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Workforce Implications of Transitioning to Zero-Emission Buses in Public Transit

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A White Paper from the National Center for Sustainable Transportation

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16. Abstract

"Workforce Implications of Transitioning to Zero-Emission Public Transit" provides educational and policy-driven approaches to sustainable transportation workforce development in the transit sector with a focus on knowledge transfer and training strategies for zero-emission bus technologies. The authors draw from a comprehensive survey of national research, interviews with transit leaders, and case studies to identify the most critical technology transfer gaps in the adoption of zero-emission bus technologies. The paper concludes with strategic transit workforce priorities and related recommendations for transit leaders, educational partners, and policy makers.

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Disclaimer

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Workforce Implications of Transitioning to Zero-Emission Buses in Public Transit

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EXECUTIVE SUMMARY

The internal combustion engine vehicle is a relatively simple collection of technologies borne out of the industrial revolution that have gone fundamentally unchanged—though significantly improved—over the last 100 years. Without question, a century is a long time for the national transit workforce to refine bus fleet operation and maintenance processes. Zero-emission vehicles (ZEVs) powered by battery-electric and fuel-cell engines are driving a new paradigm in human mobility and are redefining how public transit systems are designed, developed, operated, and maintained.

To address workforce challenges driven by the transition to zero-emission bus technologies, leaders in transit, educational partners, and policymakers must work together at the local, state, and national levels to identify strategic priorities to recruit, train, and retain a skilled workforce. To underscore this national workforce priority, one need only consider the increased demand for transit services over the last two decades. From 1999 to 2019, the total number of transit passenger miles traveled increased by 22.22 percent or 10.2 billion miles. The year 2019 also marked the emergence of another completely unforeseen factor: the Coronavirus Disease of 2019 (COVID-19).

The impact of COVID-19 on the transit sector was, and continues to be, unprecedented. Ridership numbers reduced dramatically and transit professionals suddenly became front-line workers facing a global pandemic and implementing new quarantine and social distancing standards. Without question, the COVID-19 pandemic destabilized transit use and operations. But, in some respects, the COVID-19 pandemic has also compelled leaders in transit—like leaders in every other sector of the economy—to reconsider basic notions of what mobility means to passengers and the professionals who serve them. Transformational trends in transit are reflected in the increased pilot testing of microtransit systems, automated rapid bus transit, transit on demand, and other systems that use smaller buses to transport passengers more nimbly and responsively via data-driven, crowd-sourcing technologies similar to those used by transportation network companies (TNCs) such as Uber or Lyft. In many other respects, the COVID-19 pandemic and recovery has cast a spotlight on longstanding workforce and mobility issues. Considered in this regard, implementing zero-emissions technologies has remained a top transit priority before, during, and in the aftermath of the COVID-19 pandemic.

Put simply, leaders in transit, policymakers, and education and training providers will have their hands full identifying strategic workforce development priorities for the transit sector. The first and most obvious step in assessing macro transit priorities calls for a look at the relevant national workforce data. In 2019, according to the American Public Transportation Association, of the 448,271 people employed in public transit, 63 percent worked in vehicle operations, 14 percent in vehicle maintenance, 9 percent in facility maintenance, 10 percent in general

administration, and 4 percent in capital occupations. That statistical breakdown means that 96 percent of those transit professionals worked in some aspect of operations. Therefore, transit operations should be a top priority. Taking that approach one step further, of those operational occupations, 49 percent of those professionals work with various modes of bus transportation.[22] That rationale informs the forthcoming focus on workforce implications of transitioning to zero-emission public transit bus fleets.

This white paper identifies demographic, technological, operational, and policy factors that are raising the most significant workforce development challenges associated with the transition to zero-emission buses in the transit sector. The workforce implications, technological summaries, and case studies in this report provide an introduction for leaders in transit, policy, and education to consider practical approaches for assessing range issues, new charging and fueling infrastructure considerations, and understanding the evolving role of original equipment manufacturers in an emerging era of modular maintenance. Finally, the workforce implications raised in this paper suggest future directions for research and workforce development initiatives.

Introduction

In January of 2016, Ohio's Stark Area Regional Transit Authority (SARTA) broke ground on a new 9,000-gallon hydrogen refueling station, part of an infrastructure improvement project that would support the launch of its first fuel cell electric buses (FCEBs) later that year. Funded under the Federal Transit Authority's Low or No Emission Deployment Program, SARTA would soon be running the largest fleet of in-service FCEBs east of California. While, at the time, neither the buses nor their hydrogen fuel were cost-competitive with their diesel or compressed natural gas (CNG) peers, the promises of cleaner air, a research program at Stark State College, and a local fuel-cell industry with high-paying jobs convinced SARTA that FCEB's were the future for Ohio public transit.[1]

As with pioneers of any start-up technology, the team at SARTA experienced first-hand the kinds of challenges that would accompany the rollout of zero-emission buses. During its ramp-up phase, supply-chain challenges would contribute to higher rates of vehicle downtime, as many components were still very much "next-generation" and vehicle manufacturers found themselves unprepared to supply replacement parts within a reasonable turnaround time.[2] Over the course of a four-year evaluation period, SARTA would report various issues relating to vehicle downtime, preventative maintenance costs, availability of technician manpower and training, HVAC-related range limitations, and SARTA's own outdated internal processes.[3]

Experiences of early adopters like Ohio's SARTA are useful touchstones to evaluate the growing deployment of zero-emission busses within the U.S. public transportation system. What follows is an assessment of ways that the transition to zero-emission bus technologies are impacting the workforce responsible for operating, maintaining, and managing the nation's transit fleets. Those assessments will provide a context for subsequent recommendations for employers to engage, recruit, and train workers to meet the growing demands of this dynamic industry.

Ability and Access to Technology

To better appreciate the broad implications of any disruptive technology on an industry's workforce, it is important to first characterize that workforce in terms of its current limitations, existing workplace challenges, and generational dynamics. The impact of technological change and how it influences the occupational demands of an industry's workforce are not unique to public transportation. Across virtually all sectors, the challenge of bridging the skills gap developing between today's aging workforce and the growing deployment of technology in the workplace remains a critical yet largely unaddressed concern. If left unchecked, this fundamental gap between the availability of efficient new technologies and an employee's ability to access or interact with them is projected to impact the national economy by $2.5 trillion over the next 10 years in terms of lost productivity.[4, 5]

One example of this is evident in many of the nation's public works and transit agencies, whose frontline workers—mainly drivers, mechanics, and laborers—often have no access to email, the Internet, or even a computer while at work.[6] This basic lack of on-the-job connectivity will often impede workers from participating in many of the available forms of professional development, such as online training, continuing education, and industry networking/engagement.

As seen from an industry perspective, today almost 80% of U.S. companies report undergoing some form of technological transformation, and roughly two thirds of all jobs that require a "technical education" now exist outside of traditional technology sectors. Despite this growing trend, ZEV technical skillsets remain a scarcity within the job market. Companies searching for qualified workers to fill new job vacancies tend to pursue new-hires over making an internal training investment that would upskill their existing workforce. The persistence of this "hiring versus promoting" human resource strategy not only contributes to many of today's employment challenges—like overly long delays in filling job vacancies—but at the same time damages the overall performance and productivity of an organization's current labor pool.[7]

The effect of this behavior is evidenced in a recent online Harris Poll, where 60% of U.S. employers reported having job openings go unfilled for more than 12 weeks due to a lack of qualified applicants. And while employers expressed concern over this growing disparity in available job talent, 20% of employees polled acknowledged that a lack of updated professional skills or credentials were keeping them from acquiring better pay or more fulfilling employment.[8]

A Changing Workforce Demographic

As the U.S. experiences its "Fourth Industrial Revolution," an era in which the exponential pace of technological advancement disrupts industry with changes that "herald the transformation of entire systems of production, management, and governance," the effects of this dynamic new technological environment on industry and its workforce are still being evaluated.[9] Yet one such effect is clearly underway: the gradual reformation of the workforce demographic.

Those industries largely defined by Middle Skills jobs—like manufacturing, agriculture, and transportation—are most directly impacted by this reformation. Middle skill jobs require more than a completed K-12 education but less than a bachelor's degree. The demand for middle skills professionals has grown steadily since due to increasing Baby Boomer retirements, hiring competition with other sectors, stagnate wage growth, and unfavorable job stigmas—all of which contribute to a decline at a time when companies are exploring ways to stay viable and competitive through the adoption of new technologies.[10, 11] Given the sheer scale of this looming labor shortage, it is critical that the transportation industry adopt employment strategies that will engage and be responsive to this changing workforce demographic.

Baby Boomers, now the longest working generation in the nation's history, are beginning to retire from the workplace in droves, taking with them a lifetime of critical job knowledge and acquired skillsets. This generation—workers of age 55 and older—hold more than a quarter of the nation's transportation jobs. Within public transit this statistic jumps to 40%.[12] Over the next decade, in an industry projected to grow by an additional 453,100 jobs,[13] almost half of its current workforce will retire. These vacancies will be filled by a younger, more ethnically diverse Millennial and Gen Z demographic, often characterized by their social conscientiousness, technical savvy, ease at multitasking, and appreciation of a healthy work-life balance—qualities that tend to distinguish them from their Boomer parents.[14]

As a consequence, employers today are having to deal with the challenges of recruiting, training, and incentivizing a multi-generational workforce that now represents a collection of value systems, career goals, and technological adaptability.[15] Even the development of occupational training—once a reasonably straightforward proposal—today requires a combination of the right technologies, a flexible learning system, and scalable curriculum in order to engage such a diverse workforce while also meeting the individual learning needs of each employee.[16] A 2020 report on the training needs of Southern California transit workers reflects on this requirement, noting that "Developing training that is responsive to the needs of the transit workforce means striking a balance between ongoing training demands and new skills and competencies required to address new technologies."[17]

The Emerging ZEV Transit Workforce

For transit agencies exploring mobility solutions that focus on environmentally friendly low- or zero-emission vehicles, having access to a modern and well-trained workforce is a critical cofactor to success. Pursuing advancements in electric propulsion, high-density energy storage, and fuel-cell technologies necessitates the upskilling of workers, as does the operation, maintenance, and management of these advanced vehicles. As a matter of practice, transit agencies tend to be rigorous providers of up-to-date technical training, certifying that their workers can safely and effectively deliver transportation services to the public. But given the scale of technological change occurring within transit and the generational change transforming its workforce, new strategies are needed to attract a broader range of talent into this industry and to provide more effective training solutions that can be adapted to individual learning styles.

By the end of 2018, the American Public Transportation Association (APTA) estimated that 28% of the nation's public transit buses no longer ran on traditional diesel or gasoline fuels but were instead operating on natural gas. Another 21% had transitioned away from fossil fuels altogether in favor of new electric powered engines. In fact at the time, almost a fifth of all U.S. transit agencies had either ordered or already deployed electric buses (either hybrid or battery-electric) into full revenue service, and a third were committed to transitioning their entire fleet over to all-electric (non-hybrid) designs by 2045.[18] The direction for public transportation seems clear, but the path is not without its challenges. As transit agencies pursue these newer low- or zero-emission vehicles, it is important they recognize the need to be more flexible and adaptable to incorporating new technology into their organization and into their workforce.

Transitioning to a zero-emission bus (ZEB) fleet is a multifactorial process that requires a range of interrelated steps to complete. During the transition, transit agency operations teams have to manage at least two distinct vehicle platforms. Agency procurement officers will need to incorporate the purchase and installation of ZEB support infrastructure into the agency's capital expenditures schedule. Inventory managers will need to establish risk/reliability profiles for new powertrain components to determine which should be stocked to minimize vehicle downtime. Maintenance personnel need to be trained and certified to service both legacy and ZEB vehicle systems. Long-term, the effects of such organizational change are expected to bring about a redistribution of responsibility within an agency's departments and staff, as its operation inevitably becomes more vertically integrated during the long transition process.[19]

When Ohio's SARTA rolled out new FCEBs to its transit ridership in Stark County, its two OEM-trained service techs were quickly challenged by technical, supply chain, and scheduling issues that directly impacted vehicle availability. SARTA's bus drivers reported experiencing range anxiety due to the lack of any "distance to empty" fuel indicator and thus logged less miles than expected and refueled more often than necessary. Operation leads worked with the FCEB manufacturer to isolate fuel-distance issues that correlated with the seasonal use of the in-bus HVAC system.[20] While each of these accounts present a sensible reaction to dealing with deployment issues of a new technology, the ideal goal is to be aware of and plan for them ahead of time.

Data Collection and Analysis

In evaluating the scope of impact on the public transit industry as it embraces the adoption of zero-emission technologies, pilot reports from early adopter states like Ohio and California offer a baseline look into the kinds of decisions, costs, and challenges that confront an agency when adding ZEBs to their fleet. Such early adopter reports offer well-documented, end-to-end analysis of actual FCEB or ZEB deployments. These pilots spotlight specific issues raised by agency management, such as how ZEBs affect organizational performance, what operational decisions were ultimately made, what internal solutions were deployed, and why.

The forthcoming evaluations and targeted recommendations were captured as part of an expansive review of national research that has tracked the evolution and viability of low- and zero-emission public transit options over the last decade. That analysis will address the disruptive influences affecting today's public transit workforce, the highlighting of key issues that industry leaders should be scrutinizing, and the recommendations for new ways to train and adapt workers to better accommodate transformational and technological change in the workplace.

Research Methodology and Focus

The following summary draws from publicly available national research and industry reporting on the nature, consequence, challenges, and inevitability of transitioning bus transit into the next generation of zero-emission, all-electric vehicle platforms, with a focus on how this transition is contributing to the industry's already problematic workforce skills gap.

Status, trends, technologies, and deployments of next-generation U.S. transit systems are documented and summarized through a comprehensive survey of published reporting from state and federal agencies, industry associations, transit authorities, training organizations, vehicle manufacturers, and zero-emission research pilots. Interviews and surveys were conducted with key industry leaders to determine:

a. The state of transit workforce training today;
b. Challenges to upskilling staff to better accommodate new technologies;
c. Effectiveness and limitations of training resources available to agency leadership; and
d. Recommendations for how to prepare the next generation of transit worker (i.e., one capable of operating within a more dynamic, data rich, and technologically advanced workplace and that can apply a broader understanding of public safety and continuity of service to the challenges that arise on the job).

A synthesis of well-documented case studies was also performed for this report to highlight the preparation, procedures, and best practices applied during the piloting of and transitioning to battery-electric and fuel-cell bus platforms within transit authorities. The evaluation of issues and successes reported during the integration of these vehicles across multiple public trials allows for a comparative analysis and characterization of factors that distinguish those states with broad support for ZEB transit from areas of the U.S. that show a slower, less monolithic adoption rate.

Ultimately, the goal of this research, analysis, findings, and recommendations is to highlight those factors associated with the transition to zero-emission transit that present the greatest challenge to maintaining an effective public transportation workforce. That rationale informs the forthcoming focus on workforce implications of transitioning to zero-emission public transit bus fleets, which begins with practical assessments of range issues, new charging and fueling infrastructure considerations, and understanding the evolving role of original equipment manufacturers (OEMs) in an emerging era of modular maintenance.

The first and most obvious step in assessing macro transit priorities calls for a look at the relevant national workforce data. In 2019, according to the American Public Transportation Association, of the 448,271 people employed in public transit, 63 percent worked in vehicle operations, 14 percent in vehicle maintenance, 9 percent in facility maintenance, 10 percent in general administration, and 4 percent in capital occupations (Figure 1).[22] That statistical breakdown means that 96 percent of those transit professionals worked in some aspect of operations. Therefore, transit operations should be a top priority. Taking that approach one step further, of those operational occupations, 49 percent of those professionals work with various modes of bus transportation. That rationale informs the forthcoming focus on workforce implications of transitioning to zero-emission public transit bus fleets.[22]

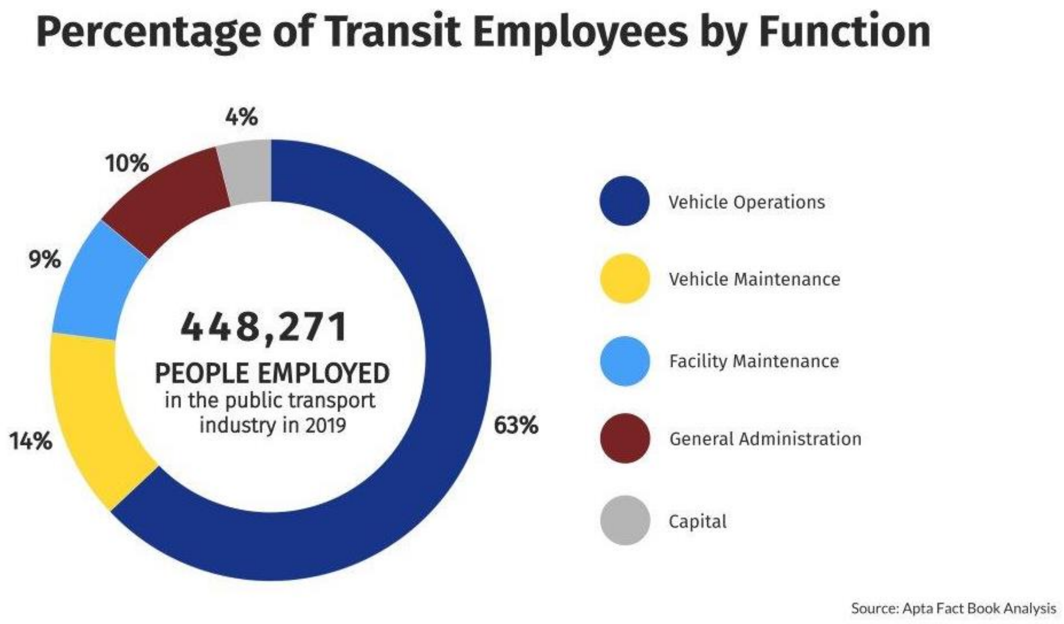

Figure 1. Percentage of Transit Employees by Function[22]

As is critical in any industry, managing the impacts of technological change in the workplace can be paramount to ensuring that workers remain productive, effective, satisfied with their jobs, and committed to the organization. From an agency perspective, job analysis and design, workforce planning, recruitment and staffing, training and development, performance, and career management, are all areas where adopting new strategies that accommodate technological change offer an organizational approach to managing worker readiness in ways that are both proven and effective.[21]

The State of Public Transportation

The American Public Transportation Association (APTA) defines public transportation as "… transportation by a conveyance that provides regular and continuing general or special transportation to the public, but not including school buses, charter or sightseeing service." Also referred to as public transit, mass transit, or simply "transit," APTA categorizes the various modes of public transit conveyance as either aerial tramway, automated guideway, bus (includes bus rapid transit), cable car, commuter rail, ferry boat, heavy rail (metro/subway), light rail (streetcar/trolley), monorail, demand response (paratransit/dial-a-ride), and vanpool (Figure 2).[22] Not included in this definition—nor covered by this paper—are the common forprofit point-to-point operations like taxis or taxis alternatives (Uber, Lyft, Arro, Curb, Fasten, etc.).[22]

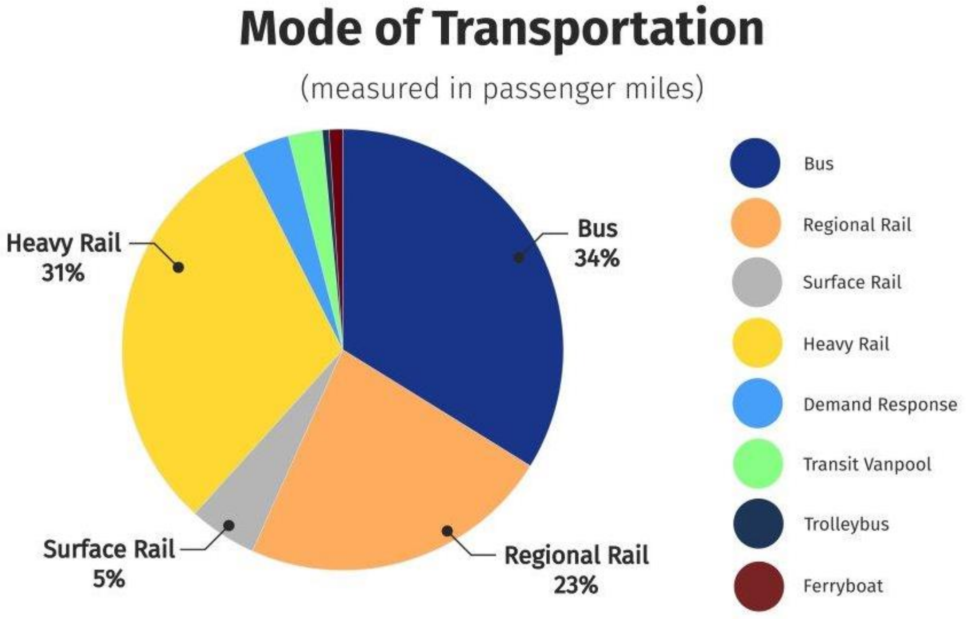

Figure 2. Mode of Transportation[22]

Transit Agency & Vehicle Deployments

Within the United States, the public transportation options deployed across the nation's metropolitan, urban, and rural areas vary greatly, but can generally be characterized as fixed-route bus systems (traditional and bus rapid transit), flexible paratransit services (taxis, carpools, and vans), waterborne transit (ferries and water taxis), subways and commuter trains, streetcars and trolleys, and monorails and tramways. Each option is designed to service a specific ridership use case while collectively providing a network of public access mobility options. Operating in almost every state in America, public transportation has grown into a $71 billion industry that employs more than 435,000 workers across some 6,800 servicing organizations.[22]

This network of services is powered by an equally varied mix of energy technologies, including petroleum-based fuels like gasoline and diesel, biofuels like ethanol and biodiesel, natural gas and propane, and electricity provided either as part of the transit infrastructure (overhead cable or powered rail) or via an on-vehicle delivery system (battery, dynamo, or fuel cell).[23]

Table 1. Primary U.S. Transit Modalities vs Energy Technology (2018)

Mode	# of Vehicles	Diesel	Gas	Bio Diesel	Natural Gas	Hybrid Electric	Electric Rail	Electric Battery	Hydrogen Electric
Bus	35,701	42%	2%	8%	29%	18%		0.7%	0.02%
Bus Rapid Transit	492	52%		12%	15%	21%			
Commuter Bus	1,434	94%	0.7%	0.5%	4%	0.8%			
Commuter Rail	577	95%					5%		
Demand Response	9,899	18%	65%	3%	12%	2%			
Ferryboat	207	90%				10%			
Heavy/Light Rail	11,757	0.2%					99%		
Streetcar/Trolley	714					5%	95%		
Vanpool	3,335		99.6%	0.4%					

In 2018, the U.S. public transportation system provided for 5 billion vehicle revenue miles of service and 336.6 million hours of revenue service, with both critical performance measures improving slightly over their 2017 counterparts. This accounts for 149,096 railcars, buses, vans and other vehicles out of a total 181,541 vehicles available for service (Figure 3).[22]

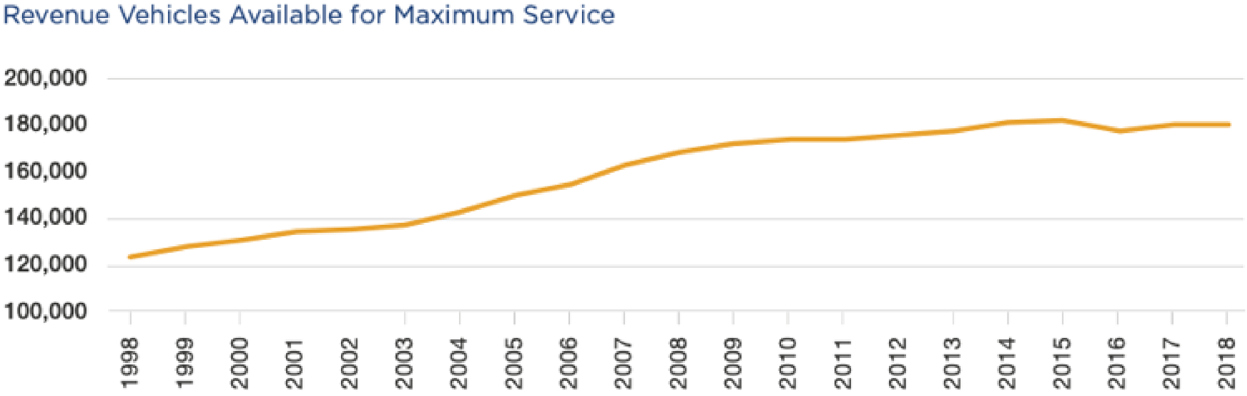

Figure 3. The Transit Vehicle Fleet On a 20-Year Upward Trend[22]

Yet, despite its complex portfolio, the public transportation system is dominated by two primary modes of operation: bus and rail. Today, rail transit—subways and trains—captures a 48% share of the nation's ridership (up 57% since 1998) while busses capture a 47% share.

However, from a workforce perspective, bus transportation eclipses all other transit modalities in terms of job demand, employing over 49% of the industry's workforce compared to rail's 23% (Figure 4).[22] That represents more than 213,500 employees and $15 billion in annual wages, with 71% of those workers (about 151,500 employees) focused on vehicle operations and vehicle and facility maintenance.

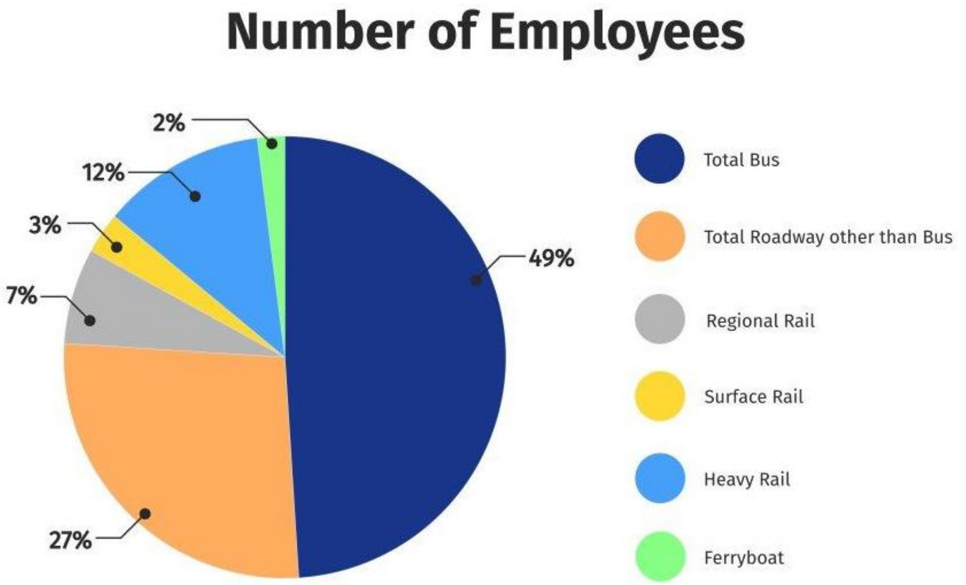

Figure 4. Number of Employees[22]

As bus transit continues its transition away from primarily petroleum-based fuel sources to more environmentally friendly alternatives (Figure 5), a corresponding shift in workplace technologies is producing an ever-widening gap between the competency set of a once diesel-dominated industry and the knowledge, skills, and abilities necessary to operate and maintain a new breed of low- or zero-emission vehicle technologies.[22]

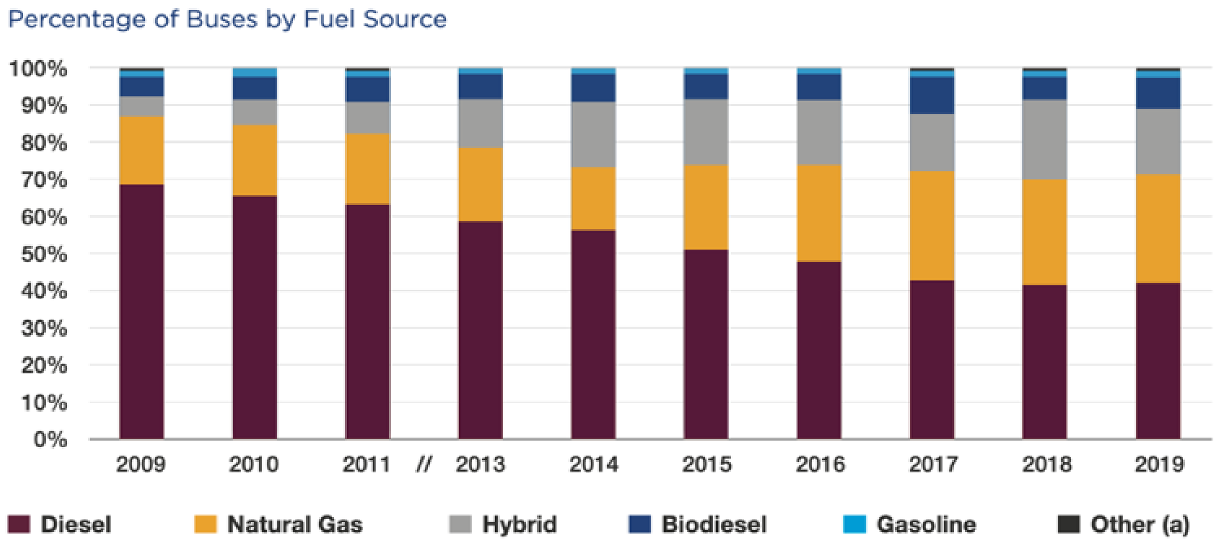

Figure 5. Buses Making Transition to Alternative Fuels[22]

Diesel's domination as the primary bus transportation fuel source has steadily declined over the last 25 years, powering as much as 95% of the nation's fleets in 1995 to 40% in 2019. This decline has largely been influenced by the introduction and growing availability of more environmentally friendly natural gas and hybrid-electric fuel source alternatives, as evidenced by the growth in market share of hybrid electric buses from 1% in 2005 to 18% in 2019 and in natural gas-powered busses from 18% in 2009 to over 29% percent in 2019.[22]

National Transit Workforce Trends

In 2018, the public transportation industry employed 435,890 people. Approximately 96% of this workforce represents transit agency operating employees responsible for providing vehicle operations and maintenance, non-vehicle maintenance, and general administration functions. Almost half of these workers (213,586) support the nation's bus transportation systems. Of the remaining half, 26% of public transit workers provide demand response services, 23% support the various modes of railway (heavy, light, commuter, streetcar, trolley), and 2% make up the ferryboat and vanpool workforce.[22]

Public transit employees represent one of the oldest workforces in the national economy, carrying a median age of 50.8 years. In 2018, more than 41% of bus services and urban transit workers were already 55 years of age or older. Age-related turnover is proportionately high in this sector, with retirement, displacement, and similar attrition factors projected to drive a significant demand for the hiring and training of replacement workers over the next 10 years.[25] This need comes in addition to an increase in hiring through transit industry growth, as many metropolitan cities expand their transit services through new bus routes and rail lines. In a 2020 synthesis of its workforce development meeting, the National Transit Institute states "the public transportation industry faces a significant skills shortage among its frontline workforce, driven by changing demographics, retirement of experienced workers, pervasive technological advances, increased demand for service, and competition from other industries."[25]

Transit occupations with the highest projected future demand include:

- Bus & Rail Technicians
- Paratransit Operators
- Frontline Supervisors
- Facilities Personnel & Building Engineers
- Communications Technicians
- Service-Line Personnel
- Fare Collection Inspectors
- Quality Control Personnel
- Safety Professionals
- Customer Service Providers

New and Old Workforce Methods for Zero-Emission Transit

As a highly skilled workforce is critical to maintaining a competitive and efficient public transportation system, the U.S. Department of Transportation's (USDOT) Federal Transit Administration (FTA) suggests that investment in building and maintaining human capital is as important as the investment in physical capital. With the resurgence of transit in recent years, transit systems face several challenges, including rapidly changing technology (to vehicles, rights-of-way, and customer information services) and a high number of impending retirements leading to the loss of institutional knowledge, growing ridership, and long-term expansion. These challenges make attracting and preparing new talent increasingly important.[27]

Transit agencies rely on technical training to ensure that their workers can safely operate and maintain the equipment and infrastructure used in delivering transportation services to the public. Providing quality transit training that is cost effective is a constant challenge. Current economic factors place budgetary pressures on agencies, impacting the resources available for training. At the same time, advancements in the complexity of transit vehicles and infrastructure increase the demand for training. Workforce demographics, including retirement of experienced workers and the recruitment of a new generation of workers who have different learning experiences, also impact training needs.

In a recent study commissioned by the National Transit Institute, the authors note that "Successfully positioning the public transportation workforce to excel requires understanding and recognition of its strengths and deficiencies." This study, which summarizes the insights of over 1800 public transit officials, offers one of the most comprehensive investigations into the training needs and gaps within the U.S. public transportation industry. The study documents skills gaps in the U.S. public transportation workforce and identifies strategies to address those gaps. Such strategies include approaches to more successfully recruiting and retaining the full spectrum of the transit workforce, from frontline to technical to professional staff. Viewed in this context, it is clear that human-capital challenges pose formidable challenges for transit agencies before, during, and after the transition to zero-emission transit systems.

While great deal of the training challenges in transit relate to addressing transformational technologies associated with the adoption of zero-emission buses, there are also practical workforce challenges that will remain the consistent across the pre and post zero-emission bus transition. Recruiting and retaining transit employees will always remain a challenge for transit agencies. Fortunately, there are many "low-tech" or "old-fashioned" workforce development approaches that will remain just as relevant in in the ZEV future as they were in the combustible-engine past. Organizational efforts to increase employee engagement—via regularly scheduled workforce planning and assessment meetings—are effective ways to identify workplace challenges, skills gaps, and reasons for employee turnover. Similarly, succession planning efforts and new employee mentor programs are other proven methods to bridge generational gaps in the workforce and to promote work cultures of continuous improvement.

Transitioning to Zero-Emission Bus Transit

In 1970, congress enacted the Clean Air Act, which defined the Environmental Protection Agency's role in protecting and improving the nation's air quality and each state's role in developing emission reduction implementation plans that would comply with new clean air mandates. Since then, the federal government has worked to support the states in reducing the amount of pollution each released into the atmosphere. Eventually, one clear solution was to begin transitioning public transportation vehicles over to lower-emission fuel alternatives, particularly in the case of bus transit, which historically operated on diesel fuel and emitted toxic nitrous oxide directly into urban communities.[26]

To help mitigate the impact of public transit on air quality, in 2016 the Federal Transit Administration (FTA) established the Low or No-Emission Bus Program (Low-No) to help subsidize the piloting and deployment of next-generation bus transit platforms. To date, more than $409 million in funding has been distributed to state and local governments for the purchase of hybrid, battery electric, and hydrogen fuel cell vehicles and support infrastructure, with 41 states receiving funding awards in 2020.[27]

Such federal investments have been augmented by many state-level grant programs designed to incentivize public transit's transition forward into a zero-emission future. California's Transit and Intercity Rail Capital Program (TIRCP)—intended to "fund transformative capital improvements that will modernize California's intercity, commuter, and urban rail systems, and bus and ferry transit systems, to significantly reduce emissions of greenhouse gases, vehicle miles traveled, and congestion."—has contributed almost $3.8 billion since 2015, to support more than $29 billion in statewide vehicle and infrastructure project costs.[28]

Over the last decade, this ready access to funding and purchasing incentives has helped to propel the growth of ZEBs across the country, as transit agencies, universities, and even private entities take advantage of regular advancements in electric and fuel cell vehicle technology. This has driven the adoption of ZEBs in public transit from a 1% share in 2005 to an 18% share in 2019, with today less than half (42%) of all buses still being powered by diesel fuel.[29]

While it remains somewhat difficult to capture a complete assessment of the number of zero-emission vehicles deployed in the U.S. (funding agencies track the vehicles they support, but do not assess the overall number that exist), the nation's active ZEB fleet is known to include 2184 Battery Electric Buses (BEBs) and 71 Hydrogen Fuel Cell Buses (FCBs) as of September 2019.[29]

Workforce Strategies for Zero-Emission Transition

Almost universally, a basic understanding of the internal combustion engine (ICE) vehicle exists within modern societies. An engine block generates propulsion power through the rhythmic detonation of an explosive gas-air mixture. A flywheel smooths these periodic detonations into a continuous stream of rotational horsepower. Gears provide for load adjustment, wheels convert horsepower to work, brakes use friction for stopping, etc. Overall, it's a relatively simple collection of technologies borne out of the industrial revolution that have gone fundamentally unchanged—though significantly improved—over the last 100 years.

By comparison, the design of all-electric vehicles (EVs) offered an opportunity to break from the constraints of traditional ICE vehicle design by re-evaluating the roles of each powertrain component in order to maximize power distribution and fuel—in this case electricity—efficiency. In EV design, the combustion engine is replaced by one or more modular electric motors.

All-electric vehicles (EVs), also referred to as battery electric vehicles, have an electric motor instead of an internal combustion engine. The vehicle uses a large traction battery pack to power the electric motor and must be plugged in to a wall outlet or charging equipment, also called electric vehicle supply equipment (EVSE). Because it runs on electricity, the vehicle emits no exhaust from a tailpipe and does not contain the typical liquid fuel components, such as a fuel pump, fuel line, or fuel tank.

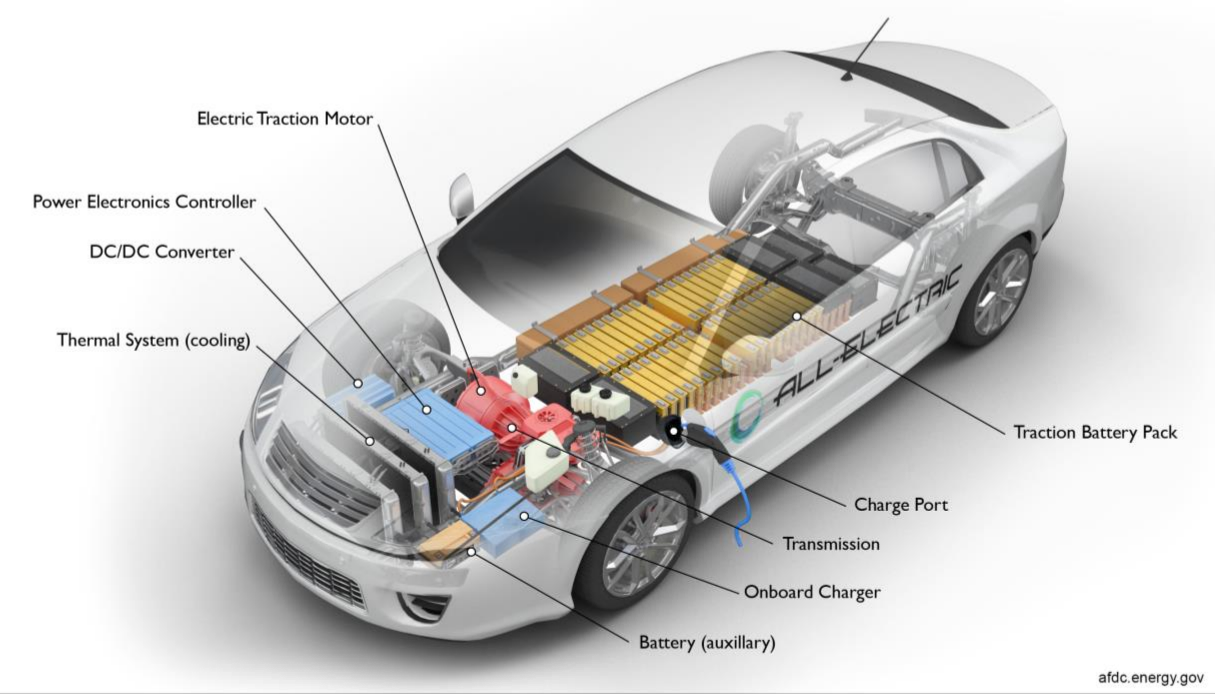

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Figure 6. Key Electric Vehicle Components

Key Electric Vehicle Components:

- AuxBattery (all-electric auxiliary): In an electric drive vehicle, the auxiliary battery provides electricity to power vehicle accessories.
- Charge port: The charge port allows the vehicle to connect to an external power supply in order to charge the traction battery pack.
- DC/DC converter: This device converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery.
- Electric traction motor: Using power from the traction battery pack, this motor drives the vehicle's wheels. Some vehicles use motor generators that perform both the drive and regeneration functions.
- Onboard charger: Takes the incoming AC electricity supplied via the charge port and converts it to DC power for charging the traction battery. It also communicates with the charging equipment and monitors battery characteristics such as voltage, current, temperature, and state of charge while charging the pack.

- Power electronics controller: This unit manages the flow of electrical energy delivered by the traction battery, controlling the speed of the electric traction motor and the torque it produces.
- Thermal system (cooling): This system maintains a proper operating temperature range of the engine, electric motor, power electronics, and other components.
- Traction battery pack: Stores electricity for use by the electric traction motor.
- Transmission (electric): The transmission transfers mechanical power from the electric traction motor to drive the wheels.

Hydrogen Fuel Cell Technology

While electric battery storage systems are for the most part well understood, fuel cell technology remains at the edge of next generation power system design due to its wide range of application, high energy transfer efficiency, lack of harmful operating emissions, and ability to supply electrical power continuously as long as fuel is supplied.[30]

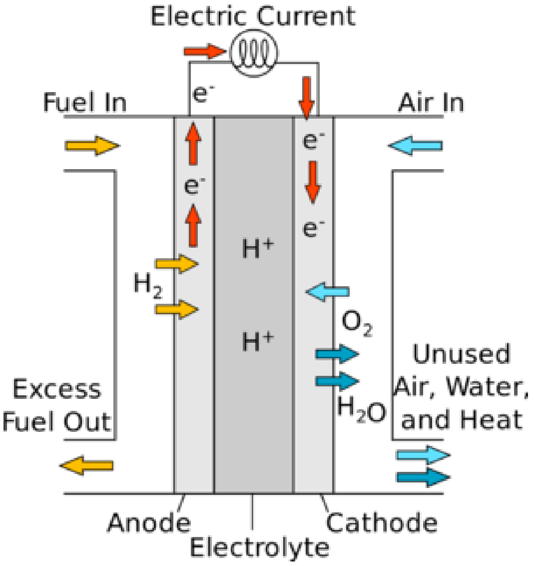

Figure 7. Hydrogen Fuel Cell

In the simplest terms, fuel cells work like batteries that never run down or need recharging. They consist of a negative electrode (anode) and positive electrode (cathode) that are sandwiched around an electrolyte. A fuel—in this case compressed hydrogen—is fed to the anode and free-air oxygen is fed to the cathode. A catalyst causes the hydrogen to undergo a process of oxidation, which frees-up electrons to leave behind positively charged hydrogen ions. These ions move through the cell's electrolyte from anode to cathode. The electrons make this same journey by way of an external circuit, producing a direct current electrical flow that is capable of delivering a substantial amount of energy. As the returning electrons and hydrogen ions recombine with oxygen at the cell's cathode, water and heat are formed as by-products of the overall energy-transfer process.[30]

Much like lithium batteries, each fuel cell produces a relatively low amount of power and are therefore stacked together and connected in both parallel and series to reach a vehicle's target voltage/current requirement. Operating at about 60% efficiency, a heavy-duty fuel cell design suitable for bus transit application will generate an operating voltage in the range of 350-580 Volts with a current rating of 10 to 260 Amps, or roughly 100kW of net output power.[31]

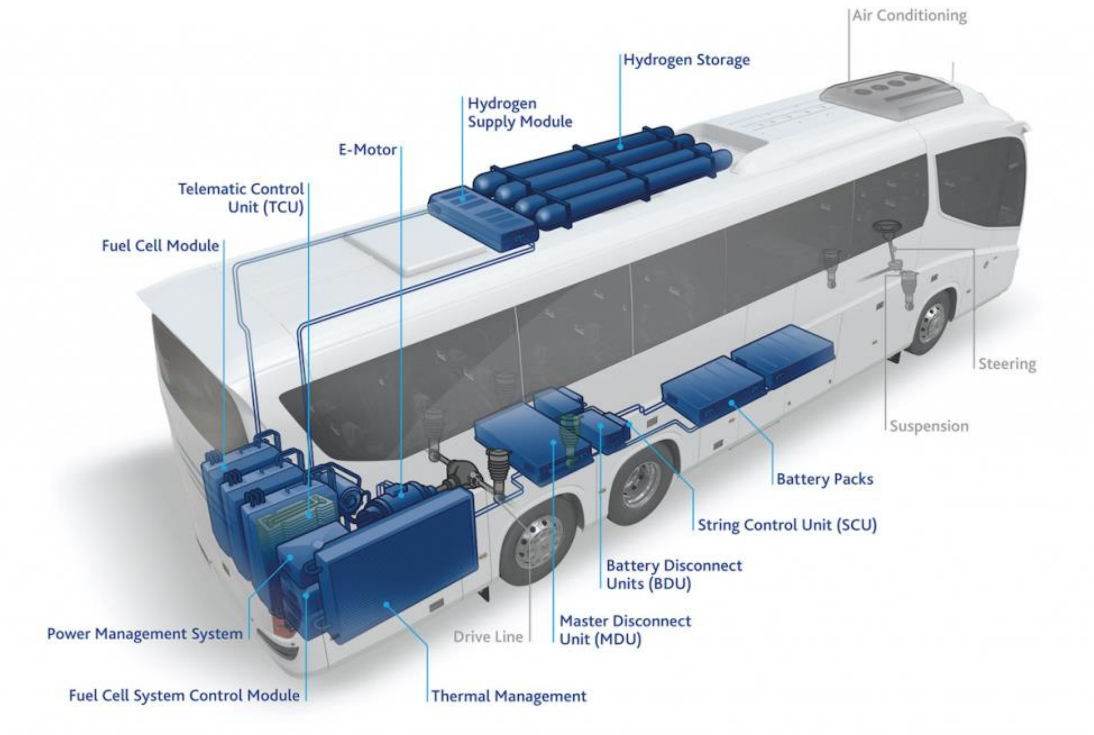

Figure 8. Fuel Cell Electric Bus Components

While the hydrogen fuel cell acts as a battery-replacement within the FCEB platform design, virtually all other powertrain and vehicle support subsystems are identical to those of battery-electric buses. As shown in this simplified diagram, the hydrogen fuel tank and power cell are part of the energy storage system, providing a continuous source of electric charge to the battery.

In terms of their in-service operation, FCEB's offer some distinct advantages over BEB vehicles in terms refueling (vs recharging) speed and fuel cost, but mostly the advantages and disadvantages between these two power storage mediums can be summarized as:[32]

1. Hydrogen's energy-to-weight ratio is 10 times that of lithium-ion batteries. Consequently, it offers greater travel range, lighter weight, and smaller storage volume than that of an equivalent battery system.
2. Both hydrogen and oxygen are widely available, relatively cheap, and fully renewable. Today, renewable hydrogen from electrolysis costs about $6/kilogram.

3. Hydrogen is an excellent fuel source due to the relative ease in which it gives up an electron and bonds with other elements. This also means it must be artificially isolated before being usable as a fuel, a process that can be expensive and energy consuming.
4. Because hydrogen is mainly extracted from water through electrolysis, the energy used in this process becomes part of the fuel's carbon footprint. If that energy was sourced by (for instance) coal-fired plants, hydrogen would be a "dirtier" fuel than gasoline.
5. Storing hydrogen gas is expensive and energy intensive (more so if stored as a liquid at cryogenic temperatures), as it tends to escape containment and is highly flammable.
6. Fuel cells require water to operate (i.e., not steam or ice), making the management of its operating temperature essential. Providing a system for heat dissipation can add considerable complexity and weight to a fuel cell's containment package.
7. Restarting a fuel cell vehicle in cold temperatures can be complicated and may make their use impractical for locations that often experience below-freezing temperatures.

In terms of safety, the compressed hydrogen used to power a fuel cell is actually safer than traditional gasoline or diesel fuels. As a gas, it is 14-times lighter than air, making it quick to rise and dissipate in the atmosphere. In terms of spills, accidents, and first-responder safety, gaseous fuels (including CNG) are far more preferable over liquid fuels. Hydrogen also holds a very good safety record when compared to other fuels. Gaseous hydrogen travels through 700 miles of pipeline across the nation and some 70 million liquefied gallons has been shipped by truck across U.S. highways, all without incident.[33]

At the refueling station, the experience of "pumping gas" is similar to that of any traditional gas station and identical to that of refilling a CNG tank. This effort is safe, reliable, and efficient.

A hydrogen refueling system generally consists of the following:

- A tank that stores pressurized hydrogen that is filled by tanker truck.
- A high-pressure buffer system that delivers gaseous hydrogen to the vehicle tank.
- A compressor to pressurize the hydrogen.
- A refrigeration system to cool the hydrogen gas being dispensed.

Each hydrogen "dispenser" looks and operates similar to that of a normal gasoline pump or CNG dispenser. Hydrogen dispensers designed to refuel heavy duty fuel cells are usually equipped with two hoses: one standard "H35" hose that pumps at 5,000 psi and one heavy duty "H70" hose that pumps at 10,000 psi. The fuel tank connectors on these hoses are not interchangeable. Refilling a hydrogen fuel tank is similar to refilling a CNG or propane tank. The driver connects the fuel nozzle to the vehicle's tank receptacle and, once an air-tight seal is formed, hydrogen flows from the station's primary storage tank into a cooling unit in the dispenser then into the vehicle's tank. In the case of refueling an FCEB (an H70 connection), the hydrogen is first compressed from 5,000 psi to 10,000 psi before reaching the dispenser. The process of hydrogen refueling takes about the same time as filling a gasoline tank.[34]

Figure 9. Hydrogen Fuel Station

Today, in terms of national infrastructure and deployment, hydrogen fuel cell technology is still in its infancy. In the short-term (through 2025), its use is highly competitive as a fuel source for powering large vehicles (trains, coaches, buses) over long distances. As hydrogen use becomes more widespread and its cost and availability (access to refueling stations) becomes more favorable, it is projected to replace natural gas in most all applications, including light-duty vehicles and power generation. According to The Hydrogen Council's "Path to Hydrogen Competitiveness: A Cost perspective," by 2030 hydrogen will become a competitive low-carbon fuel source for virtually all modes of transportation except the compact urban car.[35]

In California, a number of FCEB developments, demonstrations, and deployments have proven this technology to be reliable and robust and offering a level of route flexibility that is somewhat unmatched by BEB equivalents. There is an expectation that FCEBs will soon see a broader national adoption in both agency deployments and number of vehicles per fleet.[36]

Case Studies in Electric Bus Transit

Evaluating the pilots of regionally disparate public transit ZEB deployments offers a cursory analysis of the kinds of operational challenges and best practices that arise when agencies transition these next-generation technologies into their regular service portfolios. Two such pilots were chosen to represent each of the currently dominate ZEB platforms: battery-electric and hydrogen fuel cell. While each of these case studies present a slightly different picture in terms of infrastructure preparation, refueling considerations, and route runtime, both are characteristic of the kinds of investment, maintenance, daily workflow, and workforce skills considerations that are critical to the successful deployment and sustainability of a zero-emission fleet.

Foothill Transit Battery-Electric Bus Fleet

Back in 1988, in response to service cuts and fare increases announced by the Southern California Rapid Transit District, 22 member cities within the San Gabriel and Pomona Valleys banded together to assume control over bus operations in the area. By the end of that year, the newly approved "Foothill Transit" agency had deployed 20 fixed-route bus lines that serviced the area with expanded weekday schedules and newly available weekend service. By 1993, the agency was crowned "Outstanding Transit System" of its size by APTA.[37]

Today, Foothill Transit manages 363 transit busses (328 CNG, 35 electric) that service 39 local and express routes across 327 square miles. Considered a medium-sized municipal operator within Los Angeles County with a fleet size second only to LA's Metro, its average ridership reaches 48,000 per weekday and more than 14 million a year.[38] In North America, Foothill operates the largest known electric bus fleets and was the first to implement their use for public transit.

The case study of Foothill Transit's pilot adoption of battery electric buses (BEBs) starts in October of 2010, when it demonstrated three Proterra 35-foot quick-charge BEBs as part of its live service. The agency's goal was to evaluate whether these next generation bus platforms could assume the service responsibilities of select Foothill routes. Once this initial demo concluded, Foothill Transit would commit $10.2 million in FTA grant funds to purchase an additional 12 units in order to fully electrify their service route Line 291, which connects the cities of La Verne and Pomona and carries ~5% (750,000 people annually) of Foothill's ridership. Electrifying Line 291 would allow the agency to quantitatively evaluate the effectiveness of BEB technology and in-service viability relative to its more conventional baseline diesel and CNG vehicles.

To meet the in-route charging needs of these new BEBs, the agency approved a number of capital improvements for its mid-point Pomona Transit Center (PTC), including the installation of a high power fast-charge station that would allow two buses to be recharged simultaneously. The PTC improvement project also included the purchase of renewable energy certificates as a way of offsetting the energy demands of its charging station, allowing Foothill to set the example for what true "zero-emissions" transit would come to mean.[39]

Vehicle Technology

Considered revolutionary due to their zero-emission profile, Foothill's newly purchased pilot fleet of Proterra EcoRide BEB35FC "whisper quiet" buses, each equipped with eight 368V lithium-titanate battery packs capable of storing 88kWh of energy. Most notable for their quick 10-minute recharge time (when using two 500kW fast chargers), this EcoRide fleet made

Foothill the first transit agency in the U.S. to deploy fast-charge electric buses into revenue service.

Route Assignment

Foothill Transit selected its bus service Line 291 as ideal for evaluating limited-runtime engine technologies like Proterra's BEB35FC. Line 291 services a 16.1 mile run between La Verne and Pomona that loops through the PTC station in both directions. It's transit schedule replies on the consistent operation of seven buses during peak hours, each running at an average speed of 10.6 miles per hour. The fleet's five unused BEB35FCs were kept online as spares to allow for bus maintenance downtime and occasionally fill-in for other routes that traveled through the PCT station. In October of 2017, the elimination of another service route brought two additional electric buses (Proterra model BEB40FC) to Line 291.

Figure 10. Bus Service Line 291

Various standard CNG buses were also dispatched on commuter routes that operated out of Foothill's Pomona operation, each operating at an average speed of 17.6 mph. Statistics from these CNG buses would be captured as a way to evaluate the performance of the Line 291 BEB fleet (see Table 2 below).

Infrastructure Requirements

To meet the recharging needs of its new BEB fleet, Foothill worked with the City of Pomona to establish an on-route fast charging station at its mid-point Pomona Transit Center (PTC). The installation featured two Eaton 500kW chargers mounted in a climate-controlled building with their charge heads positioned overhead on either side (photo below). Each charger is equipped with a dedicated control system that operates independently of the other, allowing the PCT to recharge two buses at simultaneously. A communication and sensor network serve both units by detecting approaching buses and enabling the proper bus-to-charger protocols that engage positive docking, and software controls ensure the demands of fast-charging stay well within the system's available power limits. Designed to fully charge a bus in under 10 minutes, evaluation reports would later confirm that typical charge times—including head-unit docking and undocking—were more around 7 minutes. To allow riders to compensate for this delay, Foothill padded the Line 291 transit schedule to allow enough time for charging to take place.

Figure 11. On-route Fast Charging Station

Summary of Challenges and Achievements

Over the next 10 years (2010–2020), the National Renewable Energy Laboratory (NREL) would track the progress of Foothill's Line 291 electric bus pilot, publishing a series of eight evaluation reports that incrementally reveal the on-going costs, issues, solutions, and lessons learned the Foothill operations team encountered.

For an overall comparative analysis, Table 2 below offers a summary of the performance datapoints tracked between 2014 and 2019 for each of the two Proterra BEB pilot platforms (BEB 35FCV and BEB 40FC) and for a "control fleet" of 8 standard Foothill CNG buses that were also tracked operating on a route equivalent route to that of Line 291.

Table 2. Summary of Performance Datapoints

Data Item	BEB 35FC	BEB 40FC	CNG
Number of buses	12	2	8
Data period	4/2014-12/2019	1/2017-12/2019	10/2014-12/2019
Number of months	69	36	63
Total mileage in data period	1,701,071	137,003	2,370,846
Average monthly mileage per bus	2,054	1,903	4,704
Availability (85% is target)	83.1%	81.6%	95.1%
Fuel Consumption for BEBs (kWh/mile) or fuel economy for CNG buses (mpgge[a])	2.16	2.13	3.78
Fuel economy (mpdge[b])	17.41	17.67	4.33
Average speed, including stops (mph)	10.6	10.6	17.6
Miles between road call (MBRC[c])—bus	5,766	8,059	26,343
MBRC[c] —propulsion system only	14,058	19,572	40,877
MBRC[c] —ESS[d] only	212,634	137,003	—
Total maintenance cost (S/mile)[e]	0.45	0.48	0.29
Total maintenance cost without low-voltage battery costs ($/mile)[f]	*0.40*	*0.39*	*0.28*
Maintenance cost—propulsion system only ($/mile)	0.16	0.15	0.12
Propulsion system maintenance cost without low-voltage battery costs ($/mile)[f]	*0.10*	*0.07*	*0.11*

[a] Miles per gasoline gallon equivalent

[b] Miles per diesel gallon equivalent

[c] MBRC data from the clean point of April 2014 through end of current data period

[d] Energy storage system

[e] Work order maintenance cost

[f] See issue with the ow-voltage batteries explained on slide 54

The highlights of this performance trial can be best summed up as:[40]

- Foothill Transit deployed 12 Proterra fast-charge BEBs to fully electrify its Line 291, considered an optimal route for evaluating battery-electric technology due to its maximum travel distance and midway access to fast-charging facilities.
- The 12 BEBs accumulated just over 1.7 million miles throughout the 69-month evaluation period, averaging roughly 2,054 miles per-bus per-month. During this study, the 8 similarly tracked CNG buses clocked an average monthly distance of 4,704 miles.
- The BEBs delivered an 83% operational uptime, falling slightly short of Foothill's 85% benchmark target. CNG buses performed at an optimal 95% uptime.
- On average, the Proterra BEBs ran about 5,766 miles between road calls (MBRC) versus 26,343 miles for the CNG buses. This disparity illustrates the kind of maintenance load an operation should plan for when piloting next-generation bus platforms.
- End-to-end, these next-gen BEBs ran a higher per-mile maintenance cost of $0.45 versus just $0.29 for Foothill's CNGs. This drops quickly to $0.16 per mile (versus $0.12) for just powertrain maintenance and an impressive $0.10 per mile (versus $0.11) if you ignore battery costs, which are covered by Proterra's 12-year OEM warranty.

- No major issues were attributed to advanced technology failures; the majority of issues encountered were a result of standard bus-related failures.
- The agency's on-route PCT fast charging system operated reliably with minimal issues, none of which contributed to BEB downtime.

SARTA Fuel Cell Electric Bus Fleet

Ohio's Stark County public transportation system—originally a collection of street-drawn carriages and rural railways—formalized its operations in 1997 as the Stark Area Regional Transit Authority (SARTA), operating just 13 hours a day to service 1.1 million users. Since then, its coverage has grown to provide 10 cities with 34 fixed-route schedules that are serviced by a fleet of 80 diesel, hybrid, and CNG buses and four major transit centers. Averaging just over 7,500 transit miles per day, SARTA's fixed-route fleet reaches out to within a half-mile of 79% of all Stark County residents. To support the area's less mobile population, 37 of these buses make up SARTA's ADA-compliant "Proline" demand-response paratransit service, offering a public "point-to-point" transport option for riders with disabilities. All together the SARTA system today manages an average annual ridership of just under 2.6 million.[41]

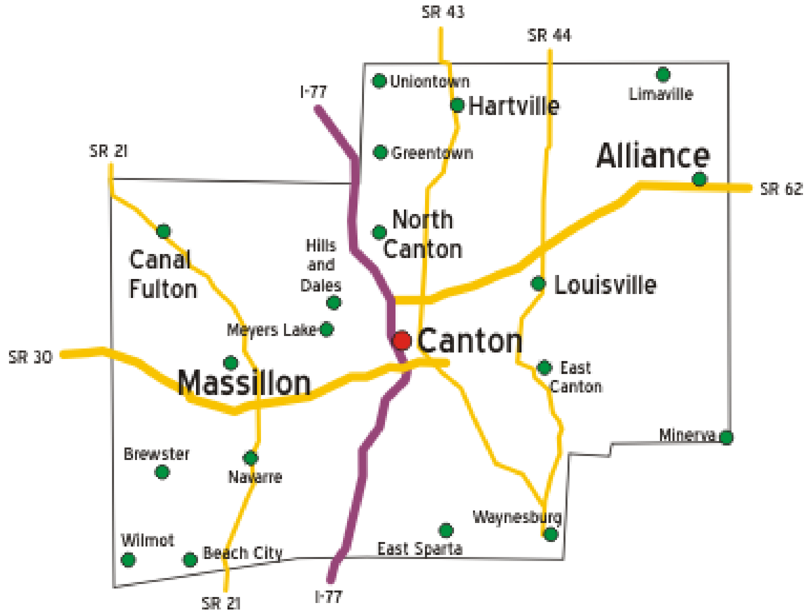

Figure 12. Stark County

With an eye towards environmental sustainability, the SARTA leadership team began introducing hybrid diesel-electric buses into its fleet in 2009 as part of a community-wide commitment to exploring cleaner-burning public transportation options. Not long after, the agency invested in 20 new CNG buses to replace some aging diesel versions on both its fixed-route and Proline services, and by 2014 used grant funds to pioneer the use of one of the nation's first Hydrogen-powered bus platforms. No stranger to piloting new public transit technology, SARTA's leadership affirmed its decision to adopt FCEBs by noting "*Hydrogen is a practical, safe, cost-effective and environmentally friendly alternative to traditional fuel. We believe our innovative program will make Stark County and Ohio the focal point of what will undoubtedly be a growing and dynamic industry.*" This commitment to zero-emission public transit has made SARTA the largest operator of Hydrogen FCEB's outside of California.[34]

Ultimately, SARTA's decision to deploy a fleet of FCEB's came down to:[34]

- FCEBs were projected to cut fuel costs by as much as 50% in the years ahead.
- FCEBs would reinforce their position as "trailblazers in the use of green technology".
- SARTA's leadership in deploying FCEBs and their associated hydrogen infrastructure would drive investment, research, business development, and job creation.
- FTA and DOT estimates showed that for each FCEB that replaces a diesel bus:
    a) carbon emissions would be cut by 100 tons annually,
    b) 9,000 gallons of fuel would be saved annually, and
    c) there would be an overall annual savings of $37,000.

Project Funding

Starting in 2011, SARTA pursued grant funds to build a state-of-the-art zero emissions fleet and refueling facility. Construction of the $2.9 million hydrogen refueling facility was funded by the Ohio Department of Transportation (ODOT), the Federal Transit Administration (FTA) and contributions from local sales tax.

Funding for the 10 FCEBs was provided through $20 million in state and federal grants:[42]

- $14 million from the federal Low or No-Emission Bus Program.
- $4 million from the National Fuel Cell Bus Program.
- $1 million from the Ohio DOT.
- $1 million from the Ohio EPA Diesel Emissions Reduction Program.

Of significant note, SARTA was able to avoid FTA's normal 20% grant match requirement through a partnership with Ohio State's Center for Automotive Research and Penn State's Altoona Bus Testing and Research Center, by supplying each with an initial FCEB delivery in order to conduct research and testing.[34]

Vehicle Technology

As part of its commitment to using clean-fuel buses, SARTA chose to deploy ten 40-foot FCEBs manufactured by ElDorado National-California (ENC). These ENC bus platforms incorporate a BAE Systems hybrid-electric propulsion system that is powered by a Ballard FCveloCity series HD6 heavy duty 150kW fuel cell. When loaded with 50 kilograms of hydrogen gas, these buses can operate for about 16 hours or up to 320 miles.[3]

Infrastructure Requirements

To prepare for its new FCEB fleet deployment, SARTA committed to a $1.9 million construction project at its Canton Ohio headquarters to bury a 9,000-gallon tank that is capable of storing liquified hydrogen at a temperature of 273 degrees below zero. This tank and its associated fuel dispensary system form a state-of-the-art, 350-bar hydrogen refueling station that is capable of delivering 300 to 400 kilograms of compressed gas per day. It was designed to fuel up to 20 FCEBs, built to allow for future expansion upgrades, and includes two gas compressors to reduce the chance of downtime due to failure.

Figure 13. Liquified Hydrogen Storage Tank

Built and installed by Canadian manufacturer Air Products, construction of the station took about eight months and opened in late 2016. Air Products retains ownership of the hydrogen storage equipment and compressors. Its contract with SARTA covers lease of the equipment, operations, and maintenance for about $10,000 per month plus fuel cost, which Air Products delivers from its hydrogen production facility in Ontario, Canada, about 300 miles away.[43]

The fuel dispenser provides hydrogen at 350-bar pressure for the El Dorado FCEBs and is located in the station's fueling island next to a public access CNG station. To the driver, this user end of the system looks and operates much like that of a CNG refilling pump. A complete refueling cycle takes approximately 20 minutes due to the dispenser's slower fill rate, a result of SARTA's decision to avoid having to "top off" a tank once it cools. When hydrogen is filled at a high rate, the gas heats up in the process, expands, and then prematurely triggers the dispenser's 350-bar pressure setpoint. This leaves the vehicle's tank "full," but not to full compressed capacity and therefore not to full travel distance.[20]

In the future, SARTA plans to add a 700-bar dispenser to accommodate light-duty fuel cell electric vehicles (FCEVs).

Route Assignment

SARTA selected two routes for its initial FCEB pilot: Route 102, a 10-mile loop that travels from downtown Canton to downtown Massillon, and Route 105, a 12-mile loop that travels between downtown Canton and the Beldin Village Mall. Both routes are heavily used and service about 35,000 riders per month. These routes were selected for FCEB trails due to their high stop frequency, which is considered an efficient use-case for fuel cell powered engines.[44]

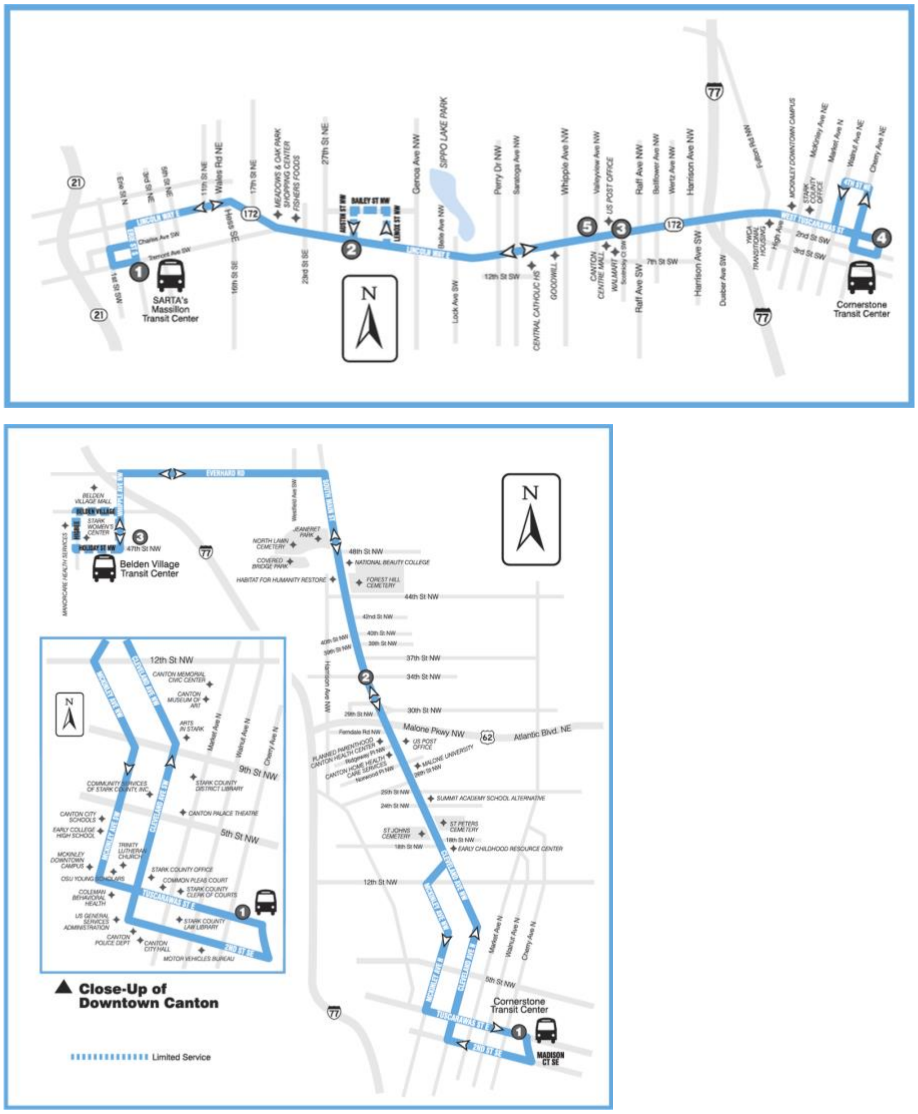

Figure 14. Routes 102 (top) and 105 (bottom)

Conclusions and Recommendations

As combustion-engine focused transit operations are replaced by battery-electric and fuel-cell technologies, the required skill sets of the future will be very different from the predominantly fossil-fueled past. From operations and maintenance to leadership and management roles, new upskilling programs and talent pipelines will be required to recruit and train for professional occupations associated with the operation of zero-emission public transit systems.

Identifying workforce development solutions for the emerging ZEV bus paradigm requires innovations on many levels including maintenance, operations, planning, management, human resources, and executive leadership. Further complicating this transition is the range of differing timelines for implementation of ZEV requirements determined by the regulatory priorities in each state. It is therefore incumbent upon transit leaders to carefully track the unique regulatory requirements in their home states and then determine the most efficient and expedient ways to prepare their workforces for future challenges associated with planning, designing, operating, and maintaining their ZEV bus fleets.

To get a clearer sense of this challenge, consider the reality of a transit operator managing a diesel or CNG bus fleet in a state where mandates will be passed within the next five to ten years requiring a transition to ZEV bus fleets. In 2022, as depicted in Figure 15, that operator oversees a workforce with employees in four different generations—Baby Boomers, Gen X, Gen Y, and Gen Z. In order to make decisions that account for the unique workforce challenges affecting employees of every age demographic, transit operators across the country will need to address a range of technology and workforce challenges including, but not limited to:

1. Whether to purchase battery-electric or hydrogen fuel cell buses;
2. How to plan for the implementation of charging/fueling infrastructure and the workforce that operates it;
3. Training programs to upskill existing employees;
4. Recruitment strategies to hire a new generation of employees with the knowledge, skills, and abilities (KSAs) to plan for, operate, and maintain ZEV transit systems; and
5. An organizational strategy to work with original equipment manufacturers (OEMs) to maintain and repair ZEV buses and their computer operating systems in an age of modular maintenance.

In 2022, battery-electric bus technology leads hydrogen fuel cell technology in affordability. However, fuel-cell buses hold the potential of meeting longer range requirements, which is a major advantage for transit operators running longer routes. The obvious and deciding factor in the future of ZEV bus deployment is the degree to which battery technology improves in the decade ahead. If batteries of the future provide longer ranges for fixed routes and charge faster, then transit operators will find it easier to replace diesel and CNG buses with battery-electric fleets. However, slower-than-expected battery innovations could, over time, lead to increased adoption of fuel-cell buses, which rely on a “gas station” model to fuel buses with hydrogen. From an environmental policy perspective, researchers and industry leaders will also need to work together to find methods to recycle the copper, lithium, cobalt, and other materials used in current batteries to establish more sustainable battery supply chains in the future. Successful environmental innovations in battery technology will also ensure that lawmakers continue passing legislation that supports battery-electric bus deployment in the future.

Predicting the degree to which battery-electric and fuel-cell buses are adopted by transit operators in the future is impossible. What is clear is that transit operators who are evaluating whether to purchase and operate battery-electric or fuel-cell bus fleets, will need to pay close attention to not only the range and affordability improvements of both technologies but also what makes the most sense in their regions in terms of financial support from local, state, and federal funding sources. The SARTA and Foothill Transit case studies made clear that, especially in periods of early implementation, grant support is often critical in financing any such transition. The $1.9-million construction project to prepare for the new FCEB fleet in the SARTA case study shows that securing financial support is critical to building the necessary infrastructure to support the transition to a ZEV bus fleet.

Proper planning to determine the most optimal routes for early implementation of ZEV bus fleets should be another top priority for transit operators looking to score “early wins” for implementation. The Foothill Transit case study reflects a best practice for choosing optimal routes for evaluating battery-electric technology for maximum travel distance and access to fast-charging facilities, two factors that are critical for early implementation and planning. In this respect, transportation planners, who are proficient in the charging/fueling and range requirements associated with battery-electric and fuel cell buses, will play critical roles in the successful implementation of new ZEV fleets.

After deploying new ZEV buses, transit operators will need to make it a human resources priority that management and executive leadership teams have the skills and project management systems to forecast and track actual ongoing costs for their fleets as maintenance and fueling/charging costs fluctuate. Operational costs, such as per-mile maintenance costs, are another factor that transit operators will need to plan for in the short- and long-term timeframes. As stated in the Foothill Transit case study, end-to-end, the next-generation battery-electric buses ran a higher per-mile maintenance cost of $0.45 versus just $0.29 for Foothill’s CNG buses. However, that figure dropped quickly to $0.16 per mile (versus $0.12) for just powertrain maintenance and an impressive $0.10 per mile. The Foothill Transit case study also underscores the value of operational benchmarking. Upon deployment, the Foothill Transit battery-electric buses delivered an 83% operational uptime—falling slightly short of Foothill’s 85% benchmark target—with CNG buses performing at an optimal 95% uptime. Such benchmarking is essential for any agency seeking to establish metrics that inform cultures of continuous improvement and innovation.

Workforce Development Responses for the ZEV Transition in Transit

Transit operators expecting to transition to ZEV bus fleets in the decade ahead will also need to strike a balance between upskilling their incumbent workforces and recruiting skilled talent from students graduating from high school, community college, and four-year universities. For perspective on the value of investing in upskilling training programs for incumbent workers, it is useful to consider the milestones presented in Figure 15.

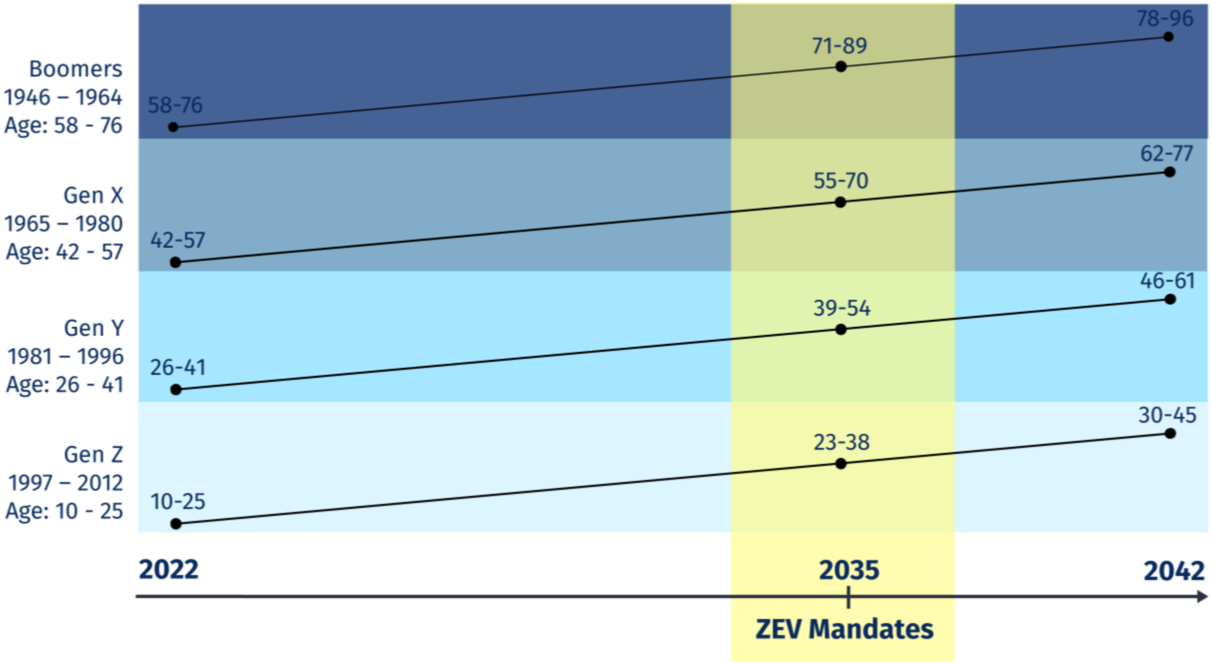

Figure 15. Age Projection by Generation for ZEV Mandates

In 2022, members of the Baby Boomer generation ranging in age from 58—76, would be 71—89 in 2035, which is the year that a range of state and federal mandates for ZEV fleets go into effect.[45,46] This is an important insight because it demonstrates that employees, who are 50 or older in 2022, will play an active role in the transition to zero-emission bus systems. That logic, of course, extends to every other age category identified in Figure 15 and underscores why investment in targeted ZEV upskilling and succession planning programs will deliver strong returns on investment for transit operators in the decades ahead. Transit operators compete with employers from other sectors of the economy to recruit skilled professionals. A common workforce trend is that organizations search for qualified workers to fill new job vacancies through new-hires rather than invest in programs to upskill their existing workforce.

By 2035, transit operators will need to assess the kind of upskilling that workers of the Baby Boomer, Gen X, and even some of the Gen Y generations will require for ZEV implementation. Planning for and executing the implementation of ZEV technologies will likely require continuing education and certification programs for those involved in operations and maintenance occupations. In an emerging era of modular maintenance, those responsibilities will involve forging new partnerships with original equipment manufacturers who will play more central and ongoing roles in the repair and upkeep of buses and their related computer operating systems. Others might require management and mentorship training to move into leadership roles that facilitate succession planning efforts related to the transition to ZEV fleets.

Though some in these generations of incumbent workforce are likely to retire, there will also likely be a significant faction who will continue working into 2042. Succession planning and knowledge transfer programs are critical for organizations to pass important institutional knowledge to future generations.

One critical way that transit operators can prepare for these shifts and anticipate skills gaps is to develop talent pipeline management strategies. *Managing the Talent Pipeline: A New Approach to Closing the Skills Gap*, a report by the U.S. Chamber of Commerce Foundation, states that such pipelines provide a means to leverage successful innovations that have developed in supply chain management, which call for “employers to play a new and expanded leadership role as ‘end-customers’ of education and workforce partnerships.”[47] Talent pipeline programs provide a vehicle for employers to become more centrally involved in customizing their “talent supply” as opposed to outsourcing their workforce to academic institutions.

Talent pipeline planning requires employers to play an active role in each phase of a talent supply chain through consultation, validation, and support of training and recruitment. Especially as ZEV technologies continue to advance and shift, the flexibility of a talent pipeline management strategy will allow employers to intervene by providing feedback, revising the focus of educational programs, and offering new methods and plans for learning, internships, and apprenticeships that furnish incoming and young professionals with practical skills that complement their theoretical training. Working talent pipeline management strategies will uphold the vision of employers to proactively close skills gaps, hire professionals with relevant KSAs, and cultivate a talent pool.

For current Gen Z and Gen Y students and young professionals, talent pipeline management strategies will ensure that they are equipped with the KSAs for the transitions ahead. If transit operators can work with academic institutions while forecasting for 2035 and beyond, the incoming class of workers in 2035 will be prepared to meet the demands of working with ZEV technology. With effective talent pipeline and upskilling strategies, Gen Z and Gen Y professionals can be properly upskilled and mentored to assume management and leadership opportunities. As witnesses to the sector before and after ZEV technology, they can serve a pivotal role for managing an incoming workforce while working with older, incumbent workers and learning how to address the ongoing workforce challenges associated with transformational transit technologies.

Next Steps for Researching the ZEV Transition in Transit

The workforce implications identified in this report introduce the recruiting, retaining, training, operational, and maintenance challenges facing future ZEV transit professionals. Those implications suggest the need for new statewide and national needs assessments to determine the skills gaps and digital access challenges facing the ZEV transit workforce. Statewide and national assessments will make it easier for educators and policymakers to identify common responses to skills gaps while making sure that digital access issues are not precluding emerging and incumbent transit professionals from accessing such training resources.

Other related workforce development efforts could include the development of online national clearinghouses that aggregate available education and training resources that address ZEV transition challenges. Such resources could include a curation of portable curriculum for mobile devices in the field. Other clearinghouses could provide aggregated and up-to-date funding opportunities that support transit agencies during and after their transitions to ZEV bus fleets. Such research and workforce development resources will contribute to the ongoing transition from legacy combustible-engine fleets to the emerging zero-emission future.

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Data Summary

Products of Research

This white paper is the result of comprehensive analysis of different reports and documents in the areas of zero-emission transit technology and related workforce development implications with a focus on bus technology. The white paper used statistics to enhance the qualitative discussion and provide a reference for the size of the workforce development challenges in transit. The authors of this white paper did not conduct quantitative analyses; thus, no dataset products were generated from this study.

Data Format and Content

No data files were generated as part of this study.

Data Access and Sharing

The data used for the figures and tables publicly available, and can be accessed by the reader at the sources referenced in the white paper.

Reuse and Redistribution

There are no restrictions on how the data from this white paper can be reused and redistributed by the general public.