses by US transit agencies was highly volatile, ranging from $1.4 billion to $3.1 billion (in 2014 dollars). As a result, "[m]any manufacturers have gone bankrupt, left the market, or been acquired by competitors. Only three major transit bus manufacturers remain serving the heavy-duty transit bus market and a similar number serve the market for small- to mid-sized transit buses."[212]

In "The Benefits of Reliable Federal Funding for Public Transportation," Sarah Kline provides a comprehensive discussion of the relationship between public transit funding and equipment manufacturing. In the words of an agency professional, "Each and every time the federal government cannot timely approve a new transportation bill, and they resort to Continuing Resolutions, we start pulling back on our commitments."[213] The impacts of this funding instability are directly felt on the supply side: a bus manufacturer made the comment that "for every job at his plant, there were at least six or seven more jobs at his suppliers that depend on a steady stream of orders from his company. Several manufacturing and supply companies … noted that they had either held back on hiring or may need to consider layoffs as a result of unpredictable federal funding."[214] Being able to confidently forecast future demand is a primary requirement for BEB original equipment manufacturers (OEMs) to make the necessary investments in workforce and technology, and is also essential for smaller manufacturers that are weighing whether to join or expand their participation in BEB supply chains. There is therefore a direct relationship between the ability of transit agencies to plan future BEB deployments, the imperative for funding and technical assistance to support those deployments, the viability of the American transportation manufacturing, and the livelihoods of the employees who build the equipment.

210 Czerwinski, D., X. Hartling, and J. Zhang, "The U.S. Transit Bus Manufacturing Industry," Mineta Transportation Institute, 2016.

211 Pollin et al., "Strengthening U.S. Manufacturing."

212 Czerwinski et al, "The U.S. Transit Bus."

213 Sarah Kline, "The Benefits of Reliable Federal Funding for Public Transportation," American Public Transportation Association, July 2018

214 Kline, "The Benefits of Reliable Federal Funding."

Battery-Electric Buses and Maintenance Workers

In addition to the changes that future BEB deployment will have on the manufacturing workforce, BEBs are already impacting bus maintenance workers. According to estimates from the American Public Transportation Association's 2018 Public Transportation Fact Book, in the US in 2016, 31,673 employees worked in bus-related vehicle maintenance; this number most likely includes helpers, cleaners, mechanics, and frontline supervisors. Maintenance workers at agencies that have started to use BEBs described challenges associated with BEB technology that maintenance staff are still in the early stages of learning. As of the writing of this report, most BEBs currently in use are still under warranty, therefore many agencies likely rely on OEMs for the lion's share of maintenance service and technical assistance. Robust information does not yet exist on the degree to which adequate trainings are available to teach agency maintenance staff about servicing BEBs, however conversations with maintenance staff have made clear that transit maintenance workers have strong concerns that they will not receive the training that they need to take care of BEB fleets. Maintenance workers also worry that at BEB technology matures, the lower maintenance needs of BEBs will eventually put them out of their jobs. As Michael Terry, President and CEO of IndyGo described it, agencies "shouldn't be under the illusion that a manufacturer's warranty is going to provide full, deep, rigorous protection." During the time that he spent overseeing the rollout of IndyGo's first BEBs in 2018, Terry was grateful for the assistance that his OEMs provided, but has spoken about the need to have well-trained staff who can diagnose problem issues and track BEB performance. Speaking at a conference for maintenance workers in February 2019, John Callahan, an International Vice President at the Amalgamated Transit Union, described how Winnipeg Transit typically includes training for maintenance staff as part of its procurements for new buses (and for new equipment of all kinds). Through this approach, maintenance workers receive training from the manufacturer when the new buses arrive; and workers also receive deferred training, which is typically provided about a year later, after agency staff have had a chance to gain more experience about the buses' needs.[215] Winnipeg Transit maintenance staff have found this to be a productive and efficient way for them to gain the necessary expertise to do their jobs well.

In order to comprehensively transition to BEBs, strategies like these will be needed to ensure that agency maintenance staff have the opportunity to develop a level of knowledge around BEB maintenance that is comparable to the expertise they have on diesel and CNG buses. Finding effective ways to include training in the requests for proposals that agencies issue for BEBs—and allowing maintenance staff to have input into the procurement process—is probably the most direct pathway that agencies can take to ensure that staff develop and retain the knowledge needed to keep the BEBs in which they have invested in a state of good repair.

215 Winnipeg Transit also has dedicated computer training facility, and three full-time training staff. This level of training support is highly unusual and probably ranks the agency as one of the highest performing in North America in terms of worker training.

BOX 1:

Los Angeles County Metropolitan Transportation Authority (LA Metro)

The staff at LA Metro consider the agency's fleet conversion from CNG to electric buses as an important part of the agency's larger commitment to environmental goals for improving air quality and reducing GHG emissions. LA Metro is putting a priority on demonstrating industry leadership by committing to transition its fleet of 2,240 to BEBs by 2030. Agency staff describe their bus fleet, which comprises mostly CNG buses, as the cleanest of its size in North America. The ability to share lessons learned on BEB implementation with the rest of the transit community is highly valued by Metro staff.

The beginnings of the current BEB transition trace back to the 1990s, when the agency's board began putting a greater priority on becoming "greener and cleaner." LA Metro pursued this goal through a complete transition from diesel buses to CNG buses (which emit substantially less particulate matter and carbon monoxide than diesel) and alternative-fuel buses.[1] In 2017, the board adopted a policy to convert LA Metro's entire bus fleet to BEBs by 2030. The transition to BEBs is part of the agency's portfolio of environmental programs, which include a green construction policy that focuses on limiting air pollution on Metro construction projects, and an agency sustainability council that pilots sustainable infrastructure measures, such as making sure that solar panels are installed on new LA Metro facilities.

In addition to improving air quality and lowering GHG emissions, the Board also cited the opportunity to create job opportunities and economic growth in Los Angeles County as another benefit of pursuing the 100 percent BEB transition. LA Metro staff also see the BEB transition as an opportunity to provide leadership and motivate other agencies to aggressively pursue a shift to zero-emission bus fleets. Because BEB deployment is so complex, "off-the-shelf" solutions do not readily exist, and agencies must each find their own ways to implement transition. In the spirit of that challenge, LA Metro is working on an ongoing basis to share their lessons learned with other agencies. Staff also acknowledged that heavy-duty trucks are a significant source of transportation-sector vehicle emissions. So far, it is unclear when EVs will be a cost-effective option for trucking. Metro staff see a large-scale transition to BEBs (and the accompanying charging infrastructure changes) as a way of potentially lowering the bar for the trucking industry to adopt EVs: while such a transition would arguably be a positive outcome, to some degree it would also mean that the private sector would benefit from LA Metro's research, development, and sweat equity at minimal cost. The tension inherent in this dynamic is magnified by the substantial price of fleet transition. How the 2030 BEB conversion will be funded is still uncertain. The half-cent sales tax (Measure R) that LA County voters initially approved in 2008, and that was expanded in 2016 (Measure M), has been a significant source of funding for LA Metro in the past, but is not expected to cover the costs of the transition. Converting to BEBs is currently estimated to cost LA Metro close to a billion dollars from 2017-2027[2] (however this estimate will likely be refined during the development of Metro's BEB master plan).

1 Dan Weikel, "Diesel era ends for MTA buses," Los Angeles Times, January 13, 2011.

2 Los Angeles County Metropolitan Transportation Authority Agenda, July 27, 2017. See item number 50 (File No. 2017-0524). http://metro.legistar1.com/metro/meetings/2017/7/1231_A_Board_of_Directors_-_Regular_Board_Meeting_17-07-27_Agenda.pdf

For the moment, though, the agency is focusing on its upcoming procurements of 40-foot and 60-foot BEBs. Operating these new buses will build on LA Metro's 2015 electric bus pilot project, which involved five BEBs by BYD. Although there were reliability issues associated with the buses' driving range and weight, Metro staff saw the pilot project as having many positive outcomes, including providing first-hand experience with operating and maintaining BEBs. With its combination of flat and hilly terrain, and demanding climatic conditions (coastal air that can corrode bus components and roadway temperatures that can reach 120 degrees), Los Angeles presents an array of challenges for bus performance. By driving the pilot project buses on some of their toughest routes, Metro staff learned a range of lessons about the capabilities of the pilot BEBs. Staff also recognized that at the time, BYD faced the twin challenges of (a) building buses in the company's first US facility, and (b) building buses that had to meet structural benchmarks that are different and more rigorous than those required for the buses BYD builds for use in China. Metro staff made the comment that there may not yet be a BEB that can meet 100 percent of the agency's needs, but "we need to know what BEBs *can* do." Staff emphasized that success depends significantly on the bus manufacturer's ability to understand the needs of the agency, and in turn, the agency's understanding the capabilities of the manufacturer. Metro staff added that, no matter what kinds of buses the agency uses, their primary goal is to serve passengers and keep them safe.

As of late 2018, LA Metro had contracts for forty 60-foot BEBs from New Flyer; and for five 60-foot BEBs and sixty 40-foot BEBs from BYD. The 60-foot buses from both companies will be used on LA Metro's rapid-transit Orange Line, where both the BYD and New Flyer buses will use the same on-route charging system; staff commented that this will be the first time such a strategy will have been tried in the US. As of August 2018, Metro staff were having pre-production design meetings with New Flyer and BYD, and were concurrently developing their infrastructure plans. Staff see one of their biggest challenges as figuring out how to "future-proof" their BEB infrastructure: how do you set up charging strategies, depot facilities, and route design in a way that will most easily scale to accommodate a growing BEB fleet in the years to come? Metro staff recognized the agency's limited ability to install on-route charging across LA Metro's service area; a combination of on-route and depot charging may turn out to be the most viable long-term approach. Staff also noted that California's aggressive renewable energy targets could, at some point in the future, potentially make it more cost-effective to charge buses during the day (when a greater percentage of the grid can be powered by solar energy) rather than at night, when electricity has historically been cheapest due to low demand. Metro staff emphasized the need for cooperation with the Los Angeles Department of Water and Power and with Southern California Edison to design electricity rate structures that can accommodate such market changes and provide feasible solutions for both parties.

Photo courtesy Armando Aparicio

4 Battery-Electric Buses in Practice: Recommendations and Conclusions

American public transit is standing on the threshold of a major transition, one that encompasses a constellation of opportunities for communities, workers, manufacturing firms, and transit agencies themselves. A shift to battery-electric buses holds the promise of providing agencies with a cleaner mode of transit whose life-cycle costs are projected to be significantly more affordable than those of the diesel and CNG buses on which agencies have relied for years.

The future need for electricity to fuel BEBs can simultaneously reinforce a virtuous cycle of demand for the wind and solar energy that is already cost-competitive with fossil fuels and poised for increased deployment as growing numbers of American cities and states set goals to ramp up their renewable energy use and generation.

This paired development of clean energy and BEBs would accelerate improvements in air quality, both in terms of the original energy generation and the reductions in diesel and CNG bus exhaust. Bus-related greenhouse gas emissions would be significantly reduced, and American communities—especially low-income and environmental justice communities, which in many parts of the country have endured the highest levels of exposure to dangerous pollutants for decades—would begin to benefit from air with lower levels of NO_x, ozone, and particulate matter. Switching to BEBs will also dramatically improve working conditions for bus operators and bus maintenance staff, whose occupational health risks associated with diesel emissions are well documented in research literature. The savings in healthcare costs, reductions in missed work, and betterment in quality of life would be substantial, both for bus workers and the general public.

A full-scale transition to BEBs can also create significant manufacturing opportunities at a time when the manufacturing sector is showing signs of post-recession recovery, but is still far from reclaiming its full power in the American economy. The purchase of BEBs, as well as the related work needed to build and install charging stations and upgrade bus depot facilities, would result in a level of job creation that would comparable to the current jobs associated with diesel buses. Additionally, because the majority of BEB purchases over the next several decades will likely be made by transit agencies that are working towards fulfilling clean fleet transition goals, those agencies have the ability to shape the design and performance standards of the buses they're procuring, and also to set important benchmarks for job quality. Policies like the US Employment Plan can ensure that taxpayer dollars support not just the purchase of important transportation equipment, but also the creation of American jobs that have the family-supporting wages, benefits, and advancement opportunities that made manufacturing careers respected and desirable for past generations of workers. Transit agencies' use of good jobs policies will also reinforce nationwide efforts by workforce groups, and manufacturing firms themselves, to correct past inequities and encourage women and people of color to seek manufacturing careers.

Actualizing this unique and far-reaching collection of benefits will require persistence and creativity, because the BEB challenges that agencies currently face are in almost all respects totally different from the considerations that have guided their bus programs in the past. In thinking about how these issues can be addressed, there is a fundamental consideration to keep in mind: the mission of a transit agency is to provide the public with reliable, safe transportation. Environmental and manufacturing factors are, at best, secondary or tertiary concerns from a transit perspective—and yet, the great majority of transit officials believe that zero-emission buses—overwhelmingly in the form of BEBs—are the future of bus transit in America. Some stakeholders have gone further, expressing the view that electric buses are a strategic technology the US must master to stay competitive with Asian and European nations.

How can this mastery be developed? The simple answer is to create the conditions for agencies to succeed with their BEB programs. However because BEBs require such complex planning, each agency will need to develop its own unique approach. For instance: an agency with cheap, plentiful hydropower but limited capital funds and highly constrained land availability (a problem when installing on-route charging or depot charging) could need help in areas that are very different from those that would benefit an agency that has plentiful real estate but an understaffed maintenance department and a contentious relationship with the local utility. To whatever degree that advocacy, labor, and community groups want to support BEB deployment, the effort must be made to understand the specific challenges that their local agencies face.

Interviews and conversations with numerous stakeholders have shed light on a range of ways in which these challenges can be addressed. "Early-mover" agencies that are already preparing for large BEB procurements can be encouraged to document as much information about their BEBs as possible. The value of accurate data on BEB performance—especially in different operating environments—is essential for understanding BEB capabilities, both now and as the technology develops in the coming decades. Numerous stakeholders have made the comment that significant differences can exist between BEBs' advertised performance and how they actually perform during the course of typical duty cycles: having data that clarifies how BEBs work in the field will help set clear benchmarks for manufacturers. For agencies that are preparing to launch BEB pilot programs, assistance in connecting with other agencies that have more BEB experience may help significantly as well: supporting peer-to-peer networking will be critical in making sure that agencies around the country can master the BEB learning curve as smoothly as possible without repeating each other's mistakes.

All agencies with BEB experience agree on the imperative of involving utilities in the planning process as early as possible. Is there clear communication on why supporting BEB deployment is important, and more fundamentally, on how transit is a public service, not unlike electricity itself? Can other stakeholders assist in facilitating this communication? Is the utility willing to consider sharing the costs of the infrastructure build-outs that may be required, especially for larger BEB fleets? Theoretically, the dynamic between utilities and agencies should be a win-win: BEBs will make the agency a major new utility customer, and the utility can potentially provide the agency with rates and demand charges that will help the agency benefit from BEBs' excellent fuel efficiencies. What can be done to help agencies and utilities fully realize this synergy?

While agencies are still in the process of learning their buses' capabilities, it may be necessary for them to initially run their BEBs on specific routes that match what the buses can do (at some agencies, this has been key to the success of their BEB deployment). Agencies may even need to consider designing routes specifically for their BEBs. Is it possible to locate BEB routes in environmental justice communities, or other areas where air quality improvements are especially needed? As bus operators and maintenance staff hone their abilities to work with BEBs, there will likely be opportunities to expand BEB use. Will the agency staff who handle route- and schedule-setting be willing to adapt accordingly?

The experiences of agencies so far have begun to reveal the remarkable range of complications that can arise with BEBs. Conversations with bus professionals provide examples of just some of the real-life issues that agencies have already experienced. For instance: How much will different types of tires impact a BEB's range? Is the charging infrastructure adequately protected against lightning strikes, which can damage both chargers and the buses themselves? Similarly, are the bus's electronics protected from outside moisture and condensation, especially if the buses will operate in a wide range of temperatures? Can high winds periodically interrupt a BEB's connection with an overhead charger? Circumstances can also arise that may have an outsized impact on an agency's ability to utilize all of its BEBs. For instance: bus operators need specialized training to drive BEBs. Does the agency have the resources to train enough bus operators to drive all of the agency's BEBs if some trained drivers unexpectedly become unavailable? Or if an agency has five BEBs that all depend on the

BOX 2:

Chicago Transit Authority (CTA)

The electric bus program at CTA began in 2014 with the introduction of two New Flyer BEBs. The goal of the pilot project, not unlike LA Metro's, was to put the BEBs through their paces to assess the potential for benefit as BEB technology matured. Although they experienced some early operational glitches with the two pilot BEBs, CTA staff did not find anything out of the ordinary or unexpected considering the newness of the technology. The New Flyer buses by and large met the staff's expectations, and did not have any significant road performance issues. Although bus operators expressed some initial apprehension about the new buses, they liked the quiet engines and were interested in learning about BEB technology.

Based on the success of the two-bus pilot project, in June 2018, CTA announced the award of a $32 million contract for 20 BEBs from Proterra. Staff and leadership at CTA see BEBs—with their substantially lower GHG emissions—as an important component of Chicago's efforts to limit and prevent the effects of climate change. In the press materials accompanying the announcement, Mayor Rahm Emanuel was quoted as saying that the new BEBs represent "a new path for Chicago's public transit, one that is greener, healthier and more efficient".[1] (Expanding the BEB fleet is part of a range of environmentally focused CTA initiatives, including conversion to energy-efficient LED lighting and recycling operations-related substances such as metals, oil, lubricants, and batteries.) The press release also stated that the two pilot BEBs had saved "CTA more than $24,000 annually in fuel costs, and $30,000 annually in maintenance costs, when compared to diesel buses purchased in 2014."[2] Staff plan to closely monitor the maintenance requirements and electricity usage with their next-generation BEBs to develop a more comprehensive understanding of the operating costs of a larger BEB fleet.

For the two pilot BEBs, maintenance issues were generally routine, and consisted largely of work that could be handled by CTA staff. Maintenance on the pilot BEBs' electronic systems was managed by New Flyer. For the new BEBs, CTA staff expect to have an on-site maintenance representative from Proterra, and to take the process of developing maintenance expertise one step at a time until the agency develops in-house proficiency.

For the incoming Proterra BEBs, CTA plans to implement on-route charging in order to maximize BEB run-time and mileage (the pilot-program BEBs charge in bus garages during the mid-day, off-peak period and overnight). The new BEBs will operate on a ten-mile, east-west route connecting the Navy Pier area to Austin Boulevard. The current plan is to have two overhead chargers at each end of the route, and to install additional chargers over time as CTA purchases more BEBs. Staff anticipate that the BEBs will need to charge for five to ten minutes, and have requested that future BEBs be built with greater battery capacity so that the buses can potentially skip one of their scheduled charges if needed. The BEBs will be some of the first generation of Proterra BEBs to use the J3105 overhead charging standard, which is being designed for maximum interoperability between all makes of BEBs.

1 "Chicago Expands Electric Bus Fleet" (press release), Chicago Transit Authority, June 13, 2018.

2 CTA, ""Chicago Expands Electric Bus Fleet."

Staff describe their main challenge as being similar to that recognized by LA Metro: how to design their infrastructure plans and charging strategy in such a way that CTA can "do it right the first time" and make its facilities expandable to accommodate larger BEB fleets in the future. With this in mind, CTA staff estimate that the up-front cost of infrastructure construction for the 20 incoming BEBs will likely be significant. In order to adequately prepare for future fleet expansion, the initial site development includes provisions for additional chargers in the future.

same on-route charger, and for unanticipated reasons the charger becomes inoperable, that will put all of the agency's BEBs out of commission, and more importantly, compromises the agency's ability to get customers where they need to go.

For agencies that may be grappling with the high upfront costs of BEBs, California provides a range of model funding programs that can complement existing federal grants to support clean transit vehicle purchases. Statewide master BEB solicitations, like those introduced by the California Department of General Services, have the potential to be highly useful in facilitating BEB purchases, especially for smaller agencies with limited procurement staff. In thinking about procurement, agencies should also carefully consider the possibilities for training. By including maintenance and operator training in their BEB requests for proposals, agencies can ensure that their own teams are given full opportunity to learn how to drive and work on this valuable new equipment. To the degree to which OEMs prefer to manufacture BEBs rather than maintain them, providing structured training should be desirable for OEMs. In procuring for training, agencies can also include specifications that meet or exceed the benchmarks that the OEM sets for honoring any warranties the agency may have on its BEBs.

To strengthen BEB supply chains, the most important step is already being taken: transit agencies of all sizes—including the New York MTA, Los Angeles Metro, and Chicago Transit Authority (the country's three largest agencies)—have announced their plans to either aggressively grow their BEB fleets or transition their bus fleets entirely to zero-emission vehicles. Standing by their commitments to those programs and providing clear signals to manufacturers about future levels of demand are perhaps the most fundamental actions agencies and elected officials can take to support the future success of public transit BEB deployment, and also of OEMs and supply chain companies. Being able to confidently forecast future demand will allow larger companies to make the necessary investments to continue improving BEB technology, and will give smaller manufacturers the assurance they need to invest in making products that allow them to join or expand their participation in BEB supply chains. And to come full circle, including good jobs programs in agency procurement policies can enrich the workforce conditions that will spur success both for OEMs and manufacturers along the BEB supply chain.

The combined ways in which BEBs can improve public transit, public health, the environment, workforce and economy, present the kind of opportunity that only comes along once in several generations. The sum of BEBs' advantages is too great not to pursue. Ultimately, capturing the combined upsides of BEBs can help America achieve an even more fundamental goal: expanding public transit availability across the country, so that people everywhere—especially those that need mobility most—can access transit services that will expand their ability to connect with their jobs, schools, families, and communities, while improving the environment and creating better jobs for working Americans.

BOX 3:
Policy Recommendations

Prepare for successful large-scale BEB deployment:

- Agencies should commit to ambitious targets for transitioning their bus fleets to BEBs over a specific period of time and create strategic transition plans for accomplishing these goals.
- In developing their transition plans, agencies should work closely with key stakeholders including their local government, current agency workers, and communities.
- All stakeholders should take whatever steps are necessary to create a constructive dialogue and a shared sense of mission between the transit agency and its utility.
- To increase the success of BEB deployment, policymakers and governing bodies that shape decisions at transit agencies should provide robust support for data gathering within the agency and sharing of best practices with peer agencies.
- Elected officials, agencies, and other groups should work together to create targeted funding streams and take any additional steps that are necessary to ensure that BEB procurements are funded and can progress on schedule.

Create community health and climate solutions:

- As part of their transition plans, agencies should identify the neighborhoods in their areas that are most impacted by air pollution and prioritize the deployment of BEBs in those neighborhoods.
- Agencies should also engage in dialogue with their utilities about options for on-site renewable energy generation to maximize greenhouse gas reductions.

Prioritize good jobs with equity and career growth:

- Large agencies should develop sustainable good jobs policies to ensure that BEB manufacturers are incentivized to create permanent jobs with family-supporting wages, benefits, and training in transferable skills.
- Agencies and manufacturers should coordinate with economic development programs to support technical skills training for BEB manufacturing workers.
- Agencies should consult bus operators and maintenance workers, and their unions, to determine what skills training is needed to ensure that bus maintenance can be performed by current agency workers.

Commit to transparency and accountability for the entire program:

- Agencies should encourage and create opportunities for large-scale stakeholder participation.
- Agencies should build re-evaluation into their transition plans over time, and commit to regular and open review of their BEB programs.

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