Policy Summary

San Francisco Muni Electrification Alternatives Analysis

July 2023

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Climate and Community Project is a progressive climate policy think tank that mobilizes a network of leading academic and movement researchers in developing cutting-edge research at the climate-inequality nexus. We've produced multiple research briefs alongside movement and political partners including the Green New Deal for Public Schools, a New Era of Public Power, and High Roads to Resilience.

Suggested citation: Matthew Haugen, "Policy Summary: San Francisco Muni Electrification Alternatives Analysis," Climate and Community Project, July 2023, climateandcommunity.org/trolleybus-decarbonization.

IN PARTNERSHIP WITH:

METRO DE MEDELLÍN CALIDAD DE VIDA

SAN FRANCISCO ELECTRICAL CONSTRUCTION INDUSTRY

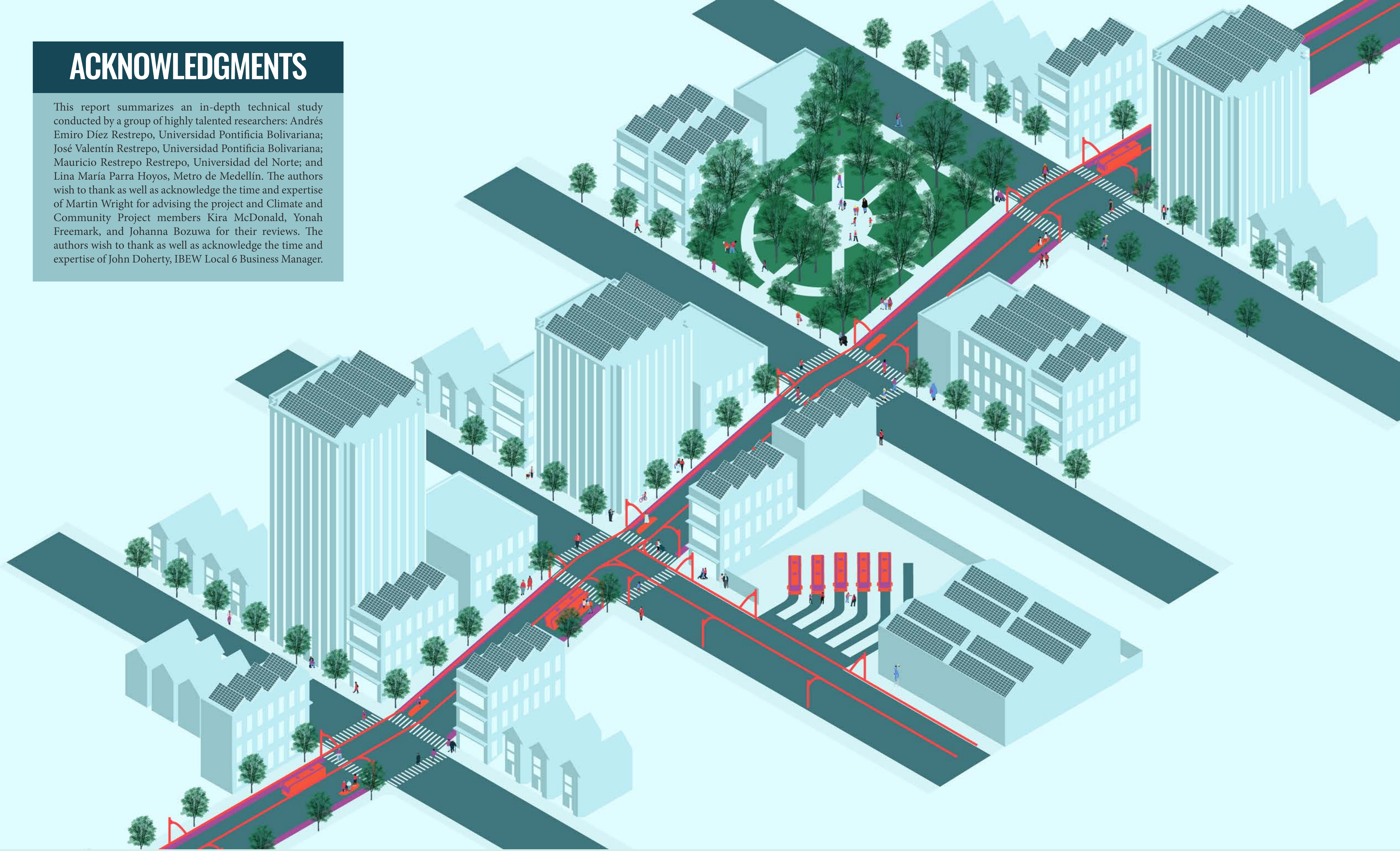
IBEW LOCAL 6 SAN FRANCISCO CHARTERED FEBRUARY 21, 1895

UDB

UN UNIVERSIDAD DEL NORTE

ACKNOWLEDGMENTS

This report summarizes an in-depth technical study conducted by a group of highly talented researchers: Andrés Emiro Díez Restrepo, Universidad Pontificia Bolivariana; José Valentín Restrepo, Universidad Pontificia Bolivariana; Mauricio Restrepo Restrepo, Universidad del Norte; and Lina María Parra Hoyos, Metro de Medellín. The authors wish to thank as well as acknowledge the time and expertise of Martin Wright for advising the project and Climate and Community Project members Kira McDonald, Yonah Freemark, and Johanna Bozuwa for their reviews. The authors wish to thank as well as acknowledge the time and expertise of John Doherty, IBEW Local 6 Business Manager.



KEY TERMS

BATTERY ELECTRIC BUS: A rubber-tired electrical transit vehicle utilizing electric motors that obtains motive power from on-board batteries.

CALIFORNIA INNOVATIVE CLEAN TRANSIT (ICT) RULE: California regulation adopted December 2018 requiring all transit agencies to transition to a 100 percent zero-emissions bus fleet by 2040.

DIESEL-HYBRID BUS: A rubber-tired transit vehicle using an internal combustion engine (ICE) for propulsion, combined with an electric propulsion system—either via a series-hybrid system, where an ICE powers an electric generator and is not mechanically connected to the drivetrain, or a parallel hybrid, where both an ICE and electric motor are connected to a drivetrain such that both can individually provide motive power.

IN-MOTION CHARGING (IMC) TROLLEYBUS: A rubber-tired electrical transit vehicle that draws power from dual overhead wires (generally suspended from roadside posts) via spring-loaded trolley poles to charge traction batteries that allow for off-wire travel of significant distances, often in excess of 15 km.

INTERNAL COMBUSTION ENGINE (ICE): A mechanical engine in which the burning of fossil fuels occurs in a confined space (combustion chamber) to drive a piston and provide mechanical energy.

LIGHT RAIL VEHICLES (LRV): An electrically propelled passenger-carrying vehicle that operates on the fixed guideway of a light rail transit system and is capable of running at grade, on an aerial guideway, or in a subway, as warranted.

MUNICIPAL RAILWAY (MUNI): SFMTA's network of light rail, cable car, streetcar, diesel-hybrid buses, and electric trolleybuses.

SAN FRANCISCO MUNICIPAL TRANSPORTATION AGENCY (SFMTA): Citywide transportation agency that oversees the Municipal Railway (Muni), parking, traffic engineering, pedestrian planning, bicycle implementation, accessibility, and taxi regulation.

TROLLEYBUS: A rubber-tired electrical transit vehicle that draws power from dual overhead wires (generally suspended from roadside posts) using spring-loaded trolley poles.

INTRODUCTION

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Nations must decarbonize as quickly as possible to stave off the worst potential effects of the rapidly unfolding global climate crisis. Transforming transportation will be a critically important part of such an effort, especially in the United States, where the transport of people and goods produces more of the nation's greenhouse gas emissions than any other sector. In broad strokes, decarbonizing transportation systems will require electrifying them and ensuring that that electricity is produced with renewable energy. **Mass public transportation will be a key pillar of the green transition, as it can move people around using far less energy and resources than personal vehicles—electric or otherwise.**

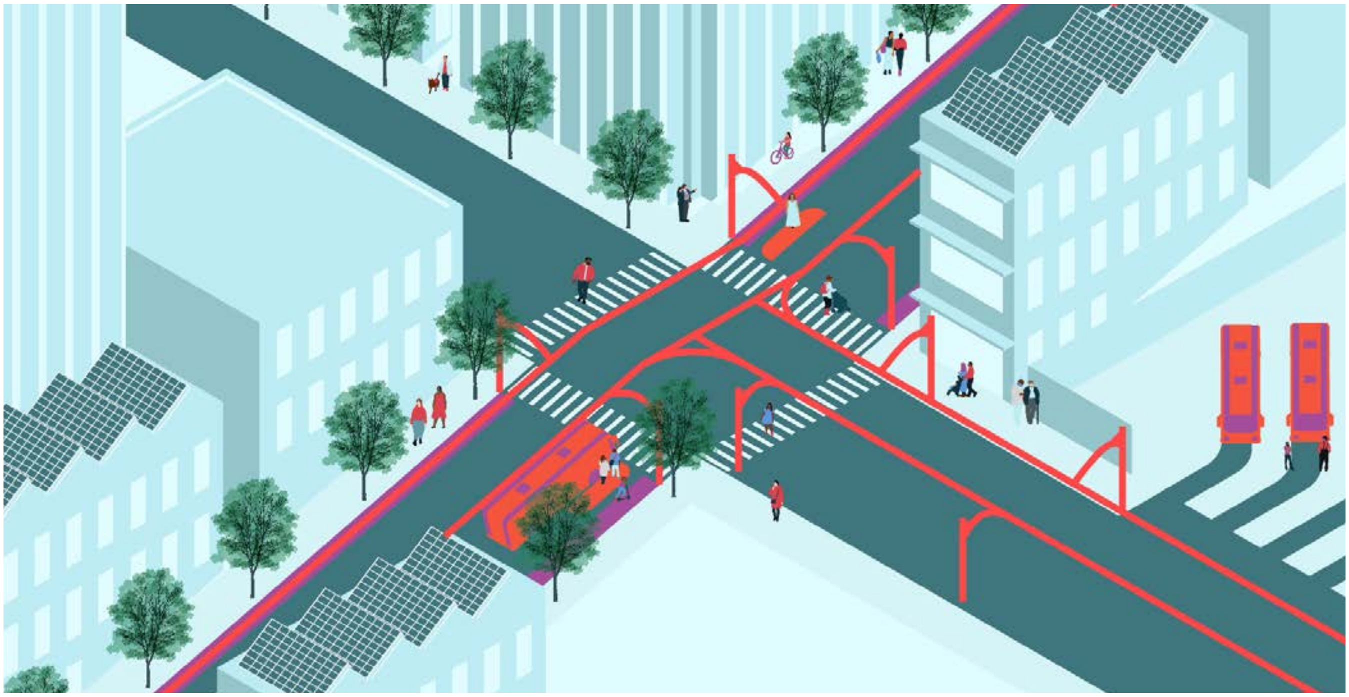
The City of San Francisco, having long recognized the many benefits of public transportation, established an official Transit-First Policy in 1973 (later enshrined in the City Charter in 1996).[1] This policy deemphasizes private cars in favor of bicycles, walkability, and mass transit like light rail and buses. This is human-centered mobility—a transportation system that prioritizes the health, safety, and flourishing of its users and the community in which it is embedded. Notably, the San Francisco Municipal Transit Agency (SFMTA) has utilized trolleybuses for over 80 years as part of its mass transit system. Trolleybuses are rubber-tired electrical transit vehicles that are powered by overhead wires rather than onboard internal combustion engines and are well-suited for the steep terrain of San Francisco.

In 2019, California passed the Innovative Clean Transit (ICT) rule, which requires SFMTA—along with the rest of the state's transit agencies—to phase out diesel-powered transit vehicles in favor of zero-emission alternatives.[2] Although there are several pathways to electrifying San Francisco's bus fleet, new analysis shows that **protecting the city's robust trolleybus system and electrifying its diesel fleet via modern, in-motion charging (IMC) trolleybus technology can unlock resource efficiency and provide climate and labor benefits competing options like battery electric buses.**[3]

1. "Transit-First Policy," San Francisco County Transportation Authority, accessed April 26, 2023, https://www.sfcta.org/policies/transit-first-policy.

2. Andrés Emiro Díez Restrepo, José Valentín Restrepo, Mauricio Restrepo Restrepo, and Lina María Parra Hoyos. "San Francisco Muni Electrification Alternatives Analysis," San Francisco Electrical Construction Institute, 2023.

3. Andrés Emiro Díez Restrepo, José Valentín Restrepo, Mauricio Restrepo Restrepo, and Lina María Parra Hoyos. "San Francisco Muni Electrification Alternatives Analysis," San Francisco Electrical Construction Institute, 2023.



"Electrification of San Francisco Muni: Alternatives Analysis," an in-depth technical study of trolleybus use in the city conducted by researchers from Universidad Pontificia Bolivariana, Universidad del Norte, and Metro de Medellín in collaboration with the International Brotherhood of Electrical Workers Local 6, the San Francisco Electrical Construction Industry (SFECI), and the Climate and Community Project (CCP), finds that IMC trolleybuses offer planners a number of operational and economic advantages:

- Unlike traditional trolleybuses, IMC trolleybuses, which are equipped with onboard batteries, do not need overhead wires for their entire routes, allowing for more flexibility in infrastructure and routes while reducing costs. A 33 percent increase in overhead wires would allow the city to more than double its zero emissions bus fleet, while adding 210 miles of electrified service.

- IMC trolleybuses are more energy efficient. They charge throughout the day via the overhead wires and therefore have a smoother electricity demand curve than battery electric buses.

- IMC trolleybuses have significantly smaller batteries than battery electric buses. Reducing battery size limits needs for both land to house the buses in the city, and limits the materials necessary to make the batteries, like lithium.

- There is a robust workforce in San Francisco that understands and can maintain IMC trolleybuses. Expanding the fleet would provide long-term security for union workers as well as offer new job opportunities.

- The efficiencies of the IMC trolleybuses would require 18 percent fewer buses than battery electric buses and could save San Francisco money over the lifetime of the bus.

As more transit agencies across the US begin to develop their own electrification plans, these findings have much broader implications and applications. Trolleybuses, an often-overlooked mode of mass transit, may hold the key to the resource-efficient, operationally simple, and economical transit systems essential to limiting the climate crisis.

THE HISTORY OF TROLLEYBUSES IN SAN FRANCISCO

San Francisco was an early adopter of electric trolleybuses in the United States. In 1935, the Market Street Railway installed the first trolleybus line to replace streetcars on the 33 Line.[4] The city's public transit agency, the Municipal Railway (also known as Muni), followed suit and started operating trolleybus service in 1941. Following World War II, after absorbing the privately owned Market Street Railway's fleet and infrastructure into its own, the Municipal Railway began expanding access to electric trolleybus service as part of a major recapitalization effort.[5] Trolleybuses were particularly well suited to San Francisco, offering more efficiency than motor-based transportation on the city's steep hills.

In the 1950s, as automobile companies mounted fierce campaigns to get people out of public transit and into cars, personal vehicles began to dominate San Francisco's streets, ensnaring trolleybuses in the process.[6] In 1968, as the city was on the verge of "diesel-ing" its fleet and eliminating the trolleybus system, labor and community groups came together to oppose the move. The San Francisco Public Utilities Commission responded by resolving to "optimize the use of the City's electrical facilities and electrical transit equipment thereby placing emphasis on electric-powered transit," which, according to the commission, would have a "resulting reduction in pollution of the environment by poisoning of the air and a rising level of objectionable noise which is produced by motor coaches."[7]

The upshot was that San Francisco retained its trolleybus system. Today, it is by far the largest system in the United States, transporting a ridership of over 24 million passengers annually and constituting a vital part of San Francisco's overall public transit system.[8]

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4. Jeremy Menzies, "Our Routes' Roots: History of the 33 Ashbury/18th," SFMTA, November 22, 2019, https://www.sfmta.com/blog/our-routes-roots-history-33-ashbury18th.

5. "The People's Road: Muni 1912-1941," Market Street Railway, January 10, 2022, https://www.streetcar.org/the-peoples-road-muni-1912-1941/.

6. Joseph Stromberg, "The Real Story behind the Demise of America's Once-Mighty Streetcars," May 7, 2015, https://www.vox.com/2015/5/7/8562007/streetcar-history-demise.

7. "Resolution No. 69-0828," Public Utilities Commission City and County of San Francisco, November 25, 1969.

8. "Public Transportation Ridership Report: Fourth Quarter 2021," American Public Transportation Association, March 10, 2022, https://www.apta.com/wp-content/uploads/2021-Q4-Ridership-APTA.pdf.

First Muni Trolley Coach on Howard Street. 1941. Muni Photo Archive.

JG Brill Trolley Coach, Two of the first Electric Rubber Trie Transit Vehicles in San Francisco. 1935. Muni Photo Archive.

Fageol twin Trolley at Potrero Yard with Muni Workers. 1970. Marhsall Maxon, photographer. Muni Photo Archive.

Inspector William Ratto of the Muni Railway points to street markings at Market & Haght. 1949. SF Public Library.

It has also been a provider of good union jobs for over 100 years. Now under the aegis of SFMTA, Muni's operations and maintenance workforce is represented by a variety of unions including the Transport Workers Union, International Association of Machinists, United Brotherhood of Carpenters, Service Employees International Union, and International Brotherhood of Electrical Workers (IBEW). Members of IBEW Local 6, which helped support this report, work behind the scenes at SFMTA in over 30 classifications. Transit power line workers, transit power cable splicers, and power house operators maintain and repair the extensive motive power system, while the electric motor repairers, electronic maintenance technicians, welders, and electrical transit mechanics keep the city's streetcars, cable cars, trolleybuses, and light rail vehicles (LRVs) in service operation.

SAN FRANCISCO'S TRANSIT SYSTEM— OPERATIONAL CONTEXT

San Francisco's Muni is among the hardest-working transit systems in the country, with high ridership and a challenging, hilly landscape. In 2017, prior to the pandemic, San Francisco had the nation's second-most utilized bus and trolley system with 191,000 passenger trips per mile—nearly 2.5 times busier than the average of the nation's largest systems (Chart 1).[9] Although Chicago and New York rival the city's passengers per mile ratio, those cities feature much flatter topographies and fewer street design challenges. San Francisco's difficult terrain, paired with high passenger rates, puts special stress on the mechanics and technicians who keep the fleet maintained and moving. Regrettably, San Francisco has lagged in its maintenance investments, leading to a backlog of deferred repairs (Chart 2). In the era of climate crisis, investing in green public transit and its maintenance must become an increasing priority for city investment.

The 2020 COVID-19 pandemic and its attendant stay-at-home orders had a chilling effect on public-transit ridership across the country. As of this writing, however, ridership is growing again, reaching 65 percent of its pre-pandemic volume.[10] Thanks to more remote work and new behavior patterns, the landscape of work has shifted, and transit providers are shifting to accommodate new needs beyond the work rush.[11]

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9. Federal Transit Administration, "2017 Annual Database Service," accessed April 26, 2023, https://www.transit.dot.gov/ntd/data-product/2017-annual-database-service.

10. Ricardo Cano, "S.F. vs L.A.: These Charts Show the City's Disparate Transit Ridership Recoveries," San Francisco Chronicle, March 18, 2023, https://www.sfchronicle.com/sf/article/transit-ridership-recovery-la-17822493.php.

11. Skip Descant, "Remote Work Flipped the Community Script. Now Transit Must Adapt," Government Technology, December 15, 2022, https://www.govtech.com/fs/remote-work-flipped-the-commuting-script-now-transit-must-adapt.

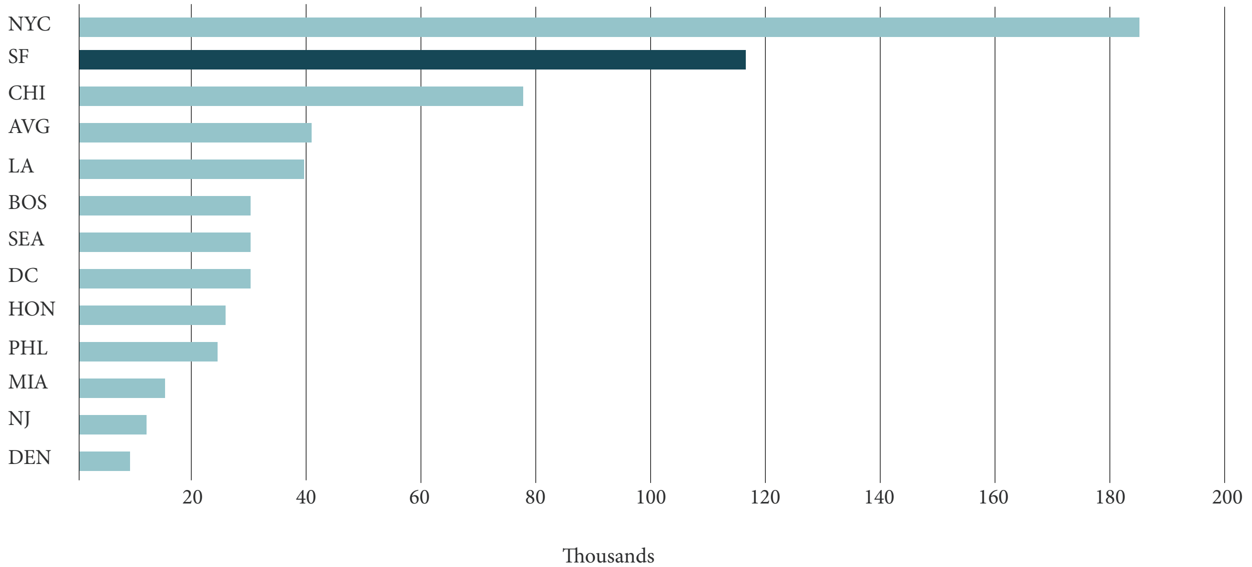

Figure 1. Pre-pandemic passenger trips per service mile in San Francisco. San Francisco's transit system was the second-most frequented in the United States, after New York City, in 2017. Source: National Transit Database.

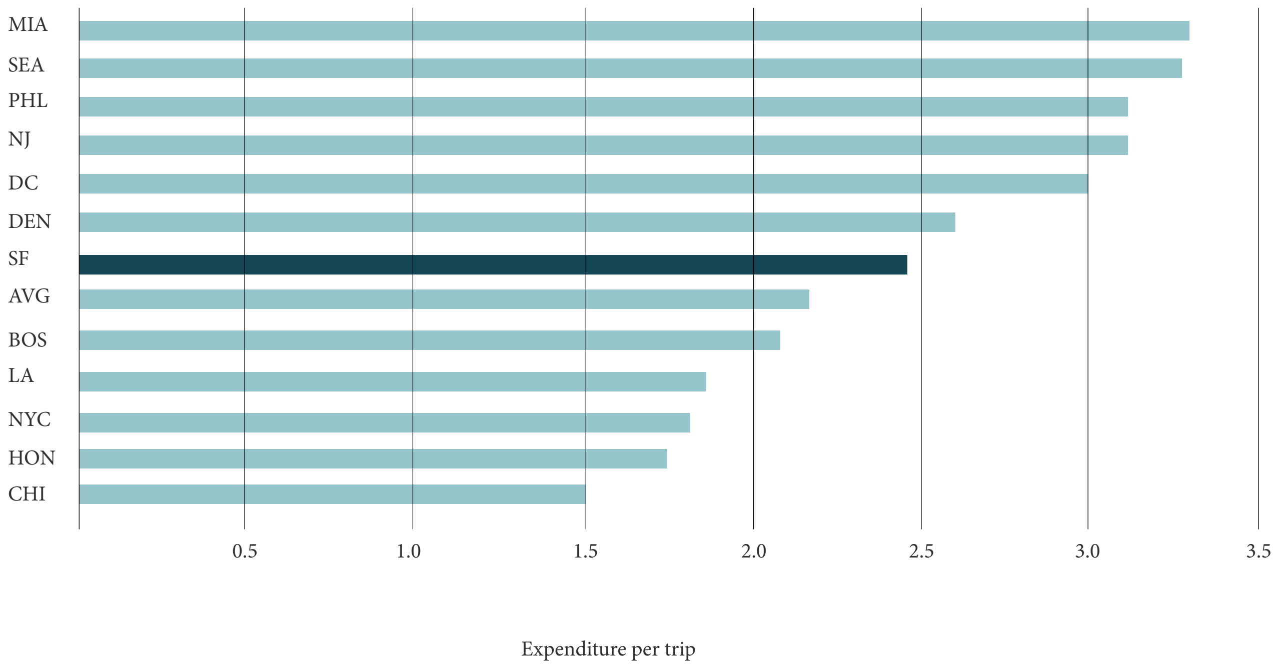

Figure 2. Pre-pandemic bus vehicle and system maintenance expenditure per trip. While San Francisco's transit was the second-most used in the US in 2017, it invested less in the maintenance of its vehicles. Source: National Transit Database.

THE CLIMATE CRISIS, ELECTRIFICATION, AND RESOURCES: WHY TROLLEYBUSES MATTER

The United States urgently needs to eliminate greenhouse gas emissions in order to limit the effects of the climate crisis, particularly considering the country's outsized role in historic global emissions. Decarbonizing transportation is crucial in this regard. In the United States, transportation accounts for around 28 percent of greenhouse gas emissions—more than any other sector—the majority of which comes from cars powered by fossil-fueled internal combustion engines (ICE).[12] In San Francisco, the transportation sector contributes a whopping 44 percent of the city's total emissions.[13]

Decarbonizing the transportation sector will require electrifying it and powering the electric grid via renewable energy. One approach to speed this change is getting far more people onto public transit. Although this approach will require major shifts in current modal systems, the transition to decarbonized transport is likely to be far quicker—and more equitable. For example, replacing every ICE vehicle in the United States with an electric vehicle (EV) would require an enormous amount of additional electricity to replace the energy produced by gasoline,[14] significant investment in electricity distribution systems that were not built for widespread EV charging,[15] and the coordinated actions of tens of millions of individuals. In comparison, electric-powered transit vehicles like trolleybuses, light rail, and electric buses carry far more people at the same time and limit the need for a 1:1 swap.

Not only is public transit more efficient from an energy-consumption standpoint, it also offers *material* efficiencies. Most electric-powered vehicles utilize lithium-ion batteries for power. Relying solely on a personal EV strategy will require more batteries—and therefore more extraction of the transition minerals necessary to power those batteries. For US cars alone, an auto-centric, status

12. US Environmental Protection Agency, "Sources of Greenhouse Gas Emissions," https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

13. City and County of San Francisco, "Greenhouse Gas Emissions," https://sfgov.org/scorecards/environment/greenhouse-gas-emissions.

14. A. Milovanoff, I. D. Posen, and H. L. MacLean, "Electrification of Light-Duty Vehicle Fleet Alone Will Not Meet Mitigation Targets," Nature Climate Change 10 (2020): 1102–1107, https://doi.org/10.1038/s41558-020-00921-7.

15. A. Brockway, D. Callaway, and S. Elmallah, "Can Distribution Grid Infrastructure Accommodate Residential Electrification and Electric Vehicle Adoption in Northern California?" Energy Institute at HAAS, December 2022, https://haas.berkeley.edu/wp-content/uploads/WP327.pdf.

quo transition could require close to 500,000 metric tons of lithium per year by 2050, which is around 5 times current annual global lithium production.[16] The United States is increasingly building bigger—and more mineral-intensive—personal EVs that will increase this need for transition mineral mining.[17] In comparison, recent Climate and Community Project research found that the United States can limit lithium extraction dramatically by investing in mass and active transit like battery electric buses, trolleybuses, and electric bikes.[18] **In fact, modern trolleybus systems require a fraction of the lithium of battery electric bus systems—offering an important intervention to limit extraction in electrified transit systems.**

The US transportation system's dependence on personal automobiles produces a number of additional social and ecological harms beyond planet-warming greenhouse gas emissions and mineral extraction: deadly particulate-matter pollution from exhaust pipes, brakes, and tires; death and injury to pedestrians and cyclists; onerous, regressive financial burdens on the working class. San Francisco, for example, is one of the most expensive cities in the United States in which to own a car.[19] An American Lung Association study estimated that switching to a zero-emission transportation system would avoid nearly 4,000 premature deaths and 113,000 asthma attacks in the Bay Area by 2050.[20] In 2014, San Francisco adopted a "Vision Zero" policy to eliminate traffic fatalities by 2024 but has made little progress, with such deaths consistently hovering around 30 per year since then.[21] **Bolstering the city's human-centric mobility with more trolleybuses would help mitigate multiple social, economic, and environmental issues simultaneously.**

Trolleybuses are an important part of that effort—and can be a model for decarbonization pathways in other cities across the country. Electrification entails making complex decisions about the future of transportation and energy systems and will require a variety of modalities. **Reducing car dependency by significantly increasing greenhouse gas–free public transit capacity will make transportation decarbonization easier and less material- and energy-intensive.** Investing in greenhouse gas–free trolleybuses is a human-centered step that will contribute to safer streets, more equitable transportation access, and less extraction.

16. Thea Riofrancos, Alissa Kendall, Kristi K. Dayemo, Matthew Haugen, Kira McDonald, Batul Hassan, Margaret Slattery, and Xan Lillehei, "Achieving Zero Emissions with More Mobility and Less Mining," Climate and Community Project, January 2023, http://www.climateandcommunity.org/more-mobility-less-mining.

17. Dan Seifert, "GM killed the Chevy Bolt–and the Dream of a Small, Affordable EV," The Verge, April 26, 2023, https://www.theverge.com/2023/4/26/23697911/gm-discontinued-chevy-bolt-small-affordable-ev.

18. Thea Riofrancos, Alissa Kendall, Kristi K. Dayemo, Matthew Haugen, Kira McDonald, Batul Hassan, Margaret Slattery, and Xan Lillehei, "Achieving Zero Emissions with More Mobility and Less Mining," Climate and Community Project, January 2023, http://www.Climateandcommunity.org/more-mobility-less-mining.

19. Daniel Robinson, "Top 10 Most Expensive Cities To Own a Car In (2023)", MarketWatch, March 22, 2023, https://www.marketwatch.com/guides/insurance/10-most-expensive-cities-to-own-a-car-in-2023/.

20. "Zeroing in on Healthy Air," American Lung Association, 2022, https://www.lung.org/getmedia/13248145-06f0-4e35-b79b-6dfacfd29a71/zeroing-in-on-healthy-air-report-2022.pdf

21. "Traffic Fatalities," San Francisco Government, accessed April 26, 2023, https://sfgov.org/scorecards/transportation/traffic-fatalities.

MODELING A CLIMATE-RESILIENT FUTURE WITH TROLLEYBUSES IN SAN FRANCISCO

In "San Francisco Muni Electrification Alternatives Analysis," Restrepo and colleagues compare different strategies for electrifying the city's diesel-hybrid bus fleet. The alternatives they examine are three: battery electric buses (BEBs) that must be charged overnight at a bus depot, conventional trolleybuses powered by overhead wires (catenary), and in-motion charging (IMC) trolleybuses with onboard batteries. Their methodology consisted in choosing a representative diesel-hybrid bus route—44 O'Shaughnessy—modeling each alternative vis-à-vis that route, and then extrapolating their results to the larger city system.[22]

After simulating all three alternatives, the authors found **that IMC trolleybuses are more cost- and energy-efficient, and have fewer negative environmental impacts, than BEBs and so should be the first-choice alternative to diesel-hybrid buses.**

Below we describe some of the authors' key results concerning the different types of electrification pathways:

BATTERY ELECTRIC BUSES: Utilizing BEBs would require 18 percent more buses—and thus more resources, space, and money to build and maintain them—than IMC trolleybuses to serve the same ridership. BEBs have lower passenger capacity in comparison to IMC trolleybuses due to road-weight limitations and BEBs' larger and heavier batteries. Furthermore, BEBs do not have the power capacity to operate for an entire shift; the purchase of additional vehicles would be necessary to substitute for buses that need to be charged.

Because BEBs charge overnight parked in depots, they require a large amount of electricity all at once, an energy demand that will strain San Francisco's grid and require infrastructure upgrades at bus yards without adequate electrical capacity. BEBs charging protocol also means that they have relatively long downtimes, further increasing fleet size requirements both in terms of the number of vehicles required and the land necessary to storing them.

CONVENTIONAL TROLLEYBUSES: The authors treated conventional trolleybuses the same as IMC trolleybuses in many respects due to their similarities in terms of capacity, size, and other metrics. Conventional

22. The authors developed a six-stage process to compare the alternatives: (1) Define operating conditions, including vehicle and route; (2) Calculate the output force and mechanical power; (3) Optimize electrification; (4) Analyze battery behavior and lifespan; (5) Conduct a detailed electrical simulation; and (6) Consider basic electrical design.

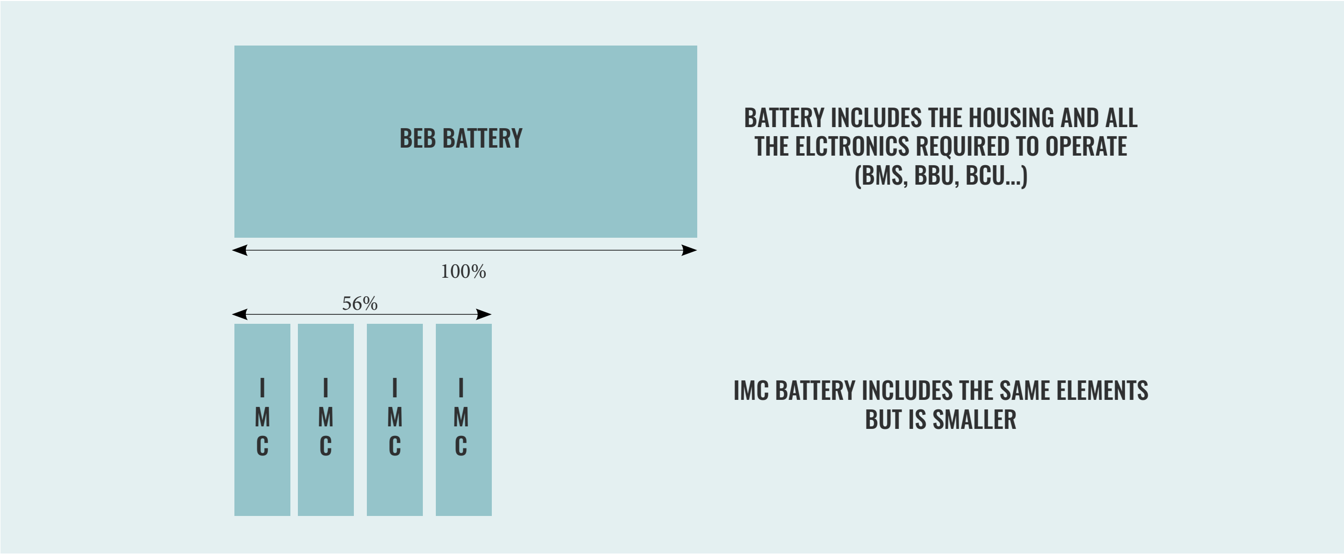

Figure 3. Reference comparison of BEB and IMC battery requirements.

trolleybuses generally were found to have a lower risk of battery issues (e.g., with regard to maintenance, fire, and disposal) because they have very small backup batteries and require the least amount of energy of all three modalities. However, expanding conventional trolleybuses in San Francisco would require new catenary infrastructure, which makes adding conventional trolleybus routes in San Francisco relatively costly compared to IMC trolleybuses.

IN-MOTION CHARGING TROLLEYBUSES (IMC): Unlike traditional trolleybuses, IMC trolleybuses do not need catenary for their entire routes because their batteries power them between connections; this allows them to take advantage of the already existing infrastructure—routes, catenary lines, and power substations—that serve San Francisco's current trolleybus system.

IMC trolleybuses use batteries that are around the size of those in electric sedans—that is, about one tenth as big as the batteries used in standard BEBs. Restrepo et al. estimate that IMC trolleybuses "allow for reductions in battery use between 90 and 70 percent, both in storage capacity and in mass" compared to BEBs.

IMC trolleybuses charge during normal operations from the overhead catenaries; they therefore have a smoother electricity demand curve than BEBs. The authors suggest that the flatter electricity demand of trolleybuses operating throughout the day would be more suitable to solar energy since solar is more abundant when the sun is overhead. This is a particularly important consideration, since solar energy is poised to become one of the major energy resources in the coming years, especially in California. If San Francisco expanded its overhead lines by 33 percent, it could more than double its electrified fleet with IMC trolleybuses— more adding 210 miles of electrified bus service.

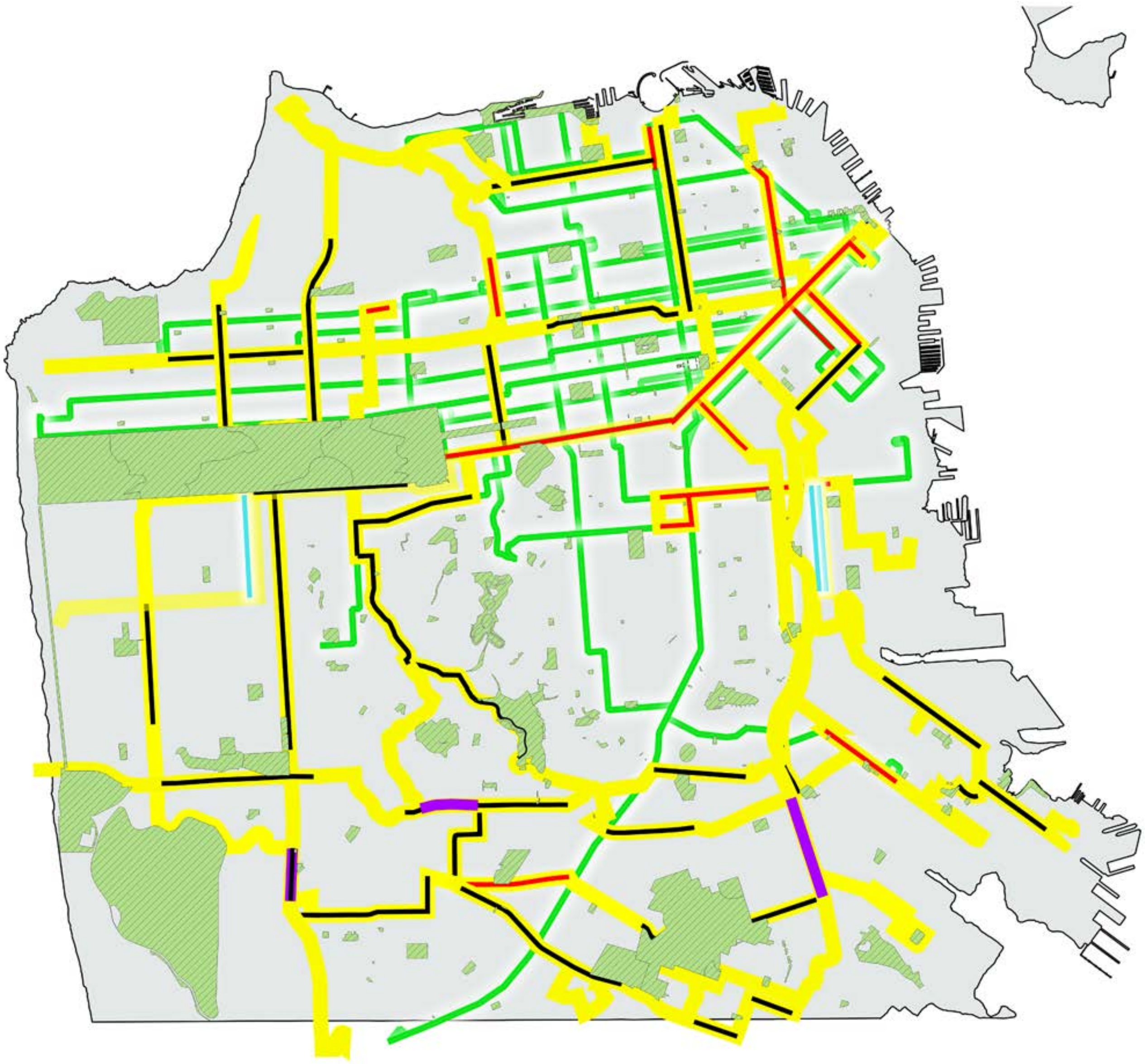

Figure 4. High Opportunity Electrification Map. San Francisco can electrify 210 miles across 10 transit routes through by adding 58 miles of new overhead catenary and leveraging existing infrastructure.

- Opportunity routes
- Existing OHL
- Existing OHL for new routes
- Double OHL
- New OHL for two routes
- New Single OHL

THE POWER OF PUBLIC COOPERATION

In its November 2022 presentation to the International Public Transport Association (IUTP), SFMTA indicated that it had initiated an IMC pilot program for four new buses and planned to convert 60 trolleys to IMC. The agency anticipated that the buses would have an off-wire range of 10 to 12 miles and be able to fully charge in 40 to 45 minutes on-wire.[23] Staff believe IMC technology could enable some diesel-hybrid routes with partial catenary coverage to become trolley routes.

San Francisco is not the only city thinking about new IMC trolleybus infrastructure. For instance, Dayton, Ohio, has extended several trolleybus routes using IMC trolleybuses, and North American operators and manufacturers are increasingly investigating IMC trolleybuses as they update their fleets.[24]

According to SFMTA, procuring reliable transit vehicles that meet Buy-America standards has been challenging. To address this long-standing problem, in 2015, SFMTA partnered with Seattle King County Metro to create a larger procurement budget, ultimately enticing a large bus manufacturer, New Flyer, to take up the bid. More recently, SFMTA has expressed interest in developing domestic manufacturing capacity and formed a strong Trolley Consortium with other agencies (Greater Dayton Regional Transit Authority, Seattle King County Metro, Southeastern Pennsylvania Transportation Authority, and Coast Mountain Bus Company in Vancouver).[25] There is an exciting opportunity to develop regional green industrial strategy around trolleybus procurement, aggregating demand across multiple transit properties—thereby lowering the cost for new IMC trolleybus systems—and increasing the long-term security of the new, green system.

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23. SFMTA, "San Francisco Trolley Overview," presentation, UITP 37th Trolley Bus Committee Meeting, San Francisco, November 29, 2022.

24. Jessica Olsen and Stephen Mosby, "Dreams Become Reality as Last Innovative NexGen Bus Rolls into Dayton," *Mass Transit Mag*, February 17, 2021, https://www.masstransitmag.com/bus/article/21206832/dreams-become-reality-as-last-innovative-nexgen-bus-rolls-into-dayton.

25. SFMTA, "San Francisco Trolley Overview," presentation, UITP 37th Trolley Bus Committee Meeting, San Francisco, November 29, 2022.

DRAWING FROM EXAMPLES ABROAD

While IMC trolleybuses are a new technology in the United States, they have helped green and expand trolleybus operations globally. Lyon, for example, France's second-largest city, has an extensive trolleybus system alongside a metro and streetcar system. The city has already begun to replace 34 trolleybuses currently in operation, and a new order calls for a further 250 IMC trolleybuses both to renew the old fleet and convert several bus routes to trolleybus operation.[26] In Latin America, Mexico City has a robust trolleybus system and has recently opened a new elevated trolleybus BRT line[27] with more under construction, while Medellín, Colombia, is planning to introduce trolleybus lines into its multi-modal transit system.

Smaller cities are also making big investments in converting their transit systems. Esslingen, Germany, for instance, currently has 10 IMC trolleybuses and is ordering another 46, with the aim of operating all bus services in the town with IMC trolleybuses.[28] Solingen, Germany, is adopting a similar approach; they are gradually introducing IMC trolleybuses to provide all bus service in the city.[29] Most striking, however, is Prague: After a gap of almost 50 years, the Czech capital has decided to revive trolleybus operation.[30] Two short sections of test line have already opened, and full operation of the first two lines will begin in 2023 and 2024 respectively.[31]

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26. SFMTA, "San Francisco Trolley Overview," presentation, UITP 37th Trolley Bus Committee Meeting, San Francisco, November 29, 2022.

27. Erik Buch, "Mexico City: An Elevated BRT Trolleybus!" ***Urban Transport Magazine,*** September 14, 2022, https://www.urban-transport-magazine.com/en/mexico-city-an-elevated-brt-trolleybus/.

28. Jürgen Lehmann, "46 Battery Trolleybuses for Esslingen," ***Urban Transport Magazine***, June 27, 2021, https://www.urban-transport-magazine.com/en/46-battery-trolleybuses-for-esslingen/.

29. Editorial Staff, "Solaris Has Won a Tender for 16 Battery-Powered Trolleybuses in Solingen (Germany)," ***Sustainable Bus***, October 27, 2020, https://www.sustainable-bus.com/news/solaris-has-won-a-tender-for-16-battery-powered-trolleybuses-in-solingen-germany/.

30. Editorial Staff, "Trolleybuses Return to Prague. 47 years later," ***Sustainable Bus***, November 11, 2019, https://www.sustainable-bus.com/trolleybus-tramway/trolleybuses-return-to-prague-47-years-later/.

31. Editorial Staff, "Trolleybuses Return to Prague. 47 years later," ***Sustainable Bus,*** November 11, 2019, https://www.sustainable-bus.com/trolleybus-tramway/trolleybuses-return-to-prague-47-years-later/.

CONCLUSION

Electrifying and decarbonizing the US transportation system will be an enormous challenge. Accomplishing it, particularly on the urgent timeline necessary to mitigate climate and ecological catastrophe, will require equitably balancing difficult questions about materials, supply chains, and urban planning. **Trolleybuses—in particular, IMC trolleybuses—are a technologically proven but underutilized tool for mobility that can play an important role in this transition.**

Because of its exceptional existing trolleybus infrastructure and requisite worker expertise, San Francisco has a clear opportunity to be a leader on climate mitigation, electrification, and labor rights by protecting and expanding its trolleybus system.

The case study of San Francisco suggests that trolleybuses could play a critical role in creating the just, energy-efficient, and sustainable transportation systems of the future. Many cities around the United States once had trolley systems of their own. Local governments and transit agencies can draw on both this legacy and the example of San Francisco to build or rebuild modern trolley systems in their cities.