Monterey-Salinas Transit System Wide Fleet Analysis Study

A Project Completed for MST by CALSTART

June 2017

Contents

Figures

Section 1

Glossary of Terms

Advanced Clean Transit (ACT) Regulation: A proposed regulation by CARB that seeks to transition all California public transit fleets to Zero-Emissions Bus (ZEB) technology by 2040.

Altoona: The Altoona Bus Research and Testing Center was established in 1987 by the Federal Transit Administration (FTA) to test new bus models for safety and performance before they can be purchased using federal funding.

B20 and B100: Biodiesel is diesel fuel made from renewable feedstocks (typically vegetable oils and animal fats) instead of fossil feedstock (oil). It generally burns lower in greenhouse gases than fossil diesel from an entire lifecycle perspective because the growth of biodiesel feedstocks pull CO_2 from the air while growing. B20 is a blend of 20% biodiesel and 80% fossil diesel while B100 is 100% biodiesel.

Battery Electric Vehicle (BEV): An electric vehicle that receives 100% of its propulsion power from on-board battery storage.

BYD: Electric bus manufacturer headquartered in China with an office and a manufacturing facility in Southern California. BYD is the maker of the K9, an all-electric 40-foot public transit bus.

California Air Resources Board (CARB): California's governmental agency in charge of monitoring, advocating for, and regulating clean air. CARB was founded in 1967 and is a cabinet-level department in the California Environmental Protection Agency (EPA). CARB has been instrumental in driving innovation in the BEV market through legislative mandates.

Complete Coach Works (CCW): Manufacturer of the Zero Emissions Propulsion System (ZEPS) bus, which is a remanufactured all-electric 40-foot transit bus that is available for purchase. ZEPS buses receive new VIN numbers and are eligible for FTA funds for new vehicle purchases.

Compressed Natural Gas (CNG): A fossil fuel that propels an increasing number of public transit buses. CNG emissions are cleaner than diesel emissions with respect to some criteria air pollutants and GHGs but not necessarily all criteria air pollutants.

Criteria Air Pollutants: The 1963 Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants that collectively have become known as "criteria" air pollutants. The six criteria pollutants are particulate matter (PM), photochemical oxidants (including ozone), carbon monoxide, sulfur oxides, nitrogen oxides, and lead.

Diesel Particulate Filter (DPF): A device designed to remove diesel PM (or soot) from exhaust gasses of diesel engines. Use of DPFs on heavy-duty diesel vehicles has become more frequent over time, particularly around 2007 when they became mandated by the EPA.

Gillig: American bus manufacturer headquartered in the California Bay area with over 75 years of experience building buses. Traditionally an internal combustion engine only bus manufacturer, Gillig has recently launched their first battery electric bus project in Walnut Creek, California.

Greenhouse Gases (GHGs): Gases in the Earth's atmosphere that are responsible for retaining emitted radiation from the sun that is reflected off the Earth. Human activity since the Industrial Revolution has increased the concentration of GHGs in the Earth's atmosphere by roughly 40%. Scientific consensus is that this increase in gas concentration is responsible for, and will continue to be responsible for, a warming trend of the Earth's atmosphere. The most recent CO_2 concentration reported by the Carbon Dioxide Information Analysis Center (CDIAC) is 405 ppm.

GreenPower: GreenPower Motor Company was established in 2014 to make battery-electric buses. They manufacture a fleet of BEV buses, from 30-foot transit buses to a 45-foot double-decker and 60-foot articulated transit bus.

Low or No Emission (Low-No) Program: The Low or No Emission Competitive program provides funding to state and local governmental authorities for the purchase or lease of zero-emission and low-emission transit buses as well as acquisition, construction, and leasing of required supporting facilities.

Monterey-Salinas Transit Bus Yards: MST operates a number of bus yards mentioned in this report, including Thomas D. Albert (TDA) – the permanent Monterey bus yard, Clarence J. Wright (CJW) – the permanent bus yard in Salinas, and Joe Lloyd Way (JLW) – the temporary facility being used by MST during construction.

Motor Coach Industries (MCI): An American manufacturer of road coach buses with manufacturing facilities in the U.S. and Canada. Subsidiary of New Flyer Industries.

New Flyer: A Canadian bus manufacturer with manufacturing operations in both Canada and the U.S. and more than 75 years of experience in building buses. In 2014, New Flyer delivered their first two battery electric buses to the Chicago Transit Authority.

OEM: Original Equipment Manufacturer. In this paper, OEM refers to the bus manufacturers.

Optima: A no longer existing brand of small transit buses that were manufactured in the U.S. In 2007, Optima was sold to North American Bus Industries (NABI).

Proterra: A manufacturer of all-new BEV 35- and 40-foot transit buses. Proterra vehicles have either a small battery and receive en-route charging from a proprietary overhead conductive charger, or a larger battery for traditional overnight charging.

Road Coach: A transit vehicle (bus) used primarily for express and intra-city connections. Seats are usually all forward-facing and elevated above the driver. Road Coaches usually have one door and three axles, and the vehicle is configured for longer distances, higher speeds and fewer stops than a standard transit bus.

Tire and Brake Wear (TBW): Particles from tire and brake wear of road-based vehicles can be a significant mobile source of PM regardless of propulsion type. As Diesel Particulate Filters (DPF) have become more and more prevalent, TBW has actually become in some instances a more prominent source of PM than actual exhaust emissions.

Total Cost of Ownership (TCO): The complete 12-year all-in cost of operating a transit vehicle including initial vehicle purchase price, the cost of any necessary infrastructure, as well as ongoing maintenance and fuel expenses.

Transit Bus: A standard transit vehicle of about 40 feet in length. Transit buses usually have at least two doors with entrances low to the ground. Seats are configured in a mixture of forward and side facing. The bus is configured for frequent stops and boardings/alightings.

Section 2

Executive Summary

Public transit agencies are under increasing pressure to lower their fleet greenhouse gas and criteria air pollutant emissions, particularly in the State of California. This pressure is coming from federal regulators, state regulatory and environmental entities, as well as local constituents and air quality advocates. Nowhere in the United States is environmental quality a bigger topic of public concern than the State of California.

The market for battery-electric buses (BEVs) is rapidly expanding, affording MST a relatively robust selection of potential options. These buses are also rapidly expanding their range capabilities to the point where they can potentially serve a meaningful portion of MST's public transit duty cycles.

The purpose of this paper is to accomplish the following:

1. Use MST's own transit data to **explore** MST's current fleet of transit vehicles along a number of relevant metrics;
2. **Calculate** and **present** a complete emissions inventory for MST's current transit vehicle fleet;
3. **Present** alternative propulsion vehicle options and **compare** their emissions impacts and total cost of ownership;
4. **Introduce** vehicle financing options including the possibility of battery leasing for BEV buses; and
5. **Recommend** to MST a plan forward for introducing BEV buses.

Our findings reveal that bus electrification is not always the best method of reducing particular types of public transit vehicle air emissions. On a state-wide air emissions level, for GHGs and NO_x, bus electrification would be MST's most effective method of reducing these emissions. But in the case of CO, VOCs and both types of PM, the best method of reducing total state-wide emissions is to use the most current available diesel technology. However, it must be noted here that in 2000, the California Air Resources Board (CARB) adopted a Fleet Rule for Transit Agencies that requires larger transit agencies to purchase and demonstrate zero emission technology vehicles. Under these circumstances, diesel powered buses would not be an option. Furthermore, as California (and the rest of the nation as well) continues to add renewable electricity generation to its power grid to meet its 2050 climate change goals, bus electrification will continue to get cleaner and cleaner with respect to both GHG and point-source air emissions.

With today's offerings of BEV buses (assuming a reliable daily range of 140 miles), a significant portion of MST's daily weekday duty cycles (29 percent) could be reliably serviced by an electric bus.[1] If charging could be incorporated during the day (either en-route charging or depot charging between block services), this 140-mile daily range limit could be extended, resulting in even more duty cycles becoming compatible with existing BEV bus offerings.

Our total-cost-of-ownership (TCO) analysis reveals that electric transit buses are more expensive to purchase than their traditionally fueled counterparts, but are generally less expensive to operate with respect to fuel and maintenance costs. For MST, the diesel 12-year TCO is lower than both electric and diesel-electric hybrid. The BEV bus option, while having lower overall fuel and maintenance costs than diesel, still ends up being about $190k more expensive than diesel over an entire bus life cycle. The diesel-electric hybrid bus is about $75k more expensive than the BEV option.

Given the above findings, we recommend that MST immediately begin the process of purchasing and integrating full-sized BEV transit buses into their fleet for the following reasons:

1. MST will increasingly be bound by CA regulatory standards to purchase and implement zero-emission vehicles;
2. Considering the erratic and higher cost of fuel and maintenance for fossil-fuel buses, MST would benefit from the financial stability of implementing BEV buses; and
3. MST should act now to benefit from a zero-emissions purchasing incentive structure that is currently strong.

In addition, we recommend that MST pursue the use of depot conductive charging, and not expand en-route charging infrastructure (either conductive or inductive). We further recommend that MST utilizes available battery leasing programs and structures grant financing in a way that allows more buses to be deployed. The main advantage with leasing batteries is that MST could deploy more vehicles at the outset with the same total grant funding amount. However, as the battery leasing financing programs and service agreements are relatively new products, it is recommended that they be evaluated carefully.

A phasing plan is provided later (**Section 7**) to assist MST in achieving a zero-emission fleet by 2040. The phasing plan addresses:

- Natural attrition;
- Implementing BEV transit buses on existing block schedules today;
- Modifying MST's block schedules in the future; and
- Modifying Monterey and Salinas bus yards to accommodate more BEVs in the coming years.

[1] This includes both routes operated by MST as well as those operated by MV.

Section 3

Introduction – The Potential for Electric Buses

About MST

Monterey-Salinas Transit (MST) was originally formed as the Monterey Peninsula Transit Joint Powers Agency in 1972. The city of Salinas joined in 1982 and in 2010, state law AB644 created MST as it exists today.

Today, MST serves 12 cities as well as the County of Monterey, and features a board of directors with a representative from each member jurisdiction. MST's service covers a 294 square-mile area and features 56 transit routes serving a population estimated at over 400,000 residents.

MST operates a fleet of 158 vehicles including low-floor transit buses, over-the-road coach commuter buses, cutaway buses, as well as trolley buses. Service options include fixed transit bus routes, on-call and paratransit services, as well as the old-fashioned trolley service along the Monterey waterfront (including an all-electric trolley with innovative wireless charging infrastructure).

MST is committed to transitioning to a zero-emission fleet and meeting eventual regulation by the California Air Resources Board (CARB) that, in its current state, requires transit agencies to purchase zero-emission buses beginning in 2018. This study provides data along with a phasing plan that supports the transition to a zero-emission fleet.

Public transit agencies are under increasing pressure to lower their fleet greenhouse gas and criteria air pollutant emissions, particularly in the State of California. This pressure is coming from federal regulators, state regulatory and environmental entities, as well as local constituents and air quality advocates. Nowhere in the United States is environmental quality a bigger topic of public concern than the State of California.

Mobile sources (vehicles such as passenger vehicles, trucks, and transit buses) and the fuels that are used to power them account for over 80 percent of smog forming NOx emissions and over 90 percent of diesel PM emissions, and close to 50 percent of the statewide greenhouse gas (GHG) emissions.[2] For this reason, the California Air Resources Board (CARB) and other environmental groups have continually pressed for the transformation away from the use of petroleum in motor vehicles.

Monterey-Salinas Transit (MST) operates 158 public transit vehicles in an area that spans more than 280 square miles and services more than 400,000 residents. MST has already begun its transformation to cleaner transit options by installing an all-electric old-fashioned trolley in 2015 along its world-famous waterfront district, and in operating four diesel hybrid vehicles. With this study, MST is further demonstrating its interest and commitment to pursuing cleaner public transit options for the residents of and visitors to Monterey County.

The market for battery-electric buses (BEVs) is rapidly expanding, affording MST a relatively robust selection of options. These buses are also rapidly expanding their range capabilities to the point where they can potentially serve a meaningful portion of MST's public transit duty cycles.

[2] Mobile Source Strategy, May 2016 – California Air Resources Board.

The purpose of this paper is to accomplish the following:

1. Use MST's own transit data to **explore** MST's current fleet of transit vehicles along a number of relevant metrics;
2. **Calculate** and **present** a complete emissions inventory for MST's current transit vehicle fleet;
3. **Present** alternative propulsion vehicle options and **compare** their emissions impacts and total cost of ownership;
4. **Introduce** vehicle financing options including the possibility of battery leasing for BEV buses; and
5. **Recommend** to MST a plan forward for introducing BEV buses.

The analysis executed for this paper includes data from MST's fiscal year 2016 – the latest complete year for which data is available. The data therefore corresponds with the time-period of July 2015 through June 2016.

Section 4

MST in 2016: By the Numbers

Fleet Characteristics

As of June 2016, MST operates 80 large public transit buses of at least 35 feet in length. In addition, MST oversees the operation of another 75 transit vehicles that are operated by MV Transportation on behalf of MST. In this section of analysis, we will explore MST's entire fleet of 150+ vehicles across three metrics: bus manufacturer (OEM), bus size (length), and bus propulsion type, and within these metrics count MST's buses and average annual mileage travelled. In addition, we will explore vehicle operation costs by vehicle type and model year.

Vehicle OEM

MST owns vehicles by Gillig, MCI, Ford, ElDorado, Optima, and Dodge – the largest number are Gilligs. In fact, all of MST's transit-specific buses are Gilligs. All road coaches are MCIs. Cutaways are ElDorado or Ford, and trolleys are all Optimas.

With respect to mileage, MST drives over three million miles annually with their Gilligs and just over half a million with MCI coaches. Fords/ElDorados drive another two million miles and trolleys 80,000 miles.

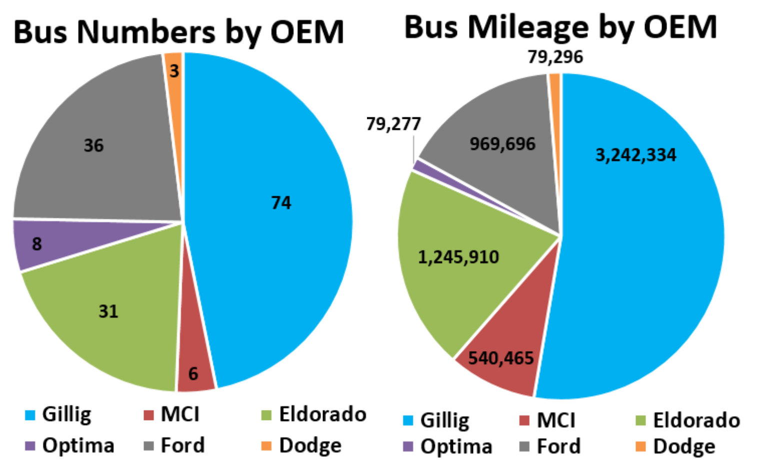


Figure 1: MST's bus fleet by OEM

Vehicle Length

MST owns mostly cutaway vehicles (22-24 ft) and full sized transit buses (35-40 ft) with a small amount of road coaches and trolleys, as well as assorted passenger vehicles.

With respect to mileage, the majority of MST service miles come from cutaways and transit buses. As of today, transit and coach services are operated by MST, while the trolleys and cutaways are operated by MV (the electric trolley is operated by MST).

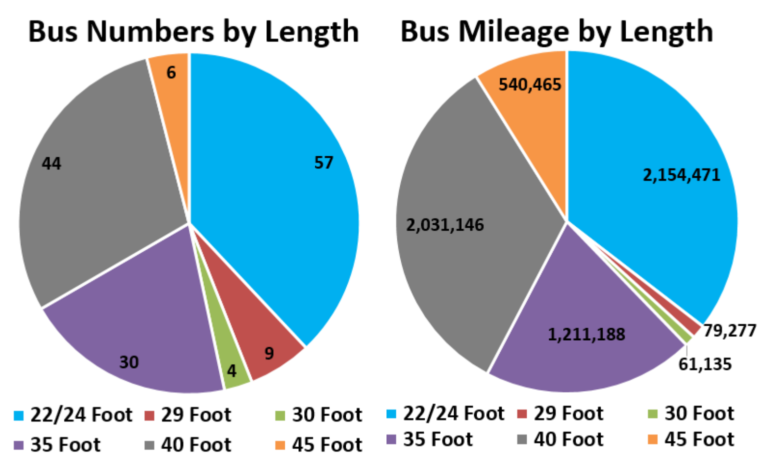


Figure 2: MST's bus fleet by length

Vehicle Propulsion Type

With one exception, MST owns a 100% fossil powered fleet, with 58% of vehicles running on diesel, and 42% on gasoline. MST owns four diesel-hybrid cutaways as well as one battery electric trolley. All of MST's full-sized public transit vehicles are diesels.

With respect to mileage, MST's diesels are the workhorse of the fleet, serving 64% of the agency's miles, with almost all the rest powered by gasoline.

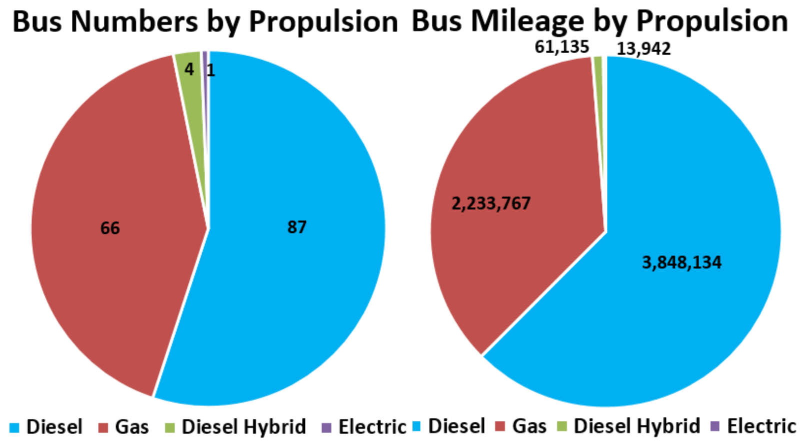


Figure 3: MST's vehicle fleet by propulsion

Vehicle Operating Costs

For this analysis, operating costs shall include fuel (liquid or electric), maintenance labor and parts, and any necessary fluids. MST's most expensive vehicles to operate are the old-fashioned trolleys, which include 2003 Optima diesel high-floor buses built to resemble old-fashioned street-car trolleys, and one all-electric trolley. The cheapest vehicles to operate are the smaller vehicles in the fleet. See **Figure 4** below for a closer look at MST operating costs per vehicle type.

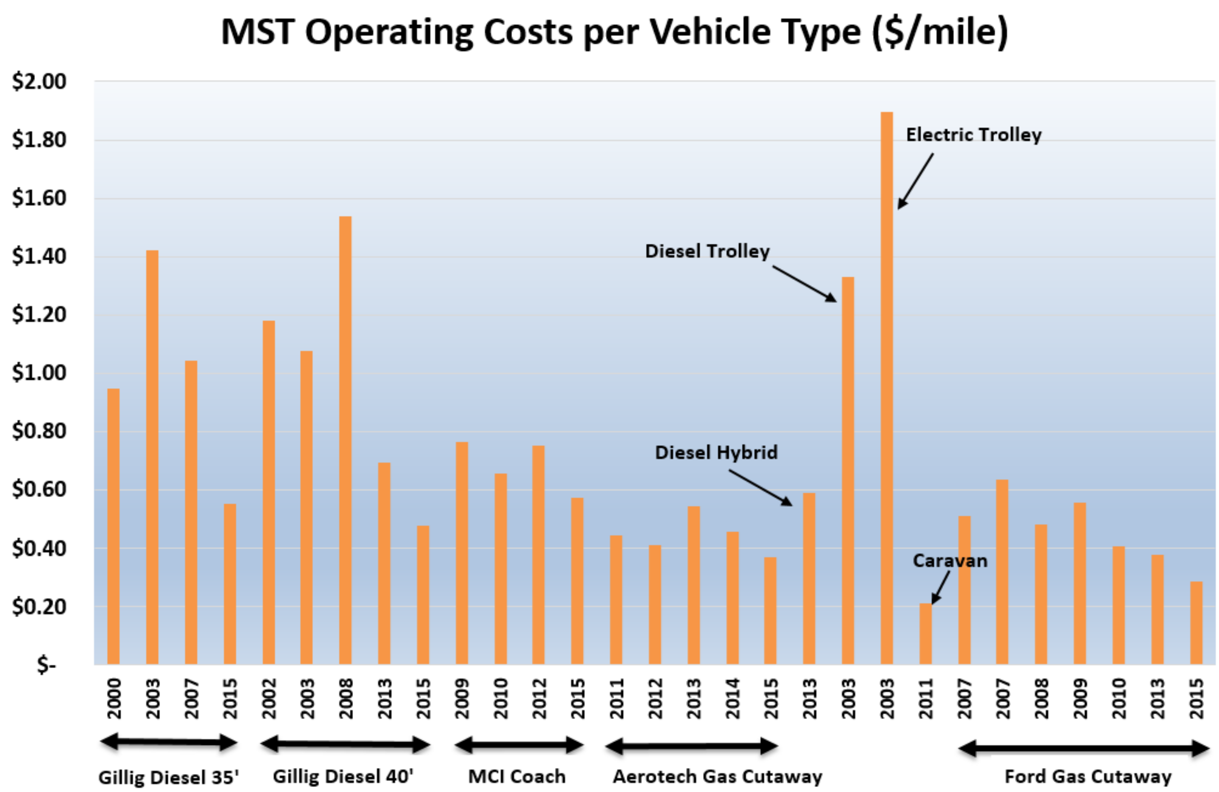


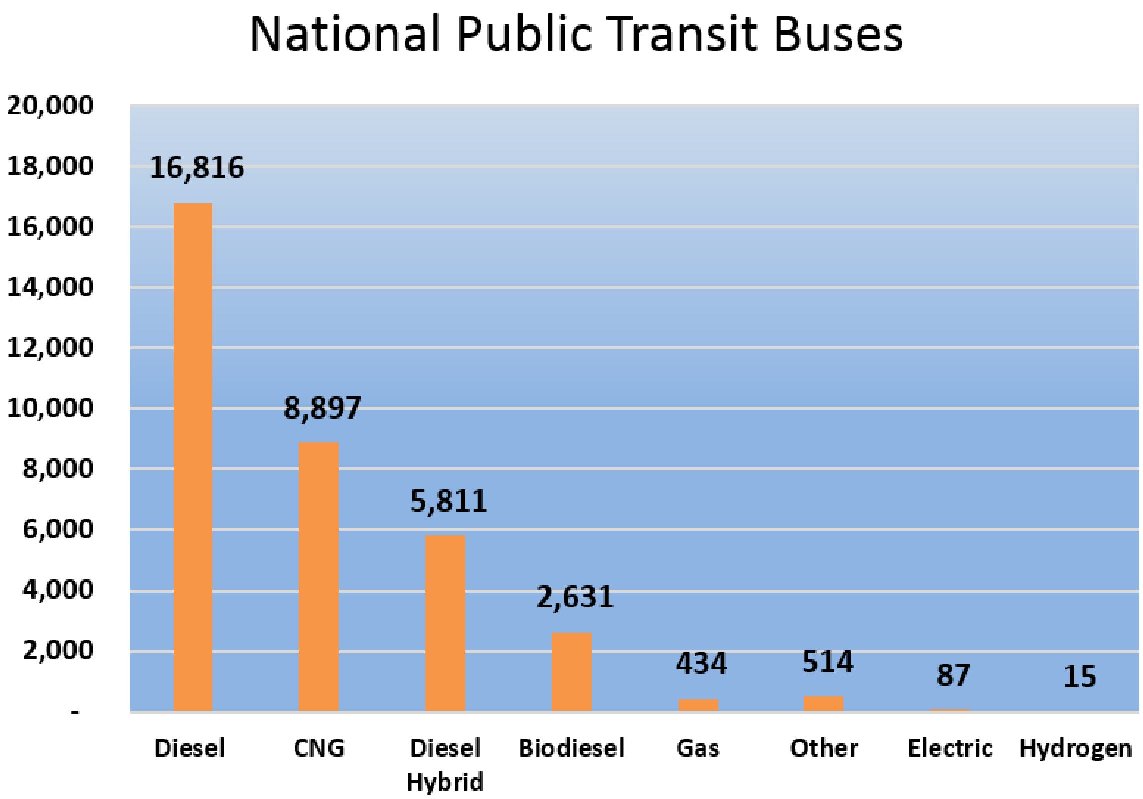
Figure 4: MST owned-vehicle operating costs per vehicle type ($/mile)

MST vs. Nation

While still diesel intensive, over the past 2 decades, national public transit fleets have shifted from almost 100% diesel powered to now just under 50% diesel. While diesel has fallen out of favor somewhat, the national transit bus fleet is still over 90% fossil-fuel powered[3], with CNG now accounting for more than 25% of all national transit buses, and Diesel-Electric Hybrid more than 16%. While constantly gaining in popularity, zero-emissions buses (BEV and Hydrogen Fuel-Cell) still make up less than 1% of all public transit buses nationally.

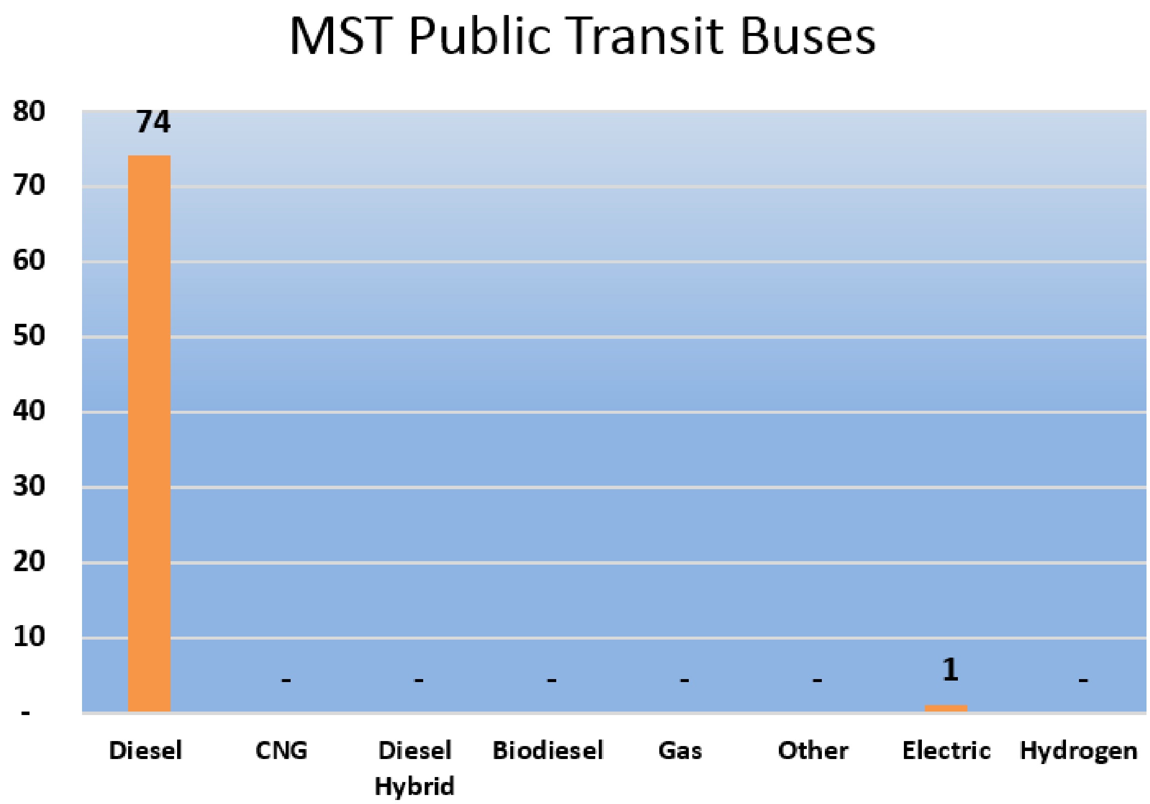
The breakdown of MST's vehicle propulsion types looks different from the national average. For full-sized public transit buses, MST remains an exclusively diesel shop. With a few fixed-route exceptions, MST- owned gas vehicles are cutaways used for paratransit and on-call services (and operated exclusively by MV on behalf of MST). MST currently owns and operates one BEV bus (retrofitted trolley) and also owns four Diesel-Electric Hybrid ElDorado cutaways. As of 2017, MST neither owns nor operates any CNG vehicles.

Please see **Figures 5 and 6** below for more detail on the comparison between MST and the U.S. national transit bus fleet as a whole.[4] Only full-sized transit buses (35 and 40 foot) are included in this comparison.



[3] The roughly 10% of national public transit vehicles that are non fossil-fuel buses are predominantly biodiesel, which in many cases operate using a fuel blend that includes fossil diesel.

[4] Public Transportation Vehicle Database 2016 – American Public Transportation Association.



Figures 5 and 6: U.S. and MST public transit buses by propulsion type

Existing Fleet Emissions Inventory: Criteria Air Pollutants

The 1963 Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards for six common air pollutants that collectively have become known as "criteria" air pollutants. Criteria air pollutants do not have any impact on climate change, but rather directly impact human health in local areas of high emissions. These six emissions types are:

1. **Particulate Matter (PM_{10} and $PM_{2.5}$):** PM is a complex blend of tiny organic and inorganic particles made up of acids, chemicals, metals, and often soil and dust. The size of the particles is important and directly linked to human health problems. The EPA is particularly concerned about particles that measure between 2.5 and 10 micrometers (PM_{10}) and particles that are smaller than 2.5 micrometers ($PM_{2.5}$), as these are the particles that are small enough to pass into the lungs and cause serious health effects. PM is typically found, among other places, in the exhaust of combustion engine vehicles such as public transit buses.

2. **Carbon Monoxide (CO):** CO is a colorless and odorless gas typically emitted from mobile sources, such as combustion engines in public transit buses. CO can cause

harmful effects to humans by reducing the amount of oxygen that the blood can deliver to the body.

3. **Nitrogen Oxides (NO_x):** Nitrogen Dioxide (NO_2) is the (NO_x) gas most relevant to this discussion as it is released in the emissions of combustion engines, particularly diesel engines. NO_2 is also harmful to the human respiratory system and is responsible for contributing to the formation of ground-level ozone and PM as well.

4. **Sulfur Dioxide (SO_2):** SO_2 is an oxide of sulfur that is linked with a number of adverse effects on the human respiratory system. It is released largely from combustion of fossil fuels at power plants. However, mobile emissions sources (diesel burning vehicles) have historically been responsible as well. Fortunately, modern advances in low-sulfur diesel fuel have greatly reduced SO_2 emissions from heavy-duty vehicles to the point where they do not need to be included in this transit bus analysis as an important source of emissions.

5. **Ozone:** Ozone is not emitted directly into the air by any processes but is rather formed by a chemical reaction at the ground level between NO_x and volatile organic compounds (VOCs) in the presence of sunlight. For this reason, NO_x and VOC emissions must be minimized near population centers to minimize the formation of ground-level ozone. Ozone can have harmful respiratory effects on humans, particularly those with asthma, as well as plant life.

6. **Lead:** Lead accumulations in the body are responsible for a number of physical and mental development challenges in humans, particularly children. Fortunately, emissions of airborne lead metal from combustion engines have declined by over 95% since 1980 due to successful EPA regulatory efforts and the availability of unleaded engine fuels. Due to its near elimination from combustion engine exhaust, airborne lead emissions are not included in this analysis.

Volatile Organic Compounds (VOCs): VOCs are technically not an EPA monitored criteria air pollutant, but they are important to include in this analysis due to their contributions to the formation of ground-level ozone. VOCs are a wide category of airborne organic chemicals with a high vapor pressure that can occur naturally or through human actions. VOCs that form through the combustion of fossil fuels are themselves not acutely toxic, but are important due to their contributions to ozone formation.

Despite enormous progress that has been made in reducing criteria air pollutant emissions in the U.S., particularly in the last 30 years, millions of Americans still live in counties with EPA monitored data that indicates unhealthy air for at least one of the six pollutant types. Measured against the California state standard for criteria pollutants, the Monterey County area is in nonattainment for ozone and PM_{10}. However, measured against the national standard for criteria pollutants, which are comparatively less strict, the Monterey County area is in attainment for all six criteria air pollutants as measured by the U.S Environmental Protection Agency.[5]

[5] Area Designation Maps / State and National – California Air Resources Board.

Through its operations of a fleet of over 150 fossil fuel burning transit vehicles, MST is responsible for emissions of several of the above defined air pollutants, the most critical being PM. As mentioned above, internal combustion engines generally do not emit all of the above-defined criteria air pollutants. For this reason, the chart below does not include SO_2, ozone, and lead emissions. A summary of MST's estimated average annual criteria air emissions can be seen in **Figure 7** below. A complete table of the estimated average annual emissions quantities for each type of MST transit vehicles can be found at the end of this report in **Appendix A**.

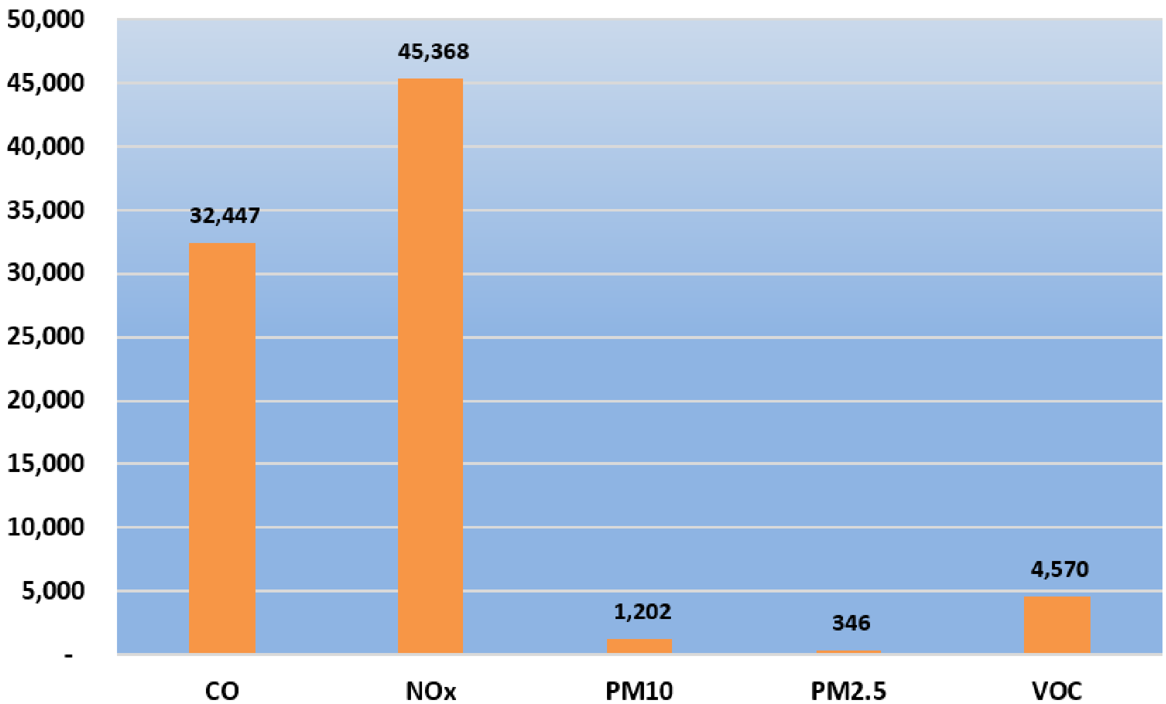


Figure 7: Estimated MST 2015-2016 fiscal year transit vehicle air emissions (lbs.)

Fleet Age: Achieving Emissions Reductions through Attrition

The above estimated emissions are not evenly distributed across MST's transit vehicle fleet. Rather, the emissions are heavily skewed towards MST's full-sized transit buses, and in particular, early model buses that emit higher levels of air emissions than late-model buses.[6] **Figure 8** below graphically illustrates the decline that can be expected in bus emissions stemming only from diesel technology improvements made from model year to model year. This data, while pertaining to the transit diesel bus market as a whole, and not necessarily the particular models operated by MST, strongly suggests that an enormously effective method of reducing MST's emissions inventory would be to discontinue the use of and replace its oldest buses, particularly those manufactured before 2007.

[6] This is why all of MST's pre-2007 vehicles (including transit buses and old-fashioned trolleys) have been retrofitted with diesel particulate filter (DPF) technology.

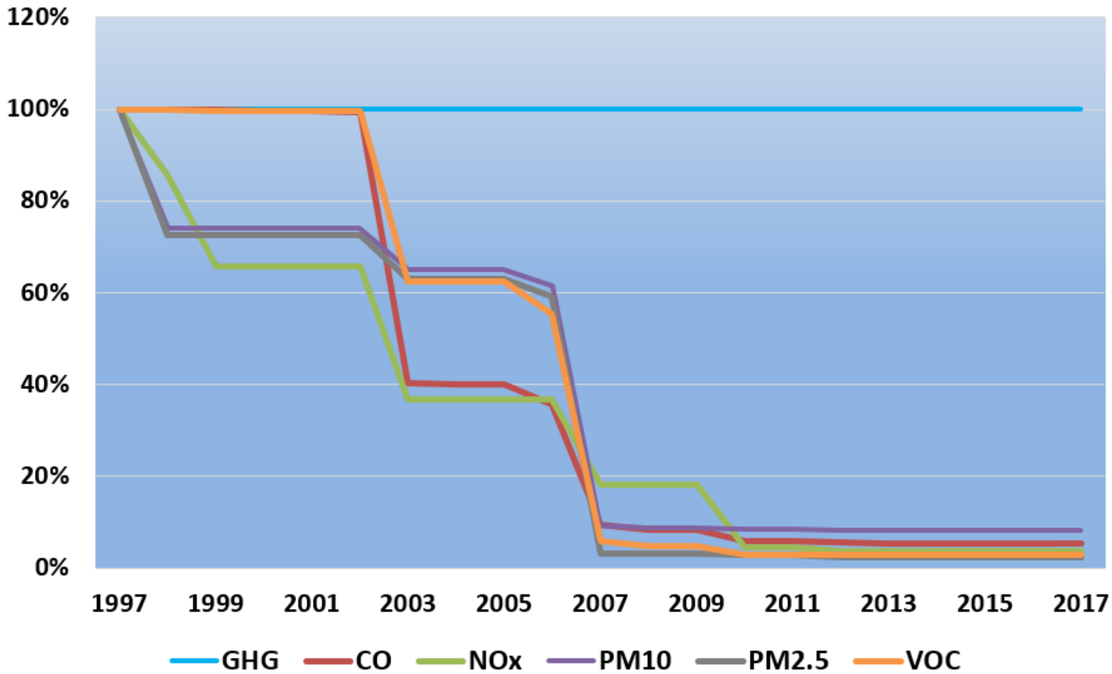


Figure 8: Decline of public transit diesel bus emissions over time by model year

MST operates 40 buses that are pre-2007 model year. As can be seen below in **Figure 9**, MST's pre-2007 model year buses remain a significant portion of total vehicle inventory, although MST's bus fleet age is roughly similar to the rest of the nation with respect to age.

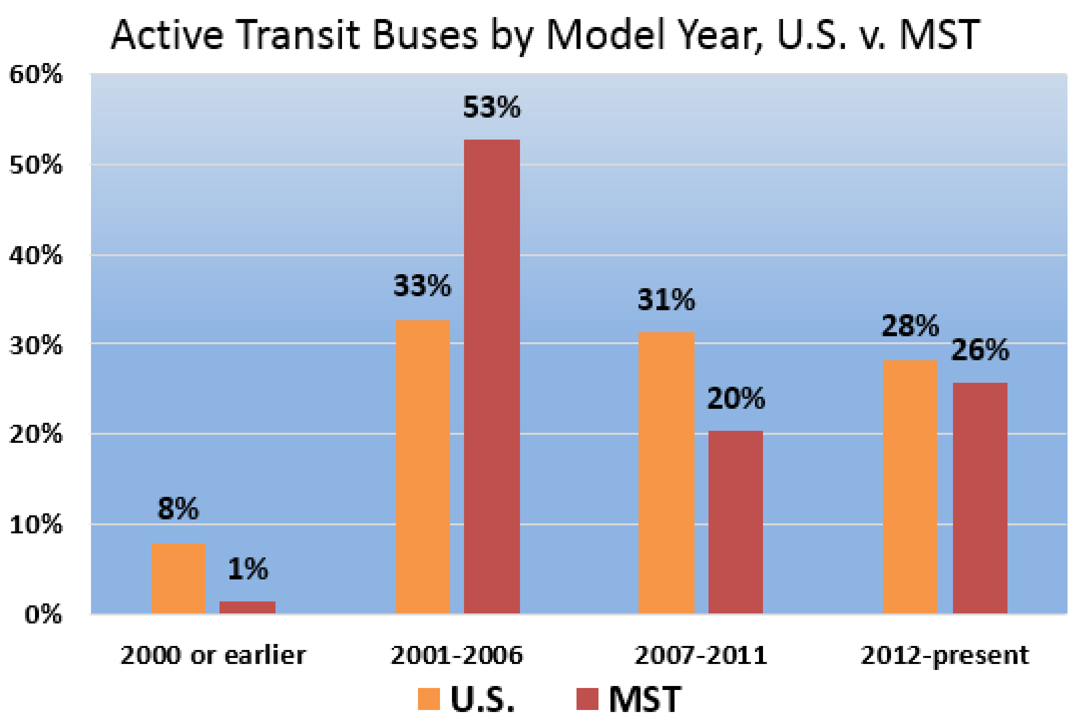


Figure 9: Comparison of model years for U.S. and MST public transit buses

Like most U.S. public transit agencies, MST owns and periodically operates a number of backup buses for reserve purposes. However, it isn't just the case that MST continues to own older public transit buses for reserve purposes only; rather, these vehicles continue to be used extensively. Please see **Figure 10** below for the average annual mileage per model year for MST's entire vehicle fleet (not just transit buses).

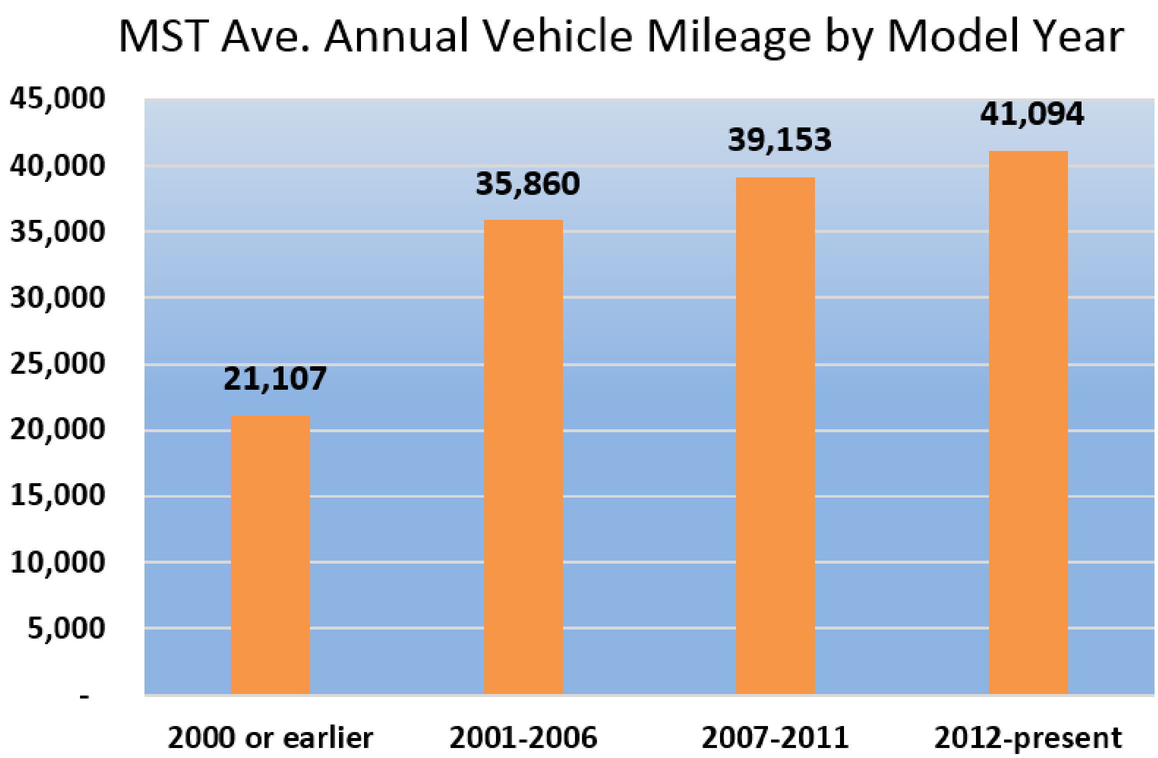


Figure 10: MST average annual vehicle mileage by model year grouping

As can be seen in the charts above, MST continues to rely on its older vehicles (particularly older diesel buses) for providing significant service miles. Replacing these buses even with just *new* diesel buses represents an excellent opportunity for MST to reduce its fleet-wide inventory of criteria air emissions.

Existing Fleet Emissions Inventory: Greenhouse Gases

GHGs in the Earth's atmosphere absorb and emit radiation within the thermal infrared range. These gases are responsible for retaining emitted radiation from the sun that is reflected off the Earth. Without *any* GHGs, the temperature of the Earth's surface would be considerably lower and more variable, making habitation and agriculture virtually impossible. However, human activity, particularly since the Industrial Revolution, has increased the concentration of GHGs in the Earth's atmosphere by roughly 40%. Scientific consensus is that this increase in gas concentration is responsible for, and will continue to be responsible for, a warming trend of the Earth's atmosphere.

While the Earth's GHGs include water vapor, carbon dioxide, methane, nitrous oxide, and ozone, among others, the release of carbon dioxide from the combustion of carbon-based fuels (like diesel and gas) attributable to human activities accounts for the majority of the increase of GHGs in the atmosphere.[7] As seen above in **Figure 8**, improvements in technology have resulted in significant decreases in criteria air emissions from our public transit vehicles over time. Unfortunately, these improvements have generally **not** decreased GHG emissions.

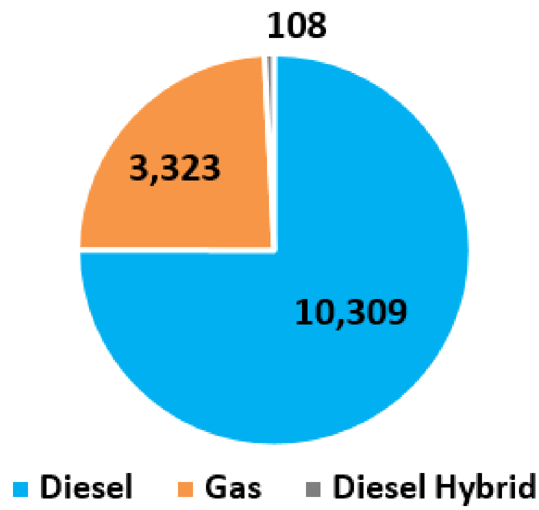


Figure 11: Average annual MST vehicle GHG emissions (metric tons)

As seen in this analysis, MST currently operates diesel and gas public transit vehicles. Please see **Figure 11** for an exploration of the sources of MST's transit fleet GHGs.

MST Duty Cycles

Considering the current state of battery technology, electric vehicles, and particularly electric public transit buses, are more limited in driving range than are internal combustion engine vehicles. Of course, BEV buses can be operated in a number of different charging modes; for example, they can be charged once per day and driven until their battery storage is exhausted, or they can be charged periodically while the vehicle is in service to extend daily vehicle driving range. Either way, it is important to explore what MST's daily duty cycles currently look like – this helps define for us MST's expectations and requirements that BEV buses will need to accommodate in order to be incorporated into the fleet.[8] Please see **Figure 12** below for a graphical look at MST's current weekday daily duty cycle lengths arranged by vehicle type. For the purpose of this figure, a 140-mile daily range assumption is inserted; in addition, the percentage of daily duty cycles that come in under this limit are labelled for each vehicle type.

[7] IPCC (Intergovernmental Panel on Climate Change), 2013.

[8] This analysis assumes that MST would operate electric vehicles in exactly the same way as they currently operate their conventional fleet. This is likely to not be the case, but it is a helpful starting point for the purpose of this analysis.

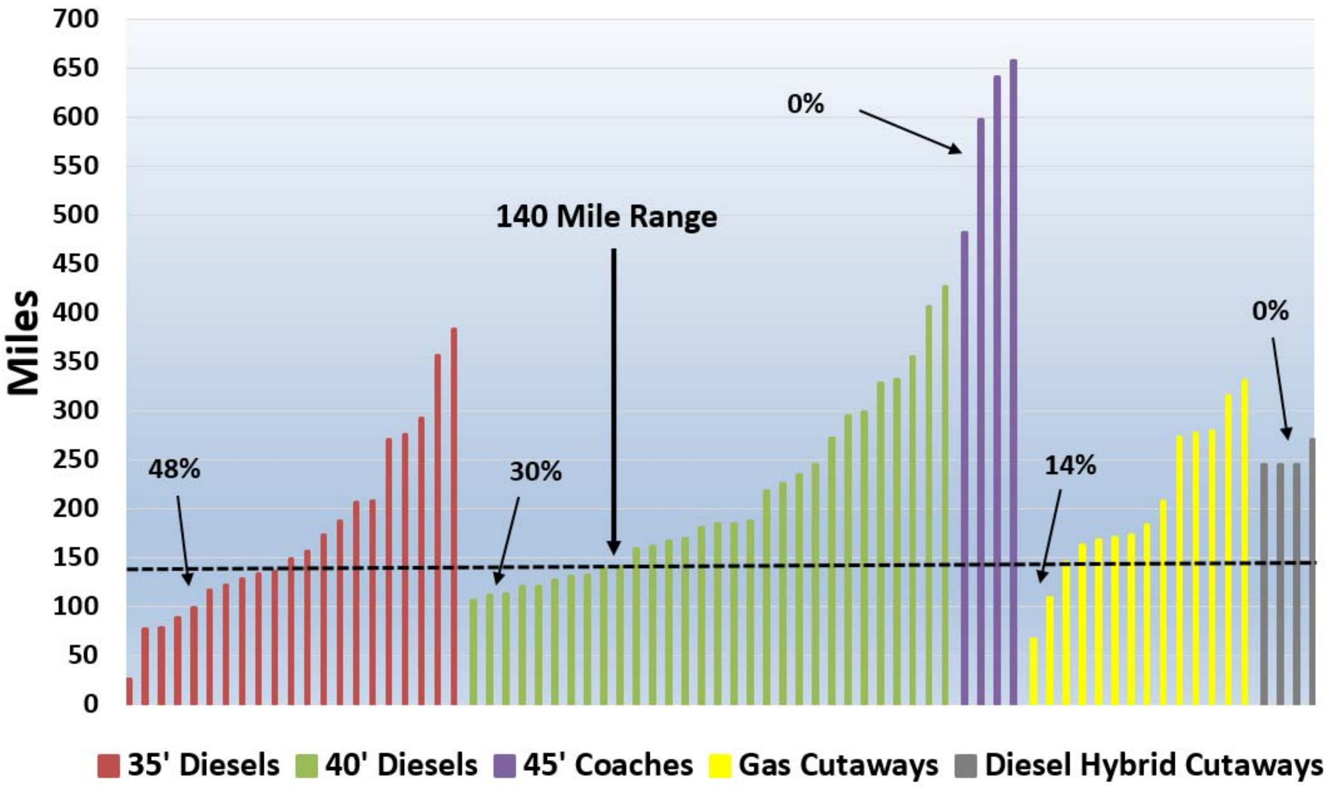


Figure 12: MST weekday daily duty cycle lengths by vehicle type

As can be seen above, a significant portion of MST's daily weekday duty cycles could be accommodated already by existing BEV bus offerings, which are assumed to have a 140 mile range.[9] If charging could be incorporated during the day (either en-route charging or depot charging between block services), this 140-mile daily range limit could be extended, resulting in even more duty cycles becoming compatible with existing BEV bus offerings. Please see **Section 5** below for more on charging options available to MST.

MST History with Electric Vehicles

MST currently operates one BEV vehicle: a 2003 Optima Trolley that has been retrofitted by Complete Coach Works of Riverside, CA to be fully battery-electric. The vehicle is also equipped with a wireless charging system developed and installed by Wireless Advanced Vehicle Electrification (WAVE) of Salt Lake City, UT. The E-trolley began operating on the Trolley Monterey service in May 2015, and has been tested on other MST lines when the trolley service is out of season.

The diesel-to-electric conversion and the wireless charging system were designed specifically for use on the Trolley Monterey route, which is a flat, 4.5-mile circulation shuttle service. Although

[9] King County Metro "Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet."

the E-trolley has been tested on other routes in the area, it has not performed as well due to range limitations and other factors associated with the vehicle conversion process.

MST's e-trolley is a one-off electric conversion project funded by MST and part of a larger wireless charging project funded in large part by a Federal Transit Administration grant. The reliability, performance, and driving range of this vehicle is not likely to be representative of BEV transit bus options that are currently available from major BEV bus manufacturers such as BYD, Proterra, New Flyer, and Gillig. Nevertheless, the operating cost for the E-trolley was calculated for this analysis, and compares poorly with MST's other transit vehicles, and even their diesel trolley fleet. Over the fiscal year 2016, the E-trolley's operating costs were $1.89 per mile, while the average diesel trolley fleet (operated by MV) operating cost was $1.33 per mile.

Section 5

Available Vehicle Comparisons

Electric public transit vehicles produce no tailpipe emissions but are responsible for some GHG and criteria air emissions via the electric power generation that is required to charge the vehicles' batteries. There is a substantial volume of analytical studies and literature written on the topic of whether conventional vehicles or electric vehicles (powered by a largely fossil fuel grid) are lower in critical air emissions. While this analysis will not take on that topic in depth, we do explore here the specific case of California's electric grid (which includes power both generated in state as well as imported from other states) and electric vehicles operated within the state.

One thing is for certain: the displacement of criteria air pollutant emissions from mobile sources in heavily populated areas to more rural areas in California (and elsewhere) where electric power is generated potentially exposes fewer persons to harmful air emissions. And once again, California's relatively clean electric power grid makes it an excellent place to leverage the air-emissions benefits of electric vehicles.

Available Electric Transit Buses

While it is still relatively early days for BEV transit buses, OEMs have already deployed several models with various configurations designed to complete similar duty cycles as traditional transit buses. **Figure 13** below lists currently available zero-emission buses in the 20'+ foot BEV bus market, and their current base prices. Manufacturers of these buses include BYD, Complete Coach Works, GreenPower, Gillig/BAE, Motiv, New Flyer, Nova Bus, Phoenix, Proterra, and Zenith Motors.

Most of the below listed electric buses come in a "full-sized" battery option that is designed to operate over a full day's duty cycle and recharge overnight. While most of these OEMs claims a daily expected range of at least 140 miles, industry range research suggests that healthy skepticism of OEM estimated range figures is warranted. While it is not the purpose of this report to explore in depth the claimed range figures of electric bus OEMs, we do explore in **Figure 25** below some limited range projections for available BEV bus options.

OEM	Model/Type	Length	Battery Capacity	Charging
BYD	K7	30'	197 kWh	Depot/En Route
	K9s	35'	270 kWh	Depot/En Route
	K9	40'	324 kWh	Depot/En Route
	K11	60'	591 kWh	Depot/En Route
	C6/Coach	23'	135 kWh	Depot/En Route
	C9/Coach	40'	365 kWh	Depot/En Route
	C10/Coach	45'	394 kWh	Depot/En Route
CCW	ZEPS	30'-40'	375 kWh	Depot/En Route
Ebus	Ebus22/40 Composite	22'-40'	>130 kWh	Depot/En Route
Gillig/BAE	Electric Trolley	30'		Depot/En Route
GreenPower	EV250	30'	210 kWh	Depot
	EV300	35'	260 kWh	Depot
	EV350	40'	320 kWh	Depot
	EV400	45'	320 kWh	Depot
	EV450	60'	400 kWh	Depot
	EV500/Coach	45'	400 kWh	Depot
	EV550/Double Decker	45'	>478 kWh	Depot
Motiv	Shuttle Bus	30'	100-120 kWh	Depot
New Flyer	XE35	30'	100-200 kWh	Depot/En Route
	XE40	40'	100-300 kWh	Depot/En Route
	XE60	60'	480 kWh	Depot/En Route
Nova Bus	LFSe	40'	<100 kWh	En Route
Phoenix	Shuttle Bus	30'	102-120 kWh	Depot
Proterra	Catalyst FC. XR, E2	35'	79-440 kWh	Depot/En Route
	Catalyst FC. XR, E2	40'	79-660 kWh	Depot/En Route
Zenith Motors	Shuttle Bus	24'	52-62 kWh	Depot

Figure 13: Available BEV bus options in 2017

Pricing data was requested from several OEMs mentioned in this report. Due to the various bus configurations and available optional equipment, the OEMs were hesitant to provide a price for a "standard" bus, as no official quote with exact specifications from the OEMs was requested. However, while we don't present current BEV bus model pricing data directly from BEV bus OEMs in response to requests for this analysis, we do have some data that can help transit agencies understand the differences in prices among BEV bus OEMs and particularly price differences across model varieties within each OEM's offerings. For example, 2015 pricing data submitted to the State of Washington reveals the following data on BEV bus and diesel hybrid options:

OEM	Model/Type	Length	Price
BYD	Heavy Duty, En-Route & Plug-In Electric	30'	$ 450,000
BYD	Heavy Duty, En-Route & Plug-In Electric	35'	$ 595,000
BYD	Heavy Duty, En-Route & Plug-In Electric	40'	$ 779,000
BYD	Heavy Duty, En-Route & Plug-In Electric	60'	$ 1,199,000
Gillig	Heavy Duty Coach, Allison Hybrid	30' Low Floor	$ 628,922
Gillig	Heavy Duty Coach, Allison Hybrid	35' Low Floor	$ 636,872
Gillig	Heavy Duty Coach, BAE Hybrid	35' Low Floor	$ 599,472
Gillig	Heavy Duty Coach, Allison Hybrid	40' Low Floor	$ 641,072
Gillig	Heavy Duty Coach, BAE Hybrid	40' Low Floor	$ 603,627
GreenPower	Heavy Duty, Plug in Electric	30'	$ 606,838
GreenPower	Heavy Duty, Plug in Electric	30'	$ 606,838
GreenPower	Heavy Duty, Plug in Electric	40'	$ 788,688
GreenPower	Heavy Duty, Plug in Electric	45'	$ 905,650
GreenPower	Heavy Duty, Plug in Electric	60'	$ 1,038,600
New Flyer	Heavy Duty Coach, Allison Hybrid	35' Low Floor	$ 623,195
New Flyer	Heavy Duty Coach, BAE Hybrid	35' Low Floor	$ 567,927
New Flyer	Heavy Duty Coach, Allison Hybrid	40' Low Floor	$ 628,195
New Flyer	Heavy Duty Coach, BAE Hybrid	40' Low Floor	$ 572,927
New Flyer	Heavy Duty Coach, Allison Hybrid	60' Low Floor	$ 940,688
New Flyer	Heavy Duty Coach, BAE Hybrid	60' Low Floor	$ 865,452
New Flyer	Heavy Duty, En-Route Electric	40'	$ 785,000
Nova	Heavy Duty Coach, Allison Hybrid	40' Low Floor	$ 673,923
Nova	Heavy Duty Coach, BAE Hybrid	40' Low Floor	$ 676,604
Nova	Heavy Duty Coach, Allison Hybrid	60' Low Floor	$ 934,476
Nova	Heavy Duty Coach, BAE Hybrid	60' Low Floor	$ 920,764
Proterra	Heavy Duty, Plug in Electric	40'	$ 759,000
Proterra	Heavy Duty, En-Route Electric	40'	$ 779,000

Figure 14: Bus pricing and classification according to Washington State Department of Enterprise Services Master Contract, 2015

For the total cost of ownership (TCO) analysis among new 40-foot transit buses presented below, price estimates are based on the above Washington State data,[10] internal CALSTART data, earlier contract pricing documentation, and other studies that include maintenance and operational costs, and adjusted for HVIP when appropriate.[11] These prices are:

- Diesel - $425,000
- Diesel-Electric Hybrid - $605,000
- Electric - $680,000

---

[10] King County Metro; Washington State Department of Enterprise Services; California Air Resources Board, Advanced Clean Transit Program – Literature Review on Transit Bus Maintenance Cost.

[11] See **Section 6** below.

Available Diesel Hybrid Transit Buses

Diesel-electric hybrid buses are powered both by an internal combustion engine (ICE) as well as an electric drivetrain. The electric motor, powered by a battery or ultracapacitors (in some cases), provides extra propulsion that allows the ICE to be downscaled or used less frequently. Hybrids also capture energy from regenerative breaking that can later on be used for propulsion. The available battery storage can also be utilized to power other auxiliary loads and reduce engine idling that ultimately leads to better fuel economy. Manufacturers of hybrid buses include ElDorado National, Gillig, Motor Coach Industries (MCI), New Flyer, and Nova Bus; the majority of the hybrid electric drive systems for these vehicles are provided by Allison Transmissions, Inc. (parallel hybrid infrastructure) and BAE Systems (series hybrid infrastructure). Other suppliers in the hybrid space include Eaton, Lightning Hybrid, Voith, Vossloh Kiepe, and XL Hybrid.

OEM	Model/Type	Length
ElDorado National	Various	30'-40'
Gillig	Standard, BRT, Trolley	29'-40'
Lightning Hybrids	Buses and Shuttles	Various
Motor Coach International	Commuter	40'-45'
New Flyer	Various	35'-60'
Nova Bus	LFS HEV	40' & 60'

Figure 15: Available diesel-electric hybrid bus options in 2017

Available BEV Charging Options

Various charging options and power levels exist for charging buses either with a conductive (physical connector) or an inductive (electromagnetic field) charger.[12] BEV buses are charged mainly in two ways – either en-route (also known as opportunity charging), or overnight at a bus depot.

As several OEMs have developed their own chargers and connectors (couplers, overhead charging mechanisms, and wireless pads), standardization and interoperability has become a challenge. Examples of chargers are: Proterra Overhead Fast Charger (450kW), WAVE Wireless Charger (50-250kW), and BYD Depot Charger (100kW). Three separate SAE standard committees have been established with the goal to set standards that satisfy customers' needs and that OEMs can agree upon. The SAE standard committees are listed here below:

SAE J3105 (Overhead Fast Charging)
Electric Vehicle Power Transfer System Using a Mechanized Coupler: This standard covers physical, electrical, functional, testing and performance requirements for a high power mechanized conductive power transfer system that can transfer DC power. The standard committee is currently evaluating different charging power levels and designs. The voltage levels

[12] Chargers are also known as Electric Vehicle Service Equipment (EVSE) in situations where the charging mode is AC and the charger is located on the vehicle.

on the infrastructure side that are being evaluated are 250 – 1000VDC and a current level of (1) up to 600 Amps and (2) up to 1500 Amps. Consensus over what the interoperable standard should be has not yet been reached.

SAE J3068 (Depot Charging)

Electric Vehicle Power Transfer System Using a Three-phase Capable Coupler: This standard covers the physical, electrical, functional, testing and performance requirements for high power conductive power transfer that can utilize three-phase AC power. The standard committee is evaluating voltage levels up to 600 VAC. The figure here below lists currently used depot chargers that are not yet part of this standard.

OEM	Connector	Charging Mode	Power Level	Max Output Power	Compatibility
Complete Coach Works	Meltric	AC	480VAC 3 Phase	50kW	Meltric
BYD	IEC62196-2 "Type 2" IEC62196	AC AC	480VAC 3 Phase AC380V/400V/415V 3 Phase	2x30kW 2x100kW	Proprietary Proprietary
New Flyer	New Flyer - Proprietary	AC	480/600VAC 3 Phase	100kW	Proprietary
Proterra	SAE J1772 Combined Charging System	DC	480VAC 3 Phase	up to 100kW	SAE J1772 CCS

Figure 16: Various OEM Depot Chargers

SAE J2954 (Wireless Charging, predominantly en-route)

Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology**:** This standard defines and covers interoperability, electromagnetic compatibility, minimum performance, safety, and testing for wireless charging of electric vehicles. Standardizing the wireless power transfer through wireless charging allows for a convenient way to charge a vehicle by just parking it over the charging pad. The standard is designed for stationary applications when the vehicle is not in motion.

Bus Emissions Comparisons

Electric transit buses have no tailpipe emissions, making them the cleanest option for MST from the perspective only of mobile-source emissions.[13] Considering this reality, switching to electric buses offers MST an immediate and effective way to reduce the point-source transit-related emissions impact to the immediate region.

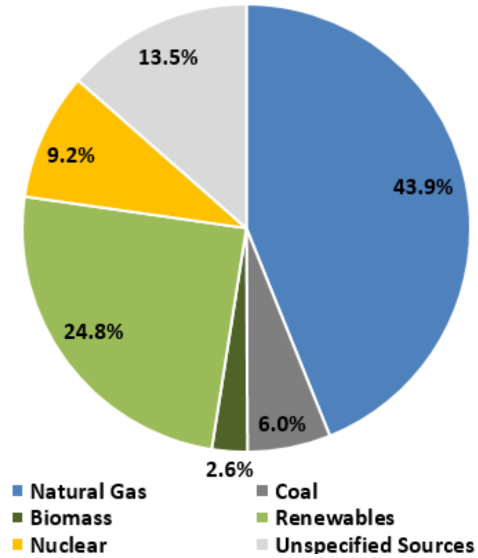


Figure 17: California electric grid generation by source

However, to the extent that MST is interested in the net impact of bus electrification to the entire California air shed[14], we look deeper at the "upstream" emissions of electric buses. To begin, the emissions profile of an electric bus depends greatly on the electricity consumption mix in the region where the vehicle operates. The electric grid in California is one of the cleanest in the country, meaning it is an excellent place to electrify a transit fleet from the perspective of air emissions mitigation. California's electricity consumption is 44% from natural gas and only 6% coal, with another 27% coming from renewables and almost 10% from nuclear. For the sake of comparison, the national electric grid is 33% coal with 27% from natural gas, 21% from nuclear, and 19% from renewables. Please see **Figures 17 and 18** for a comparison of these two grids.

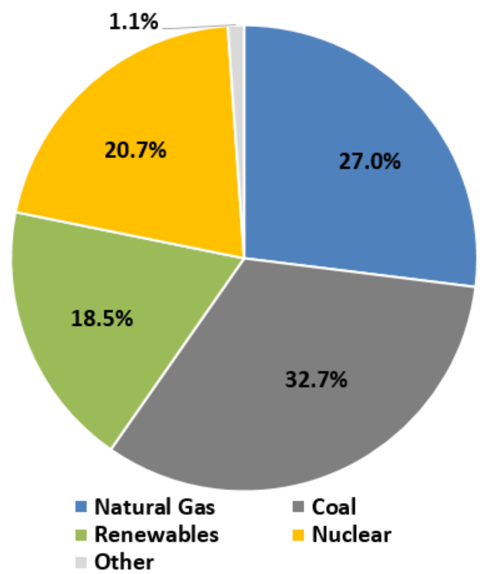


Figure 18: United States electric grid consumption by source

An emissions comparison between an electric and diesel or hybrid vehicle also depends greatly on the emissions reduction equipment installed on the vehicles, and therefore the model year of the vehicle. In the case of MST, a new electric transit bus is considerably cleaner than a 2002 Gillig diesel with respect to both criteria air emissions and GHGs, but the comparison to a 2017 diesel bus is a bit more complicated. See **Figures 19 and 20** below for a transit bus comparison between California state-wide and

[13] Electric buses, like diesel buses, do emit some particulate matter from brake and tire wear. This amount is generally low and can be seen in the complete MST emissions inventory found in **Appendix A**.
[14] It should be pointed out that California does not generate all the electricity that they consume. In fact, 34% of California's consumed electricity is imported from out of state, meaning that switching to electric vehicles in California has air emissions impacts to other parts of the country as well.

tailpipe air emissions from a 2002 diesel[15], 2007 diesel, 2017 diesel, 2017 diesel running B20, 2017 diesel running B100, 2017 diesel-electric hybrid, and 2017 BEV using California's grid power.[16] Both figures represent a "well-to-wheels" analysis, indicating that they represent a complete lifecycle analysis including emissions accounting for upstream fuel extraction and refining as well as downstream fuel combustion.

[15] All of MST's pre-2007 diesel vehicles (including transit buses and old-fashioned trolleys) are retrofitted with diesel particulate filter (DPF) technology that reduces both particulate matter (PM) and nitrogen oxides (NO_x) emissions. Therefore, for the purpose of this emissions comparison analysis, as well as MST's entire fleetwide air emissions inventory (found in **Appendix A)**, all pre-2007 buses are assumed to have 2007 levels of PM emissions, and all pre-2003 vehicles are assumed to have 2003 levels of NO_x emissions.

[16] All emissions data is calculated using the Argonne National Laboratory 2016 GREET Model. For the sake of this comparison, it is assumed that all buses travel 40,000 miles per year. The 2002 diesel bus gets 4.3 MPG (actual MST data), while the 2017 diesel bus is assumed to get 5 MPG. The hybrid bus is assumed to get 6 MPG and the electric bus is assumed to consume 2.2 kWh/mile.

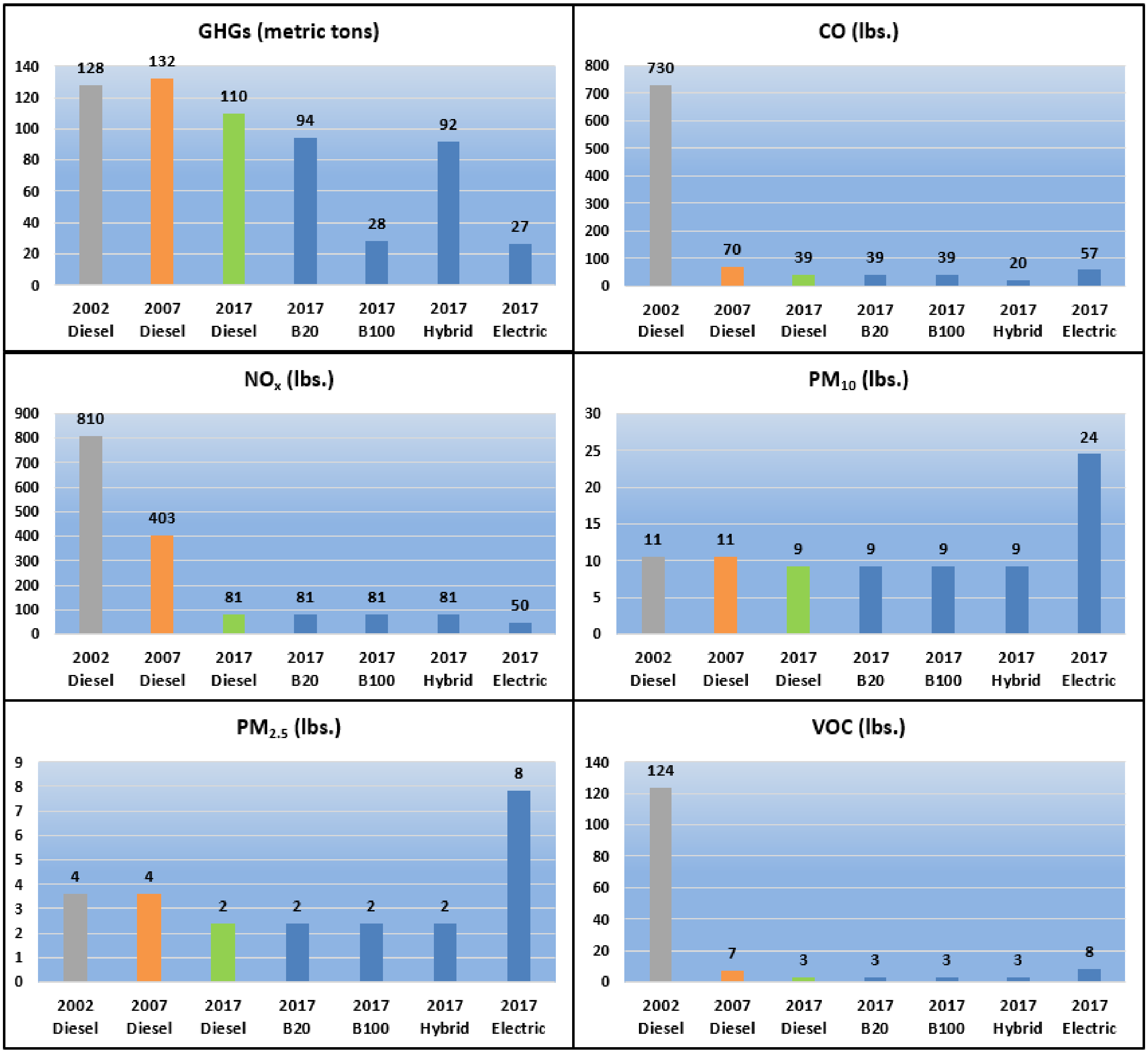


Figure 19: Complete California annual air shed emissions comparison for 2002 diesel[17], 2007 diesel, 2017 diesel, 2017 biodiesel (B20), 2017 biodiesel (B100), 2017 diesel-electric hybrid, & 2017 BEV buses

[17] Due to the installation by MST of DPF technology on all pre-2007 diesel transit buses (including trolleys), the 2002 diesel bus in this chart features 2003 levels of NO_x emissions and 2007 levels of PM emissions.

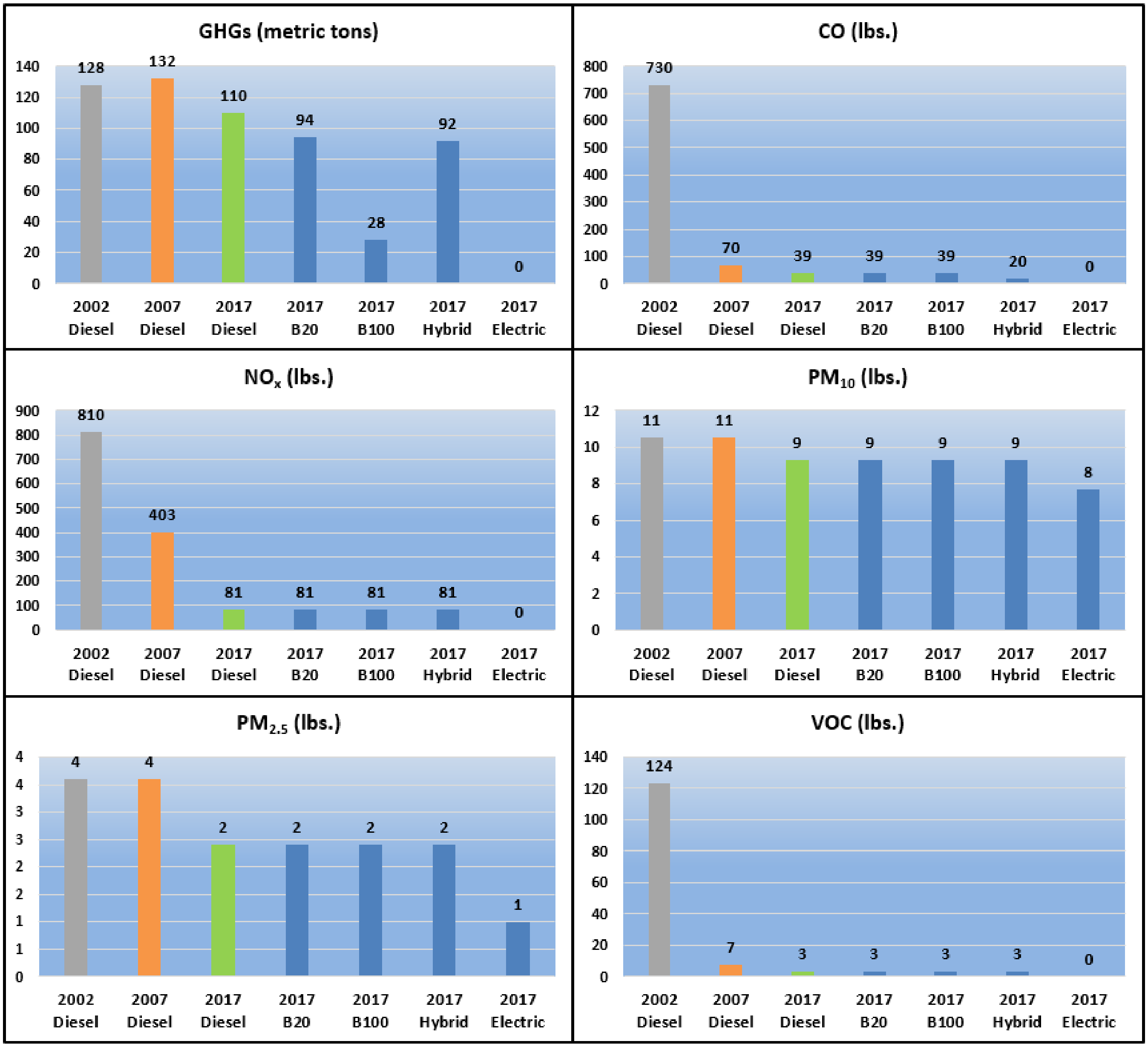


Figure 20: Mobile-source annual emissions comparison for 2002 diesel[18], 2007 diesel, 2017 diesel, 2017 biodiesel (B20), 2017 biodiesel (B100), 2017 diesel-electric hybrid, & 2017 BEV buses[19]

As can be seen in these figures, electrification is not always the best method of reducing particular types of public transit vehicle air emissions. On a state-wide air emissions level, for

---

[18] Due to the installation by MST of DPF technology on all pre-2007 diesel transit buses (including trolleys), the 2002 diesel bus in this chart features 2003 levels of NO_x emissions and 2007 levels of PM emissions.

[19] **Figures 19 and 20** feature emissions data that is "well-to-wheels" accounting for upstream fuel extraction and refining as well as downstream fuel combustion. The exception to this is the electric bus in **Figure 20**, which can feature no upstream component because it is measuring only tailpipe emissions.

GHGs and NO_x, bus electrification would be MST's most effective method of reducing these emissions. But in the case of CO, VOCs and both types of PM, the best method of reducing total state-wide emissions is to use the most current available diesel technology. However, it must be noted here that in 2000, the California Air Resources Board (CARB) adopted a Fleet Rule for Transit Agencies that requires larger transit agencies to purchase and demonstrate zero emission technology vehicles. The California Air Resources Board (CARB) is currently working on a new requirement called the Advanced Clean Transit (ACT) rule to further evaluate options for purchase requirements and phasing-in strategies that would mandate that all fleets become zero emission by 2040. Under these circumstances, diesel powered buses would not be an option.

The use of biodiesel fuel (in both B20 and B100 concentrations) in standard diesel engines is also an excellent way of reducing lifecycle GHG emissions. As far as engine-fuel compatibility goes, according to the National Biodiesel Board[20] (NBB - a nonprofit trade association representing the biodiesel industry), "most major engine companies have stated formally that the use of blends up to B20 will not void their parts and workmanship warranties."[21] However, there can be a challenge associated with procuring enough biodiesel fuel (particularly in higher concentrations like B100) to run an entire public transit bus fleet. In addition, biodiesel can be significantly more expensive than fossil diesel, particularly right now with historically low crude oil prices.[22]

Another alternative to biodiesel is renewable diesel (NEXDIESEL Renewable Diesel) that is manufactured by Neste and distributed by Golden Gate Petroleum in the state of California. Among its benefits, this renewable diesel meets the strictest quality standards set by OEMs and ASTM and can be used up to a concentration of 100% without negatively affecting the operation of the vehicle. Due to its high Cetane number (indicator of flammability), it also offers superior combustion properties compared to petroleum diesel or traditional biofuels.

Of course, all of the above emissions analysis equates the importance of emissions generated anywhere in the state of California (as well as parts of the U.S Northwest and Southwest from where California imports some of its electricity) with mobile-source emissions produced by vehicle tailpipes driving among communities in Monterey County. If MST only considers local tailpipe emissions, then vehicle electrification is by far the best method of reducing air emissions in Monterey County, as can be seen in **Figure 20** above which shows only mobile-source emissions. In this chart, we see that the only point-source air emissions that BEV buses emit are minimal tire and brake wear (TBW). They are responsible for no tailpipe emissions.

Bus Total Cost of Ownership (TCO) Comparisons

The benefits of battery-electric buses are many, including a reduction in GHG emissions and operational costs. However, there are various parameters and unique characteristics that need to

[20] The NBB website lists current biodiesel retailers and industry standards. ASTM International sets standards for biodiesel blends (ASTM D7467 for B6-B20; ASTM D6751 for B100). OEMs set their own specification for fuels that may be more stringent than the ASTM standards. Cummins Inc. and Detroit Diesel Corporation list information about the use of biodiesel in their engines.

[21] Port & Atkinson, 2006 page 53.

[22] Examples of biodiesel distributors in California are Valley Pacific Petroleum and Golden Gate Petroleum, North Star Biofuels, LLC and Western States Oil.

be considered before deploying BEV transit buses at large scale. The main challenge, from an operational perspective, is the limited range current BEV buses offer. Depending on the route characteristics, BEV buses might also need supplemental infrastructure, such as en-route fast charging equipment, to satisfy transit agency duty cycles. The upfront cost of the BEV bus and its supporting technology can be alleviated with funding strategies that include grants and incentives that will be discussed in the following section.

The total cost of ownership over 12 years for an electric bus compares reasonably well to conventional bus propulsion options available today. While being more capital intensive up front, due mostly to the high cost of on-board vehicle batteries, electric buses feature reduced operating expenses with lower expected maintenance and fuel costs. However, in addition to being cheaper than diesel on a per mile cost basis, electricity prices are also considerably more stable than diesel prices, allowing transit agencies, who generally cover fuel expenses out of their operating budgets, to plan for future fuel costs with more certainty. **Figure 21** below demonstrates the change in relevant bus fuel prices nationally from 2000 to 2016.

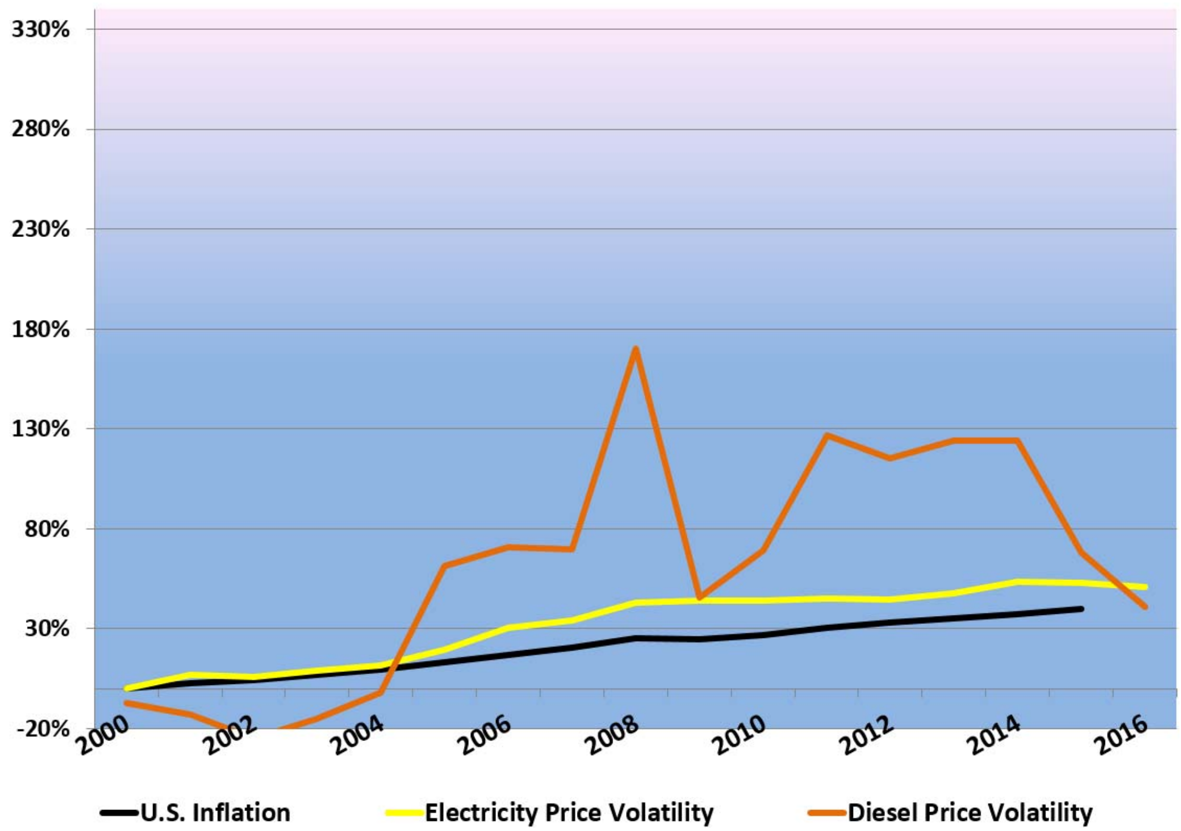


Figure 21: Fuel price volatility in the U.S. represented by total % price change 2000 - 2016

As can be seen above, electricity prices increase at roughly the rate of inflation. This is not a coincidence as electricity prices are almost entirely regulated by state governments, unlike diesel fuel prices which fluctuate according to world crude oil market forces.

For the TCO comparison among new 40-foot transit buses, some assumptions and scenario choices needed to be made. These are:

	Diesel	Hybrid	Electric
Fuel Efficiency	5.0 MPG	6.0 MPG	2.3 kWh/mile
Purchase Price	$425,000	$630,000	$680,000[23]
Fuel Price	$2.00/gal[24]	$2.00/gal	$0.20/kWh
Bus Maintenance Cost	$0.57/mile[25]	$0.78/mile[26]	$0.25/mile[27]
Fueling/Charging Infrastructure	Already Built	Already Built	En Route/Overhead (Fast): $375,000[28] En Route/Inductive: $375,000[29] Overnight/Depot: $40,000[30]
• 130 mile daily transit route with 10 miles of deadhead for a 140 mile daily total			
• Annual bus mileage of 51,135 miles			
• BEV bus comes with 12-year warranty with no required battery replacement			

Figure 22: Assumptions for TCO comparison between diesel, hybrid, and BEV 40-foot transit buses

The above scenario simulates a transit route that is short enough to be conducive to an electric bus (140 miles per day) but long enough to be realistic and add up to a substantial number of annual miles travelled (51,135 miles). See **Figure 23** for the TCO comparison of three new 40-foot transit bus models on the above route.

[23] For this TCO model, the price of a 40-foot hybrid bus has been adjusted downward $30k. The price of a BEV bus has been adjusted downward $95k. These adjustments are due to HVIP (see **Section 6** below). It should be pointed out that while there are already several BEV buses that have been approved for HVIP vouchers, there are currently no hybrid buses yet that have been approved for HVIP vouchers.

[24] Actual MST diesel fuel prices as of April 2017.

[25] Average actual MST maintenance cost per mile across all MST diesel transit buses.

[26] King County Metro, March 2017.

[27] California Air Resources Board, August 2016.

[28] Email communication with Proterra; excludes installation costs that can vary widely depending on site.

[29] Price is estimated and varies widely depending on volume and installation site.

[30] Includes charger and installation – California Air Resource Board, May 2015.

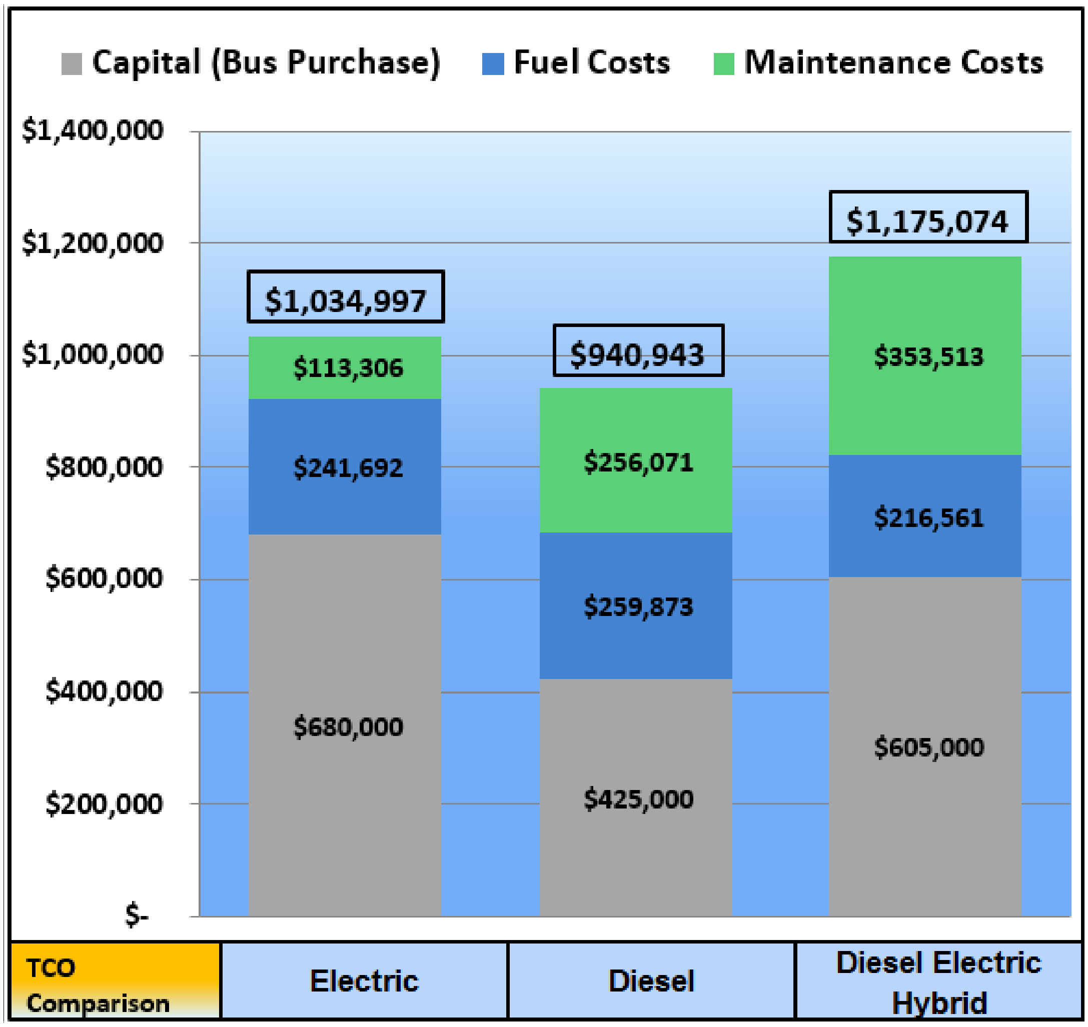


Figure 23: TCO 12-year service life comparison between electric, diesel, and hybrid buses

As can be seen above, electric transit buses are more expensive to purchase than their traditionally fueled counterparts, but are generally less expensive to operate with respect to fuel and maintenance costs.[31] In total, using input assumptions outlined above that are particular to MST, the diesel 12-year TCO is the lowest of the three bus options. The BEV bus option, while having lower overall fuel and maintenance costs than diesel, still ends up being about $95k more expensive than diesel over an entire bus life cycle. The diesel-electric hybrid bus is about $140k more expensive than the BEV option.

[31] The TCO analysis employed here does not include any charging/fueling infrastructure, nor does it include any potential electricity demand charges, given the uncertainty as to how they would be implemented or incurred by MST.

It should be noted, however, that we are currently enjoying the second lowest diesel prices in the last 10 years. Adjusting the model only to change the diesel fuel prices to $2.65 per gallon – what MST paid for diesel in 2008 (a particularly expensive time for diesel costs) – would increase the 12-year TCO for diesel and hybrid buses by almost $85k each, leaving the 12-year TCO for BEV roughly equivalent to that of diesel.

Electricity Cost for BEV Bus Operation

BEV buses are generally charged either through slow charging that takes place overnight at the bus depot, or through fast charging that can take place while the bus is in service (en-route/opportunity charging). The choice of charging method impacts the operational cost and total cost of ownership of the BEV bus due to varying electricity rates that depend on time of day and charging mechanism. Transit agencies pay per the commercial/non-residential rate schedules that typically include three fees: (1) Fixed Fees – fee for each electricity meter, for example; (2) Usage Fees – fee for each kWh consumed that is dependent on time of use (TOU); (3) Demand Charges – fee that is based on the maximum amount of electricity (in kW) that is drawn at a specific time.

Of the above-mentioned fees, the most challenging and unpredictable for transit authorities are the demand charges that can increase the electricity cost by multiple factors. Demand charges are usually metered in 15-minute intervals (i.e., the average kW used in a 15-minute interval) and based on the highest 15-minute average usage recorded on the demand meter within a specific month (i.e. the monthly price point for the transit agency is calculated based on the highest demand charge that occurs in any single 15-minute interval). **Figure 24** below illustrates the impact of high demand charges on the total fuel cost per mile.[32]

The California Air Resources Board has developed a Battery Electric Bus Charging Cost Calculator[33] to help transit authorities estimate the total cost of energy. Their modeling[34] has shown that a PG&E customer on average can expect to pay (1) $0.25/kWh for depot charging in a 5-hour period; (2) $0.17 for depot charging in a 10-hour period; and (3) $0.24 for en-route charging in a 10-min period.

---

[32] The blue color indicates fuel cost per mile for diesel and electricity. The orange color indicates total demand charges as cost per mile. It is assumed in the example that each bus drives 40,000 miles per year. The fuel economy of the diesel bus is 4 miles per gallon and the diesel is priced at $2.00 per gallon. The electric transit bus has an efficiency of 2.3 AC kWh/mile, the usage charge for electricity is $0.20/kWh, and the demand charge is $20/kW. One electric bus charging en-route draws on average 150kW (assuming that 450kW is drawn for 5 minutes during an interval of 15 minutes) from the grid, 4 draw on average 280kW (assuming that 450kW is drawn for a full 9 minutes and 20 seconds during an interval of 15 minutes), 6 draw on average 330kW and 8 draw on average 380kW, and the overnight charging is rated as 40kW. (Peak Demand Charges and Electric Transit Buses – CALSTART White Paper).

[33] See ARB's Battery Electric Bus Charging Cost Calculator at: https://www.arb.ca.gov/msprog/bus/rate_calc.xlsm

[34] 100% off-peak (80 kW charger); 100-bus fleet; 130 miles/day; 2.1 kWh/mile. Depot charge in 5-hour period means all buses charged at the same time during the billing period. Depot charge in 10-hour period means no more than 50% of buses charged at the same time at 4-5 hours per bus.

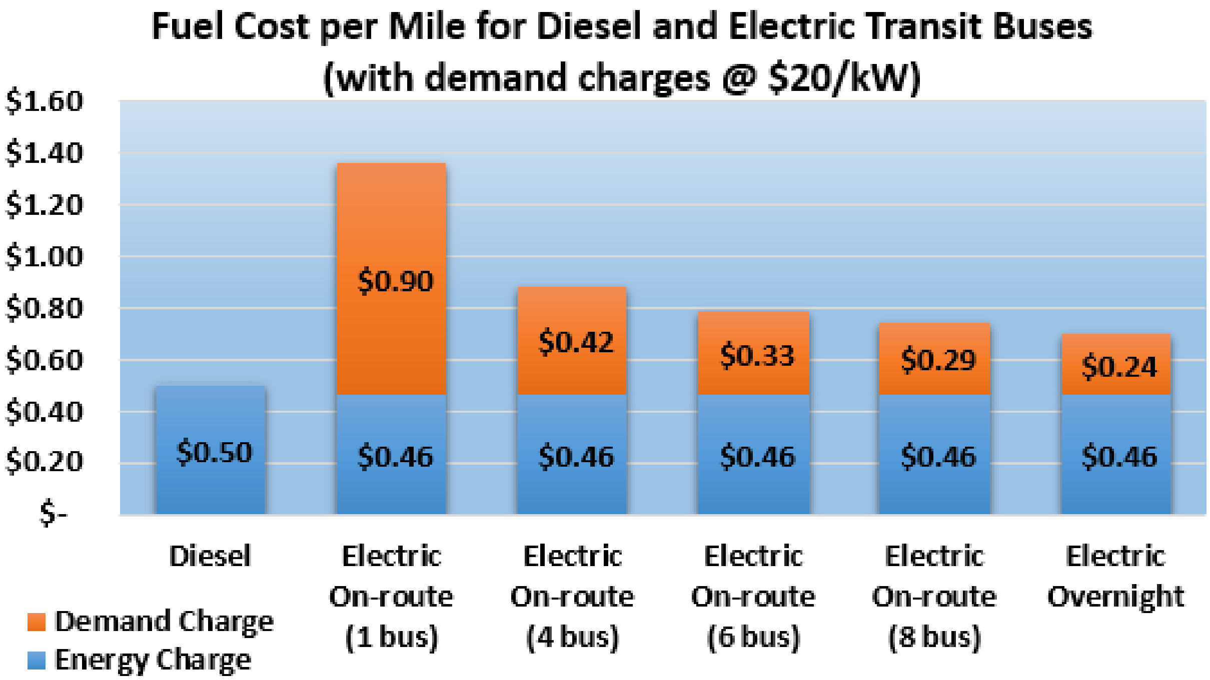


Figure 24: The potential impact of demand charges on per mile fuel expenses

Supporting Calculations:

Example – Electric en-route (1 bus):

Electricity consumption: **2.3 kWh/mile**
Electricity cost: **$0.20/kWh**
Total average demand in a 15-minute interval: **150kW**
Demand charge: **$20/kW**
Total mileage: **40,000 miles**

Total demand charge for a year = 150kW x $20/kW = $36,000

Electricity cost per mile = 2.3kWh/mile x $0.20/kWh = **$0.46/mile**

Total demand charge for year = $36,000 / 40,000 miles = **$0.90/mile**

Electric Bus Projected Range

As mentioned above, this analysis does not tackle the issue of projected electric bus driving range in detail. The research and analysis that has been done on this topic already has suggested that OEM-stated ranges should be treated with skepticism. For example, *average* bus range data may be useful for public transit agencies, but a far more useful figure is *reliable* range, or range that a user can depend on achieving every day (rather than on an "average" day). For the purpose of this analysis, we present **Figure 25** below which projects bus range based on the following simple formula[35]:

$$\text{Projected Bus Range} = \left(\text{Battery Size} \times \text{90\% Charge Buffer}\right) / \text{Projected Consumption (kWh/mile)}$$

40-Foot BEV Bus Model	Battery Size (kWh)	Consumption (kWh/mile)	Expected Daily Range (miles)
BYD	324	1.8-2.5	117-162
Proterra (slow-charge)	330	1.8-2.5	119-165
New Flyer	300	1.8-2.5	108-150
GreenPower	320	1.8-2.5	115-160
Complete Coach Works	375	1.8-2.5	135-188

Figure 25: Expected daily driving range for currently available 40-foot BEV transit buses

In the above figure, a range of expected battery consumption for 40-foot BEV buses is given at 1.8 kwh/mile – 2.5 kwh/mile.[36] This results in a range of projected driving ranges for the above listed buses. As can be seen, these ranges differ slightly between bus models, and will differ even more for the models that offer significantly larger battery sizes as an option (like Proterra). Several of these OEMs (as can be seen above in **Figure 13**), offer smaller-battery fast-charge models. These buses have smaller battery storage because it is expected that they charge while en-route, and therefore require smaller batteries. However, these buses do require additional and potentially expensive charging infrastructure compared to slow-charge models.

There are several factors that affect a BEV's energy consumption, and therefore affect driving range. These include:

[35] In this analysis "charge buffer" specifies the depth of discharge that a battery should be drawn down. In this case, the remaining 10% of battery life is not used; this is generally done to preserve battery longevity.

[36] Battery consumption (kWh/mile) is another topic studied extensively that we will not discuss at length in this analysis. The projected range of consumption for a 40-foot BEV bus of 1.8 kWh/mile to 2.5 kWh/mile comes from a combination of Altoona results (The Federal Transit Administration (FTA) reports ranges for new model BEV buses they test by measuring the kWh/mile consumption for three different simulated transit type service cycles/test phases (Central Business, Arterial, and Commuter)), academic articles, OEM claims, and experiences of the authors in their own electric bus tests. Furthermore, this projected battery consumption is for a 40-foot bus only. This consumption would need to be adjusted downward or upward if MST were to conduct similar range analysis for shorter or longer buses.

Driver Characteristics: Drivers of transit buses are generally accustomed to operating traditionally fueled buses, which have large gas tanks and significantly longer daily driving range than BEV buses. For this reason, they have not learned to rely on conservative driving techniques that could extend the range of BEVs. These techniques include slower, smoother accelerating, using regenerative braking (whenever possible), and strategically using auxiliary loads (such as HVAC). An intentional shift in driver training and behavior could yield significant benefits for transit operators switching to BEV buses.

Auxiliary Loads: Due to limited battery storage, conservative and intelligent use of auxiliary loads on BEV buses is much more important than on ICE vehicles. For example, HVAC use on a cold or hot day results in a significantly lower driving range with a BEV bus than if the bus were operated on a temperate day with no heating or cooling requirements. Other auxiliary loads that draw battery power and therefore impact driving range include internal and external lighting and vehicle communications.

Passenger Load/Vehicle Weight: Buses that carry high passenger loads generally see increased battery energy consumption, and therefore diminished range. For this reason, BEV bus manufacturers generally invest more money into decreasing vehicle weight than do traditional bus manufacturers.

Route Characteristics: Hilly routes draw more battery energy than flat routes, therefore resulting in decreased vehicle driving range. In addition, routes that require constantly variable speeds and more stops reduce vehicle driving range compared to routes with more steady driving speeds and less stops. This is generally why routes served by coach buses see better fuel/battery efficiency than city transit routes, despite the fact that coach buses are generally larger and heavier than transit buses.

As can be seen in the analysis in **Figure 25**, and as is demonstrated above in **Figure 12**, currently available BEV transit buses feature driving range that is sufficient to serve some, but not all of MST's existing duty cycles as they currently exist.

Section 6

Vehicle Financing and Incentives

Incentive Funding for Alternative Vehicles

The Hybrid and Zero Emission Truck and Bus Voucher Project (HVIP)[37] was launched in 2009 to accelerate the purchase of cleaner, more efficient trucks and buses in California. For CA transit authorities, this project provides incentives for purchasing zero-emission, hybrid, and low-NOx natural gas buses. The project addresses the higher cost of alternative fuel buses and supports CA's commitment to cut petroleum usage. HVIP works directly with bus dealers to provide point-of-sale price reductions to purchasers. The available voucher amounts are dependent on the gross vehicle weight rating and can be up to $95,000 (BEV bus/zero-emission) and $30,000 (hybrid) per bus. Buses deployed in disadvantaged communities are eligible for an additional rebate of up to $15,000. Voucher enhancements of up to $20,000 per bus are available for fast-charge capable buses. OEMs offering extended vehicle and component warranties can apply for extended warranty voucher enhancements that can result in up to an additional $6,000 voucher.

Bus OEM	Model	Length	HVIP Voucher
BYD	C6 23-Ft Zero-Emission Electric Coach	23'	$80,000
	K7M 30-Ft All Electric Zero-Emission Transit Bus	30'	$95,000
	35-Ft Zero-Emission Transit Bus	35'	$101,000
	K9M & K9S 40-Ft All Electric Zero-Emission Transit Bus	40'	$95,000
	C10M 45-Ft Articulated All Electric Coach	45'	$95,000
	K11M 60-Ft Articulated All Electric Transit Bus	60'	$95,000
GreenPower	EV350 40-Foot All Electric Bus	40'	$95,000
	EV550 40-Foot All Electric Double Decker Bus	40'	$95,000
Motiv	All-Electric Powertrain for Ford E450 - Shuttle Bus	30'	$80,000
	All-Electric Powertrain for Ford F59 - Shuttle Bus		$95,000
New Flyer	Xcelsior Bus with Lithium-Ion Battery Pack	35'	$117,000
	Xcelsior Bus with Lithium-Ion Battery Pack	40'	$117,000
Phoenix	ZEUS 300 Shuttle Bus	30'	$80,000
Proterra	Catalyst 35-foot Urban Transit Bus	35'	$95,000
	Catalyst 40-foot Urban Transit Bus	40'	$95,000
	Catalyst 40-foot Urban Transit Bus (Extended Range)	40'	$95,000
	Catalyst 40-foot Urban Transit Bus (Fast Charge)	40'	$115,000
	Catalyst 35-foot Urban Transit Bus (Extended Range)	35'	$95,000
	Catalyst 35-foot Urban Transit Bus (Fast Charge)	35'	$115,000
Zenith Motors	Electric Shuttle Van	24'	$50,000

Figure 26: HVIP's vehicle eligibility list

[37] HVIP is administered and implemented through a partnership between California Air Resources Board (CARB) and CALSTART. CARB has sole discretion to determine eligibility for HVIP funding.

Transit agencies that operate BEV buses and own charging stations that are sub-metered are eligible to generate Low Carbon Fuel Standard (LCFS) credits that they can later sell and trade in the California LCFS market. The market is active and the price of the credits will fluctuate over time.[38] Each credit represents one metric ton of reductions in GHGs. The focus of the LCFS regulation is to reduce the overall GHG emissions of transportation fuels in California. A Carbon Intensity (CI) score that is based on a lifecycle assessment (i.e. total GHG from production, transportation, distribution, and use) is given to each transportation fuel under this regulation.

	Representative Carbon Intensity **(CI) (gCO2e/MJ)**	Energy Economy Ratio for Transit Buses	LCFS Credit Revenue in 2016	LCFS Credit Revenue in 2020
Electricity (Grid)	105	4.2	$0.11/kWh	$0.10/kWh
Electricity (Solar)	0	4.2	$0.15/kWh	$0.14/kWh

Figure 27: LCFS credit revenue from electricity 2016-2020 at a credit price of $100/MT

Supporting Calculations/Example:

Vehicle: 40’ BEV Bus
Electricity consumption: 2.3kWh/mile
Total mileage: 40,000 miles

A bus operating 40,000 miles per year and averaging 2.3kWh per mile will consume a total of 92,000kWh. At a LCFS credit value that is equivalent to $0.11/kWh, the total proceeds per bus would be: **$10,120.**

When both HVIP funding and proceeds from LCFS credits are utilized, the total cost of ownership for zero emission buses is significantly improved. It is recommended that MST apply for both of these incentives.

Battery Leasing vs. Ownership

The most significant cost component for BEV buses are the batteries that are used for energy storage. To help reduce the high incremental cost of BEV buses, some OEMs[39] are offering battery lease programs as a financing option. The benefit of a lease program is that the BEV bus can often be acquired with the same cost as a conventional diesel bus, while the leasing fees for the battery can be recorded as operational costs and taken from the operational budget in the same way as diesel fuel costs, for example. A lease program also removes some of the risks from the transit authority and transfers them to the OEM that is responsible for the performance and the warranty of the battery. The FTA has confirmed that federal funds can be used for battery

[38] CARB discussion document – How LCFS Credits Change Over Time.

[39] BYD & Proterra.

leases.[40] Various federally supported financing mechanisms for public transportation are available such as: capital leasing, revenue bonds, debt service reserve, public-private partnerships, the Transportation Infrastructure Finance and Innovation Act (TIFIA), and state infrastructure banks.[41]

BEV batteries are especially well suited to be leased as they potentially need to be replaced, depending on their lifecycle, which renders a certain flexibility desirable (i.e. battery technology is still rapidly evolving and no current BEV buses have been in actual operation for their entire lifetime; costs are projected to decrease as technology is maturing). While batteries have a warranty, leasing them removes any additional maintenance costs associated with their performance that otherwise would be levied on the transit operator. An additional direct benefit with leasing is that there are no upfront sales tax payments, as well as no disposal processes that the transit agency must directly undertake once the batteries are not performing and have reached their end of service life. However, cons associated with leasing include (1) a higher cost paid over time due to financing charges and ancillary costs, and (2) the transit agency does not have any equity in the battery. In addition, the transit operators are solely reliant on the OEM to respond and maintain the batteries when needed.

For planning purposes, the transit agency should have a clear understanding of the lease term, associated payments and other costs, and types of maintenance and service that are included (if any). Further analysis of specific routes that would utilize BEV buses with leased batteries is also warranted to understand what the specific benefits of leasing vs. buying could be.

Traditional lease structures[42] that can apply for battery lease situations are listed here below. The following criteria, among others, should be further evaluated as they impact the lease classification: transfer of ownership, purchase option, economic life, and asset value.

- **Financial/Capital Lease**: Some of the ownership risk and benefits are transferred to the lessee. Traditionally no maintenance services are included in this type of lease. The finance/capital lease is usually fully amortized (i.e. the lease payments cover the entire equipment cost). A bank or leasing company is usually the party who buys the equipment that is then leased to the lessee. Cancellation is typically more challenging as the bank or leasing company must be fully paid off before the lease can be cancelled. From an accounting perspective, a lease is considered a capital lease when the lease terms equal or exceeds 75 percent of the asset's useful life and/or when the present value of the lease payments equals or exceeds 90 percent of the total cost of the asset.

- **Operating Lease**: No ownership is assumed by the lessee under an operating lease and the lease can generally be cancelled if needed before the lease term ends. The right to operate the equipment is transferred to the lessee and the equipment is returned at the end of the lease to the lessor. Operating leases include both financing and maintenance

[40] California Air Resources Board – Advanced Clean Transit Regulation, Discussion Draft, 2015.

[41] Federal Transit Administration – Options for Financing Public Transportation in the United States.

[42] Conditions and accounting rules for leases dependent on lease classification.

services and the associated costs for these are built into the lease payments. Operating leases are traditionally not fully amortized (i.e. operating/service lease payments do not fully cover the entire equipment cost) and are consequently not offered for the full expected life of the equipment. When a lease is classified as an operating lease, the lease payments can be covered as operating expenses. From an accounting perspective, the lease can be classified as an operating lease when the lease term is less than 75 percent of the asset's useful life and/or when the present value of the lease payments is less than 90 percent of the total cost of the asset.

A net present value analysis[43] in the figure below shows that the buy option is more cost competitive overall than the lease option. In this analysis a discount rate of 7% has been used to demonstrate the impact of the time value of money. It has further been assumed that the battery lease program cost will decrease at year 6 (the midpoint of the lease) as battery prices continue to decline. The analysis has been done for a period of 12 years that is aligned with the full life of a bus.

As the buy option can generally be more cost competitive from a net present value analysis perspective, it is noteworthy that the main advantage a transit authority has when leasing batteries is that it can utilize some of the available grants to cover these operational/lease costs and thus deploy more buses as the upfront capital expenses are lower. Depending on the OEM, several innovative funding structures might be available to help transit agencies deploy larger quantities of BEV buses. One scenario could be to use 5307 and/or 5339 Urbanized Area Formula Grants for the initial base BEV bus model that does not include the battery packs and then lease the batteries through a lease program/Battery Service Agreement with set monthly/annual installments and fund the lease with Low-No funds.

General Assumptions		
BEV Bus Cost	$	750,000
BEV Bus w/o Battery Cost	$	500,000
Battery Cost	$	250,000
Term (Service Life)	12 years	
Market Value at End of Term	$	-
Discount Rate	7%	

43 For the cash flow analysis for the buy option no tax savings or write down allowances/depreciation expenses have been taken into account, as it is assumed that a transit authority is not able to take advantage of these. Also, no residual value is assumed, and the disposition costs of old batteries have not been accounted for. In a similar way, for the cash flow analysis for the lease option, no tax savings for the battery lease payments have been incorporated in the calculations. Also, special equipment, chargers, and charger installation costs have not been included in the net present analysis model as these are the same for both buy and lease options.

Lease Option		
Lease Payments (years 0 to 6)	$	40,000
Lease Payments (years 7 forward)	$	35,000
Total Payments	$	(990,000)
Net Present Value	**$**	**(841,826)**

Buy Option		
Battery Replacement (midlife, year 6)	$	(75,000)
Total Payments	$	(825,000)
Net Present Value	**$**	**(799,976)**

Figure 28: Battery lease-buy analysis

The following are excerpts from the Low or No Emission (Low-No) Program FY 2017 Notice of Funding Opportunity Announcement that support leasing:

- *Page 19448; Eligibility Information – 2. Cost Charing and Matching: "the maximum Federal participation in the costs of leasing or acquiring a transit bus financed under the Low-No Program is 85 percent of the total transit bus cost"*
- *Page 19448; Eligibility Information – 3. Eligible Projects: "Purchasing or leasing low or no emission buses", "acquiring low or no emission buses with a leased power source"*
- *Page 19451; Application Review – iv. Local Financial Commitment: "Applicants must identify the source of the local cost share and describe whether such funds are currently available for the project or will need to be secured if the project is selected for funding. FTA will consider the availability of the local cost share as evidence of local financial commitment to the project."; "In addition, an applicant may propose a local cost share that is greater than the minimum requirement or provide documentation of previous local investments in the project, which cannot be used to satisfy local matching requirements, as evidence of local financial commitment."; "FTA will also note if an applicant proposes to use grant funds only for the incremental cost of new technologies over the cost of replacing vehicles with standard propulsion technologies."*

In addition to the FTA Lo-Now program, leasing is also supported thorough the HVIP program:

- *Page 38; 5. Battery Leasing: "Arrangements in which a vehicle, with the exception of the battery, is purchased and the battery is leased to the vehicle purchaser may be allowed by the CARB Project Liaison on a case-by-case basis if the battery lease term is a minimum of three years."*

The 5307 Urbanized Area Formula Grants also support leasing of capital assets as long as the applicant can prove that it is more cost effective. Battery lease expenses can be covered up to 80% by 5307 funds.

Section 7

Recommendations

It is indeed an exciting time to be contemplating and implementing alternative bus technologies for public transit agencies that are interested in decreasing their air emissions inventory and reducing or eliminating their dependence on fossil fuels. It is also important to observe that imminent and likely regulatory restrictions will further encourage or require public transit agencies, particularly those in the State of California, to make these critical updates to their bus fleets. With these factors in mind, our recommendations to MST are the following.

Next Steps for Implementing Zero-Emission Vehicles

MST should immediately begin the planning process for purchasing and integrating full-sized BEV transit buses into their fleet. There are a number of factors that support this conclusion.

1. MST will increasingly be bound by CA regulatory standards to purchase and implement zero-emission vehicles. Given the holistic nature of integrating new technology into a vehicle fleet including maintenance requirements, driver training, and customer/stakeholder awareness, MST would benefit from as much advanced experience using zero-emissions technology as possible. Given the stated preferences of MST, fuel cell bus technology was not considered or reviewed for this analysis. Diesel-electric hybrids, while an improvement over diesel buses with respect both to emissions and fuel efficiency, will not serve to satisfy CA regulatory requirements regarding zero-emission vehicles. For these reasons, MST should choose to implement BEV buses.

2. In addition to being historically much less consistent and reliable than electricity prices, fossil fuel prices are likely to eventually increase based on historical data. Considering most public transit agencies, including MST, rely on their operating budget to cover fuel and maintenance costs, a switch to BEV buses could yield significantly lower operating expenses for the future.

3. Given the increased awareness of air emissions reduction and fuel efficiency concerns in the State of California, there currently exists an excellent zero-emissions purchasing incentive structure. However, due to the inherent uncertainty of future political support for zero emissions vehicles, as well as the likely evolution and maturity of the zero-emission bus market, these incentives may not be permanent. For this reason, MST should avail itself of HVIP and LCFS incentives before zero-emission buses become a *requirement* for CA transit agencies, rather than just an *option*. Now is the time for this transition to BEV bus use to begin.

It is important to point out that the above recommendation for near-term implementation of BEV transit buses is for full-sized (30, 35, or 40 foot) transit buses. At this time, BEV options for paratransit/on-demand services (smaller cutaway buses) and commuter services (over-the-road coach buses) are not quite ready for widespread implementation due either to limited available options or insufficient vehicle range.

Depot Charging Infrastructure

Regardless of the choices made to potentially implement en-route charging infrastructure, MST will need to install depot charging infrastructure on MST property to charge BEV buses overnight and potentially during the day between bus block service. This infrastructure should be installed in places where the BEV buses will be stored when not in use. It is the authors' understanding that MST has already committed to installing charging infrastructure to accommodate the charging of nine BEV buses simultaneously at its Monterey Peninsula bus garage, as well as charging infrastructure for two BEV buses at the Salinas bus yard. This is an excellent start.

When contemplating the need for further charging infrastructure installation, it is first critical to consider charging methodology. For example, one option requires charging infrastructure to be installed for each BEV bus. In this model, a bus would be connected after its daily duty cycle and disconnected only when the vehicle would be required in service again (likely the next morning). However, considering the improved speed with which today's BEV buses charge, an alternative method would be to install significantly less charging infrastructure and rotate charging among buses as they complete their charging. This method would likely require human input to physically move charge cables between buses, and possibly require the moving of buses during charge rotation as well. The lowest cost methodology (and therefore the best option) depends on the costs of the particular charging infrastructure selected as well as potential labor requirements involved. This tradeoff has not been studied in depth for this analysis.

MST currently owns and operates more than 80 vehicles that are potentially appropriate for replacement with BEV buses (diesel low-floor transit buses and diesel trolleys). Given this, and regardless of the charging methodology chosen by MST (depot vs. en-route), consideration should be made for installing significantly more depot charging than what MST is currently planning. This installation process could and should closely follow the phasing plan for BEV bus purchases pursued by MST.

Guidance on Beneficial Electrical Rate Structures with Local Utilities

In January 2017, the investor owned utilities (IOUs) filed applications with the California Public Utilities Commission (CPUC) that outline how they will meet the transportation electrification requirements as they are set by California Senate Bill (SB) 350. In these proposals, the IOUs must show how they intend to accelerate transportation electrification while minimizing the costs and maximizing the benefits. The three main IOUs (SDG&E, SCE and PG&E) requested collectively that $1 billion is invested (rate-based/publicly funded) in a portfolio of projects. The projects are designed to address general barriers to widespread transportation electrification, such as the upfront costs of charging infrastructure, vehicle operating costs, access to charging, and lack of awareness and understanding.

The share that PG&E is requesting to invest over a five-year period is $253M divided between three initiatives: FleetReady, Fast Charge and Priority Review projects. Of special interest for MST is the FleetReady program, which will focus on supporting make-ready infrastructure (utility T&D, utility meter, panel, and conduit) installations for non-light-duty fleets. Under this program, additional incentives will be available for disadvantaged communities, schools and transit buses as well. The program will demonstrate how utility assistance can lead to lower cost of ownership for customers that undergo fleet electrification. However, it is estimated that the procedural application reviews will take over a year and that funding for projects that address demand charges and infrastructure development will not take place for some time. It is furthermore unlikely that significant changes to the existing rate structure will be implemented in the short term.

Regarding rate structures, PG&E has several schedules that are dependent on the customer's maximum power demand. The following schedules/tariff numbers are available: PGE A-10 (maximum demand of 75-500kW); PGE E-19 (maximum demand of 500-1000kW); and PGE E-20 (maximum demand of over 1000kW). If MST were to electrify its entire fleet, it would most likely fall under the PGE E-20 schedule. A data modeling analysis is recommended to better understand what PGE schedules would apply to MST in a specific scenario of BEV bus deployment. Current and proposed demand charges are dependent on the specific tariff numbers.

<u>The current Time of Use (TOU) periods are defined as follows:</u>

SUMMER (service from May through October):

- Peak: 12:00 noon to 6:00 p.m., Monday through Friday (except holidays).
- Partial-peak: 8:30 a.m. to 12:00 noon, Monday through Friday (except holidays); AND 6:00 p.m. to 9:30 p.m.

WINTER (service from November through April):

- Partial-peak: 8:30 a.m. to 9:30 p.m., Monday through Friday (except holidays).
- All year weekends and holidays are off-peak

<u>The proposed TOU periods are defined as follows:</u>

SUMMER (Service from June through September):

- Peak: 5:00 pm to 10 pm, all days
- Part-peak: 3:00pm to 5:00pm, 10:00pm to midnight, all days

WINTER (Service from October through May):

- Peak: 5:00pm-10:00pm, all days
- Super-off-peak: March/April/May, all days, 10-3pm

Purchasing vs. Leasing Bus Batteries

The main advantage with battery lease financing programs is that MST can deploy more BEV buses initially with the same overall grant funding amount, as funding that has traditionally been used for capital expenses can now be dedicated to operational expenses. By leveraging federal and state/local funding sources, more buses can be deployed with a lower Low-No amount, for example. FTA Low-No, Urbanized Area Formula Grants, and HVIP incentives all support leasing arrangements. Moreover, depending on the overall battery warranty that is offered, leasing programs can alleviate the transit authority of some of the risk associated with battery performance and midlife battery replacement costs.

It is recommended that MST utilizes available battery leasing programs and structures grant financing in a way that allows more buses to be deployed. As mentioned in earlier sections, this could be achieved by using 5307 and/or 5339 funding for the basic bus cost, and then using Low-No funds for operational expenses/battery lease payments.

Viability of Expansion of Use of En-Route Charging Technology

As discussed elsewhere in this report, MST already has experience installing and operating en-route charging infrastructure (wireless) thanks in large part to an FTA Clean Fuels grant. This infrastructure has been successful in extending the daily range of the electric retrofitted vehicle serving the MST Trolley Monterey route along the waterfront. In addition to the possibility of extending MST's wireless charging infrastructure, MST could also select overhead conductive charging infrastructure from Proterra (proprietary), New Flyer (proprietary) as well as other additional OEMs that are participating actively in developing an interoperable overhead charging standard (ABB, F+F Opbrid, Gillig, Nova, Schunk, Siemens, TransTech and others). However, given that the transit station in downtown Monterey is in an historic district and is not owned by MST, local design guidelines should be consulted regarding permitting of overhead conductive charging infrastructure.

MST's existing investment in wireless en-route charging infrastructure, while currently only used to charge MST's BEV trolley, could be leveraged to charge BEV buses on other MST routes. There are currently 25 MST routes that use the Monterey Transit Plaza's Gates 2, 3, or 4, which are located immediately adjacent to the WAVE wireless charger at Gate 5 on the corner of Tyler and Pearl Streets. Of these 25 routes, 9 use full-sized transit buses operated by MST to service the route and are therefore appropriate to consider for use of the existing wireless charger. These routes are 2, 55, 69, and 78 at Gate 3 (Pearl), and 10, 12, 20, 56, and 78 at Gate 4 (Tyler). More research would be needed to determine the amount of wireless charging time that would be required to accommodate BEV buses for these routes, as well as logistics as to how to share the charger with the existing electric trolley.

However, despite the relative success of the wireless charger project to date, and for the reasons outlined below, the authors of this report recommend that MST does not further invest in additional en-route charging infrastructure for BEV bus charging at this time, but rather rely on depot conductive charging infrastructure.

1. Conductive depot charging infrastructure is significantly **cheaper** than both wireless and conductive en-route charging equipment. This is due both to lower cost of the charging equipment itself, but also due to considerably lower construction and installation costs. Depot charging infrastructure is also **more reliable** and **cheaper** to maintain than more complex en-route charging infrastructure.

2. Due to the ongoing standardization efforts of the Society of Automotive Engineers (SAE), the use of depot charging infrastructure is more flexible across BEV OEM equipment than is proprietary en-route charging infrastructure. For example, a Proterra overhead charger costs in the neighborhood of $650,000 and works only with Proterra buses. However, the use of depot charging infrastructure allows transit agencies to potentially use the same chargers across their entire BEV bus fleet, regardless of OEM.[44] In addition to more OEM flexibility, depot chargers are located where all BEV buses return after their duty cycle, allowing for the buses to have more flexibility as to the routes that they serve. En-route infrastructure, by definition, is installed in a fixed location on a particular route, limiting the options for where a transit agency can utilize their BEV buses.
3. It is acknowledged by the industry that en-route charging infrastructure is more expensive than depot chargers. However, the conventional wisdom is that strategically located en-route infrastructure is capable of extending BEV bus range to allow the vehicles to be used on routes where depot charged vehicles could not serve. While this is true to a degree, on-board BEV battery storage is getting increasingly **cheaper**, **lighter**, and **more energy dense**. These technology improvements are allowing BEV buses to carry more on-board energy, and therefore serve longer and longer daily duty cycles with only their on-board battery storage. Coupled with the intelligent use of depot charging (perhaps between bus block service), as well as selective redesign of existing transit routes, BEV buses will only become more capable of servicing longer daily duty cycles over time.

If needed, MST can always invest in en-route charging infrastructure down the road. But considering the pace of improvement of on-board battery technology, as well as the likely pace of adoption of BEV buses that will be undertaken by MST, it makes more sense to wait on further investment in en-route charging infrastructure.

Phasing Plan

As discussed above, CARB has proposed implementing the Advanced Clean Transit (ACT) regulation, which seeks to transition all public transit bus fleets to zero-emissions technology by 2040. Given an expected 12-year service life for FTA-funded transit vehicles, the implementation of ACT implies that all transit buses purchased by CA public transit agencies after 2028 must feature zero-emissions technology. Indeed, the timing of the regulation was designed such that transit agencies would be able to only purchase zero-emissions buses when naturally replacing their existing buses at the end of their service lives. In order to transition intelligently, the authors of this report recommend the following phasing plan for MST:

Natural Attrition:

MST operates 41 diesel transit buses (including one trolley) that are model-year 2003 or older and therefore subject to immediate retirement and replacement. In addition to these vehicles, MST also operates 15 diesel transit buses from model years 2007-2008, meaning they will be eligible for retirement within the next three years. At the time of this report, 25 new diesel vehicles are on order and expected for delivery in spring-to-summer 2018, and another 6 to 7 diesel buses will be

[44] SAE is approaching a standard for OEM BEV bus charging cables but is not quite there yet.

ordered in late 2017 for delivery in 2019. Even with these procurements, a large number of diesel buses will still need replacing in the coming years. MST therefore has a number of available options with respect to the timing of retiring older diesel buses and replacing them with buses that will be ACT compliant. Considering that all transit vehicles in California purchased after 2028 (only 11 years from now) must be ACT compliant, MST would be wise to begin the process of converting its fleet with at least a modest number of the replacements that are due either immediately or in the next three years (more than half MST's transit bus fleet). For example, with 74 full-sized diesel transit buses in the current fleet and a 2040 deadline to convert the entire fleet, MST should be averaging 3-4 zero-emissions replacements per year (this is assuming the MST transit bus fleet stays the same size). At the time of this report, MST has one electric trolley bus in operation and 2 BEV BYD buses on order for delivery in late 2017, which is a great start.

MST's Blocks/Duty Cycles Today:

As discussed in more detail above, a considerable number of MST's public transit diesel buses serve daily duty cycles of less than 140 miles, and therefore are excellent candidates to be operated with BEV buses. For example, of the 16 daily duty cycles served by MST's 40' Gillig diesels, seven are excellent candidates for operation with BEV buses. A similar point can be made looking at MST's 35' Gillig diesel buses that serve at least eight daily duty cycles that could be immediately served using today's available BEV bus technology. Even with MST's current scheduling and operating practices, a number of existing duty cycles could be operated with BEV bus technology on the market today.

Please see **Appendix B** below for a complete table of daily duty cycles (including block numbers) run by MST owned and operates transit buses. Any of these duty cycles that are less than 140 miles could be comfortably served by BEV buses today. It should also be pointed out that this analysis does not consider the possibility of charging BEV buses between blocks served, potentially making the list of daily duty cycles that could be served today using BEV buses even longer.

MST's Blocks/Duty Cycles Tomorrow:

The data shaded green in the two tables found in **Appendix B** below represent MST's daily duty cycles that, as they exist today, are excellent candidates to be served by BEV technology right away. However, these daily duty cycles could be modified by MST to better accommodate BEV bus usage. For example, MST could pursue any or all of the following options:

1. Charge BEV buses between blocks (using whatever available time there is) at either of MST's bus garages in order to extend daily range and accommodate more of the daily duty cycles;
2. Alter (slightly or significantly) the block durations and mileage seen in the tables of **Appendix B**; or
3. Charge BEV buses using en-route charging infrastructure while they serve their duty cycles. This is by far the most expensive option of the three and should only be considered by MST as a last resort.

Likely the most intelligent approach would be to begin the process of replacing MST's older diesels with BEV buses and placing them into service on the daily duty cycles that are easily handled by BEV buses using today's available technology. As MST continues to replace more vehicles over time, it is expected that BEV daily range will grow as battery technology improves, making it extremely likely that more and more of the daily duty cycles found in **Appendix B** could be serviced by BEV buses. Following this strategy, MST could likely service the majority of their daily duty cycles over time with BEV buses with minimal changes to schedules or block length.

Potential Modifications to MST's TDA and CJW Bus Yards:
The infrastructure that is being installed to support eleven charging stations at various MST facilities can potentially support the charging of up to 33 buses (dependent on charger and battery capacity). It is recommended that MST as a next phase further evaluates, together with PG&E, the kind of additional upstream infrastructure (i.e. transformer and sub-station upgrades etc.) that is needed for full electrification of its fleet at both bus yards. Any potential upgrades that are now planned for the CJW site should accommodate for full electrification of the bus fleet. An analysis performed by PG&E to identify the charging zone loads should be undertaken when possible. The impact of full electrification and associated electricity cost could be determined by considering the following basic parameters:

- kWh/mile – number varies by deployed vehicle model;
- Max bus/charger – to evaluate whether there is a possibility to schedule charging to prevent a situation where all vehicles are charged simultaneously – if chargers can be shared between vehicles, upfront installation costs and demand costs will be lower;
- Charger kW – higher kW results in higher demand costs but also allows for faster charging;
- Time of use – for rates that have a time of use component the charging time (peak, mid-peak, and off-peak) impacts the overall cost. It is noteworthy that the peak period will shift as the CA grid evolves and more renewables are incorporated;
- Overall load – overall demand should be evaluated to estimate what the eventual demand charges might be.

It is also recommended that MST tours the Antelope Valley Transit Authority (AVTA) bus depot that has recently undergone substantial power supply upgrades to be able to support 85 BEV bus chargers. AVTA has concluded that it would have been beneficial from a cost perspective for them to have done all the required infrastructure upgrades that were needed for the chargers at once.

It is further recommended that MST also installs charging monitoring software once several BEV buses have been deployed. By incorporating smart charging practices, cost can be kept to a minimum and demand spikes can be controlled. Examples of companies providing both BEV bus monitoring software as well as overall charging management software are Viriciti/Cohere and I/O Controls.

Ideas and Concepts for Future Projects

As is usually the case, the analysis performed over the course of this project has highlighted opportunities for further research into the use of zero-emission buses by MST. These opportunities include:

1. *The use of fuel-cell buses*: Per MST's wishes, this project's research was limited to only BEV buses with respect to zero-emissions transit options. This was due in large part to fuel-cell buses being less commercially ready and considerably more expensive than available BEV options. However, this area remains an opportunity for further research as to how MST could potentially benefit from the implementation of fuel-cell vehicles.

2. *Exploring the redesign of existing transit routes to better accommodate BEV buses*: The transit routes operated by today's public transit agencies have been designed with the diesel bus' capabilities and strengths in mind, particularly with respect to long daily range. There is no reason that public transit agencies can't begin to redesign their transit routes to be more accommodating of the attributes of zero-emission buses. However, this redesigning of routes will require significant forethought and research to ensure that transit agencies maintain an uninterrupted and excellent level of service for transit customers. The planning process should begin early enough to account for route design and modeling, as well as bus procurement schedules. In MST's case, given the significant number of long-distance, rural routes, including what is believed to be the longest public transit route in the US at 120 miles in each direction (the equivalent of Washington, DC to Philadelphia), route redesign to accommodate these super-long distance routes may not be sufficient with today's BEV ranges. As battery technology improves in the coming years, more of these routes may become suitable for BEV buses.

3. *Use of conductive chargers between bus blocks to extend BEV duty cycle range*: The range analysis seen in **Figure 12** in this report assumes that MST's diesel buses operate continuously throughout the day to serve their daily duty cycle. In reality, MST's buses frequently have time between daily bus blocks that could be used for depot charging. Strategic use of this charging time could indeed extend daily range of BEV buses to serve an even greater selection of MST daily duty cycles than what is shown in this report. Again, this process would require forethought and research to execute effectively. In addition, MST could benefit from the strategic rotation of depot chargers. This process could potentially eliminate the need for MST to install one depot charger for each BEV bus operated, and therefore reduce costs. This possibility requires further research.

4. *Demand charges*: Demand charges remain a potentially important but inadequately researched factor with respect to cost-effective implementation of BEV buses, particularly in California. Due to larger battery size and faster charging capabilities, BEV buses have the potential to incur prohibitively high electricity demand charges, particularly if charged during the day when electricity demand is peaking. To this point, some transit agencies (ex.: Foothill Transit) have been able to avoid demand charges for BEV buses by negotiating directly with their electric utility, but it is unclear how sustainable this practice will be long-term. More research clearly is needed as to how demand charges

will affect the roll-out of BEV buses. Earlier this year, all investor owned utilities submitted (in accordance with SB350) proposals to the California Public Utilities Commission (CPUC) that outline their plans for supporting transportation electrification. It is expected that these plans will further spur the deployment of electric vehicles and address the current challenges of infrastructure and electricity costs.

5. *Lessons from other transit agencies*: As more BEV buses become available to public transit agencies, it becomes increasingly important for MST to avail themselves of lessons learned by other transit agencies who are also experimenting with the use of BEV buses. This includes accessing research executed by other transit agencies, such as the recently released "Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet" by King County Metro in March of 2017.

6. *Electrification of other vehicles in MST's fleet*: As seen above, the authors of this report recommend that MST immediately begin planning to pursue the implementation of BEV buses into their full-sized transit bus fleet due to the maturity of this segment of the BEV market. However, as the market continues to mature, it will continue to benefit MST to expand BEV implementation into other segments of their vehicle fleet, such as over-the-road coach buses, cutaway vehicles for paratransit/on-demand service, as well as light duty vehicles. This implementation process will require additional research.

7. *Distributed energy generation and storage to prevent demand charges*: MST is encouraged to evaluate various state and federal grants that could be utilized for infrastructure projects that could help MST manage demand charges while it operates increasing numbers of BEV buses in the future. Ideas for projects could be the installation of solar power that is connected to battery storage on site at the bus yards. Excess energy could be drawn from batteries as needed to prevent demand charges that would result in lower overall charging energy costs.

Section 8

Sources

- American Public Transportation Association 2016 Vehicle Database.
- Argonne National Laboratory Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool. https://greet.es.anl.gov/afleet
- California Environmental Protection Agency Air Resources Board (CARB) Advanced Clean Transit Program: "Literature Review on Transit Bus Maintenance Cost." August 2016.
- California Air Resources Board, Advanced Clean Transit Program – Literature Review on Transit Bus Maintenance Cost.
- California Air Resources Board, How LCFS Credits Change Over Time. https://www.arb.ca.gov/msprog/bus/lcfs.pdf
- California Energy Commission; Total Electricity System Power. http://www.energy.ca.gov/almanac/electricity_data/total_system_power.html
- California Environmental Protection Agency Air Resources Advanced Clean Transit Regulation. https://arb.ca.gov/msprog/bus/faqactoverview_1.pdf
- California Environmental Protection Agency Air Resources Board Zero Emission Vehicle (ZEV) Program. https://www.arb.ca.gov/msprog/zevprog/zevprog.htm
- CDL Life News: "California Passes 20 Cent Diesel Tax Hike." April 7, 2017. https://cdllife.com/2017/laws-and-regulations/california-passes-20-cent-diesel-tax-hike/
- Cummins Inc. https://cumminsengines.com/biodiesel-faq
- Detroit Diesel Corporation. http://www.ddcsn.com/cps/rde/xbcr/ddcsn/Detroit_B20_Position_Statement.pdf
- Federal Transit Administration – Options for Financing Public Transportation in the United States. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/Roundtable%20Discussion%20on%20Innovative%20Finance%20-%20Innovative_Finance_Web_Version.pdf

- Federal Transit Administration – Low or No Emission Vehicle Program. https://www.transit.dot.gov/funding/grants/lowno

- Golden Gate Petroleum. http://ggpetroleum.com

- Institute for Transportation, Iowa State University (Annual Bus Maintenance Data): http://www.intrans.iastate.edu/publications/_documents/t2summaries/hybrid_transit_bus_tech_brief1.pdf

- Intergovernmental Panel on Climate Change, 2013. http://www.climatechange2013.org/report/

- King County Metro: "Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet." March, 2017. http://kingcounty.gov/~/media/elected/executive/constantine/news/documents/Zero_Emission_Fleet.ashx?la=en

- National Biodiesel Board (NBB). http://biodiesel.org

- Port, David & Atkinson, John. *Bus Futures 2006*. Inform: Strategies for a Better Tomorrow. http://energy-vision.org/pdf/Bus_Futures_2006.pdf

- Proterra: "FE_Catalyst_Simulation_Summary_presentation."

- Stanford University Electric Bus Project using BYD Electric Buses; 2013 – 2014. http://cahigheredusustainability.org/documents/ThomasWard_Jun173113Adams4.15pm_000.pdf

- United States Department of Energy Alternative Fuels Data Center Clean Cities Alternative Fuel Price Reports: 2000 – 2015. http://www.afdc.energy.gov/publications/search/keyword/?q=alternative%20fuel%20price%20report

- United States Department of Energy: Energy Efficiency & Renewable Energy Biodiesel Statistics. https://www.fueleconomy.gov/feg/biodiesel.shtml

- United States Energy Information Administration: Electric Power Monthly. http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_03

- United States Energy Information Administration: Net Generation by Energy Source. https://www.eia.gov/electricity/data.cfm#generation

- United States Environmental Protection Agency: http://www3.epa.gov/airquality/urbanair/

- Valley Pacific Petroleum: http://vpps.net

- Washington State Department of Enterprise Services: https://fortress.wa.gov/ga/apps/ContractSearch/ContractSummary.aspx?c=09214

- Monterey-Salinas Transit data on several fleet characteristics including vehicle attributes, capital and operating costs, utilization, and efficiency.

Section 9

About the Authors

Kristian Jokinen is a Project Manager at CALSTART. He is responsible for overseeing advanced vehicle development and deployment projects with a focus on the transit bus and medium and heavy duty truck industries. Prior to CALSTART, Kristian worked with several startups active in the electric vehicle space. He also gained extensive experience in the clean technology sector during his tenure as the Environmental Specialist for the Finnish Consulate in Los Angeles, where he was charged with developing the Finnish Foreign Ministry's clean technology strategy for the U.S. West Coast. Prior to this post, he worked for Nissan Nordic Europe's headquarters in Finland. Kristian has a MS in Chemical Engineering and Industrial Economics from Abo Akademi University, Finland, as well as a Certificate in Sustainability and Energy from University of California, Los Angeles. He is a dual citizen of the United States and Finland.

James W. May is an economist with 15 years of consulting and business development experience. He spent seven years as an economics consultant for Charles River Associates, has public policy experience with the United Nations Environment Programme and Rocky Mountain Institute, and entrepreneurial experience co-founding and building WAVE, an energy infrastructure company that innovates and builds wireless charging infrastructure for electric vehicles. With over seven years of experience building costing and range models in the public transit vehicle space, Mr. May is an expert in alternative transportation for the public transit industry. He is currently the Director of Business Development for SCVsoft, a custom software development consulting firm that specializes in data-intensive applications development and cloud platforms in the energy and IoT industries. Mr. May has earned a BA in Economics from Middlebury College as well as Master's Degrees in Public Policy and Environmental Management from Duke University. He lives in Park City, UT.

Appendix A: Complete MST Transit Vehicle Air Emissions Inventory

QTY	Vehicle Type/Number	OEM	Model Year	Length	Propulsion	TOTAL GHG (short tons)	CO (lbs.)	NOx (lbs.)	PM10 (lbs.)	PM10 TBW (lbs.)	PM10 Total	PM2.5 (lbs.)	PM2.5 TBW (lbs.)	PM2.5 Total	VOC (lbs.)
1	Aerolite 290	Ford	2015	29	Gas	-	-	-	-	-	-	-	-	-	-
1	Phantom	Gillig	2000	35	Diesel	67.5	386.2	427.6	1.5	4.0	5.5	1.3	0.5	1.8	65.3
8	Phantom	Gillig	2003	35	Diesel	784.6	1,741.7	4,783.2	16.7	45.3	62.0	15.0	5.7	20.7	458.1
12	Low Floor	Gillig	2002	40	Diesel	1,533.7	8,743.9	9,700.4	33.9	91.8	125.7	30.5	11.6	42.2	1,480.0
12	Low Floor	Gillig	2003	40	Diesel	1,563.8	3,396.5	9,327.8	32.5	88.3	120.8	29.4	11.2	40.6	893.3
5	Low Floor	Gillig	2008	40	Diesel	626.5	239.2	1,580.5	9.3	30.1	39.5	8.7	3.8	12.5	23.2
4	Low Floor	Gillig	2015	40	Diesel	529.9	203.1	424.6	8.3	39.9	48.1	7.3	5.0	12.4	17.9
3	Suburban	Gillig	2002	40	Diesel	545.6	3,365.3	3,733.4	13.0	35.3	48.3	11.8	4.5	16.3	569.6
4	Suburban	Gillig	2003	40	Diesel	740.0	1,818.1	4,992.9	17.4	47.3	64.7	15.8	6.0	21.7	478.1
10	Low Floor	Gillig	2007	35	Diesel	1,456.3	770.6	4,436.1	31.1	84.5	115.6	28.2	10.7	38.9	77.7
11	Low Floor	Gillig	2015	35	Diesel	1,400.8	501.2	1,047.7	20.4	98.4	118.8	18.1	12.4	30.5	44.1
1	Low Floor	Gillig	2013	40	Diesel	135.9	56.8	116.2	2.2	10.9	13.1	2.0	1.4	3.4	4.9
3	Low Floor	Gillig	2015	40	Diesel	495.4	233.8	488.8	9.5	45.9	55.4	8.4	5.8	14.3	20.6
2	Commuter	MCI	2009	45	Diesel	422.6	250.1	1,669.2	9.9	31.8	41.7	9.1	4.0	13.2	24.5
1	Commuter	MCI	2010	45	Diesel	240.9	105.8	241.4	4.7	18.5	23.2	4.5	2.3	6.8	9.2
1	Commuter	MCI	2012	45	Diesel	209.4	85.9	173.9	3.3	16.2	19.5	3.2	2.0	5.2	7.4
2	Commuter	MCI	2015	45	Diesel	450.2	189.2	395.4	7.7	37.2	44.8	6.8	4.7	11.5	16.7
4	Aerotech	Eldorado	2011	24	Gas	182.8	675.9	28.0	1.2	10.4	11.5	1.2	1.4	2.6	16.0
1	Aerotech	Eldorado	2013	24	Gas	62.2	111.9	5.3	0.2	3.1	3.3	0.2	0.4	0.6	3.0
5	Aerotech 240	Eldorado	2014	24	Gas	360.9	747.6	35.5	1.4	20.3	21.7	1.4	2.8	4.1	18.9
15	Aerotech 240	Eldorado	2015	24	Gas	1,347.5	2,832.3	133.5	5.3	77.3	82.5	5.3	10.5	15.8	72.0
1	Aerotech 240	Eldorado	2016	24	Gas	-	-	-	-	-	-	-	-	-	-
4	Aero Elete 320	Eldorado	2013	30	Diesel Hybrid	119.0	112.8	50.4	0.8	5.9	6.7	0.8	0.8	1.6	3.6
7	AH-28	Optima	2003	29	Diesel	161.0	482.0	1,323.6	4.6	12.5	17.1	4.2	1.6	5.8	126.8
1	AH-28	Optima	2003	29	Electric	-	-	-	-	-	-	-	-	-	-
3	Grand Caravan	Dodge	2011	18	Gas	53.8	406.8	16.1	0.7	5.2	5.9	0.7	0.7	1.4	11.2
6	Allstar	Starcraft/ Ford	2010	22	Gas	401.7	1,593.2	64.4	2.8	24.6	27.4	2.8	3.4	6.2	39.2
1	Aerotech	Eldorado	2012	22	Gas	66.3	144.9	6.8	0.3	3.9	4.2	0.3	0.5	0.8	3.9
11	Elkhart	Ford	2013	22	Gas	771.1	1,692.4	79.8	3.2	46.8	50.0	3.2	6.4	9.6	44.7
8	Allstar	Starcraft/ Ford	2015	22	Gas	197.6	441.0	20.8	0.8	12.0	12.8	0.8	1.6	2.5	11.2
5		Ford	2016	0	Gas	-	-	-	-	-	-	-	-	-	-
1	Allstar	Ford	2009	24	Gas	34.8	139.7	6.0	0.2	1.7	2.0	0.2	0.2	0.4	3.5
1	Allstar	Ford	2008	24	Gas	60.2	285.0	15.2	0.4	2.9	3.3	0.3	0.4	0.7	7.1
2	Allstar	Ford	2007	24	Gas	82.0	467.5	29.4	0.6	4.0	4.7	0.5	0.5	1.1	12.6
1	Allstar	Ford	2007	22	Gas	42.5	226.9	14.3	0.3	2.0	2.3	0.3	0.3	0.5	6.1
						15,146	32,447	45,368	244	958	1,202	222	123	346	4,570

Appendix B: Complete MST (owned & operated) Transit Vehicle Daily Duty Cycle List, Sorted by Mileage

JLW Garage

Bus Series	Block	Mileage	Duration	Block	Mileage	Duration	Block	Mileage	Duration	TOTAL MILEAGE	TOTAL DURATION
2000	1202	25.4	1:38							25.4	1:38
Jazz35	9032	32.6	2:23	9034	43.8	3:21				76.4	5:44
2000	5601	59.8	3:08	7603	27.3	1:47				87.1	4:55
Jazz35	9031	44.3	3:28	9033	43.8	3:21				88.1	6:49
2000	1203	58.1	3:20	1205	40.6	3:12				98.7	6:32
1700	7501	31.5	2:19	6806	39.8	3:21	6902	35.0	2:41	106.3	8:21
1700	7602	31.9	2:26	6807	79.3	7:33				111.3	9:59
Jazz40	9016	126.5	12:26							126.5	12:26
2000	7502	52.4	4:25	7504	76.1	5:29				128.5	9:54
1700	6801	50.3	4:09	6804	36.0	2:53	6809	44.1	3:49	130.4	10:51
1700	6802	35.5	2:42	6805	39.8	3:25	6810	57.0	5:21	132.3	11:28
2000	1201	37.7	2:15	1204	94.9	6:26				132.6	8:41
Jazz40	9014	137.9	13:31							137.9	13:31
Jazz40	9012	140.5	13:32							140.5	13:32
2000	1101	66.0	4:11	1102	82.6	5:54				148.6	10:05
1700	6803	35.0	2:32	6808	41.9	3:27	6901	84.7	8:21	161.6	14:20
1800	7601	72.0	4:48	6811	39.8	3:07	7402	57.5	3:51	169.3	11:46
2000	7001	44.9	3:08	7503	128.2	10:01				173.1	13:09
Jazz40	9011	184.1	17:40							184.1	17:40
Jazz40	9013	184.3	17:39							184.3	17:39
Jazz40	9015	186.3	17:53							186.3	17:53
1100	202	186.7	15:59							186.7	15:59
1100	201	206.6	18:13							206.6	18:13
1700	2004	217.6	12:49							217.6	12:49
2100	7801	113.7	4:19	5501	169.7	6:04	7802	123.3	6:33	406.7	16:56
4500	8201	189.8	5:44	8503	291.7	8:56				481.5	14:40
4500	8601	271.1	7:55	8202	325.8	10:10				596.9	18:05
4500	8501	369.7	10:49	8602	271.3	9:06				640.9	19:55
4500	8502	657.9	18:35							657.9	18:35

CJW Garage

Bus Series	Block	Mileage	Duration	Block	Mileage	Duration	Block	Mileage	Duration	TOTAL MILEAGE	TOTAL DURATION
1700	7401	52.358	2:31	7202	59.7	3:42				112.0	6:13
2000	1002	57.66	2:55	1004	58.3	2:54				116.0	5:49
1700	4104	120.11	12:12							120.1	12:12
1700	4901	120.69	14:07							120.7	14:07
2000	4301	121.7	12:07							121.7	12:07
2000	1001	77.746	3:51	1003	58.3	2:54				136.0	6:45
994	8401	144.75	4:05							144.7	4:05
2000	4402	156.52	13:12							156.5	13:12
1700	4102	158.1	15:19							158.1	15:19
1700	7201	54.02	2:50	4105	111.9	11:27				165.9	14:17
1700	4103	180.58	17:16							180.6	17:16
2000	4401	207.58	14:57							207.6	14:57
1800	2304	112.47	4:23	2308	113.6	4:23				226.0	8:46
1700	2003	233.83	13:42							233.8	13:42
2100	2302	132.2	4:35	2307	112.5	4:16				244.7	8:51
2000	1602	270.2	16:51							270.2	16:51
1700	2001	271.6	15:48							271.6	15:48
2000	1603	274.84	17:13							274.8	17:13
2000	1601	291.52	18:19							291.5	18:19
1700	4101	54.024	4:37	2005	240.8	13:59				294.8	18:36
2100	2305	166.44	6:06	2309	131.4	4:45				297.9	10:51
1800	2301	108.5	3:29	2306	112.5	4:23	2311	107.1	3:19	328.0	11:11
2100	8402	332.08	9:50							332.1	9:50
1700	2002	355.11	19:56							355.1	19:56
2000	2902	355.53	16:59							355.5	16:59
2000	2901	382.88	17:53							382.9	17:53
1800	2303	313.75	11:10	2310	112.5	4:11				426.2	15:21