Cleaner Air for Denver with Electric School Buses

Prepared by VEIC for
Denver Public Schools & Conservation Colorado

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Scope

This report summarizes analysis conducted by VEIC on Denver Public School's bus fleet and the suitability of replacing existing diesel buses with electric school buses.

Colorado is undertaking efforts to reduce harmful emissions from diesel engines as part of a legal settlement with Volkswagen Group of America. The Colorado Department of Public Health and Environment (DPHE) is administering over $68.7 million in funds as part of the settlement. The Beneficiary Mitigation Plan budgets $18 million to replace and scrap Class 4-8 school buses from model year 2009 and older, among other vehicle types.

This analysis considers both diesel-powered and electric-powered school buses. Additional fuels (propane, natural gas, etc.) can power school buses, but these vehicles are not considered in this report.

Methodology

This analysis considered (1) existing vehicle miles expected to be displaced by a new vehicle, (2) vehicle and fuel production emissions tied to an existing diesel bus, a new diesel bus, and a new electric bus, and (3) related costs for each scenario.

Calculating Annual Mileage and Displaced Miles

Approximately 200 school buses with model years (MY) between 2000 and 2009 are located at DPS's Northeast Bus Terminal. Annual mileage and maintenance costs are available for nine and eight years, respectively. The data show that older buses tend to be used less as they age and maintenance costs tend to increase. The median bus in this subset travels 9,300 miles per year, which is 52 miles per day when averaged over 180 days of operation.

By preemptively replacing an existing bus before its expected life of 20 years is complete, a new bus displaces miles of older, dirtier operation with miles of cleaner operation. Based on the mileage trends present in the 2000 to 2009 era buses, VEIC calculated the avoided miles of operation for each model year. For example, replacing a 2006 model year bus would displace the mileage the bus would have traveled until its expected retirement in 2026; in turn, the new bus acquired in 2019 would eliminate the miles driven by the replacement bus that would have been purchased in 2026.

Air Pollutants and the Electricity Grid

VEIC used AFLEET to calculate the quantity and economic impact of pollutants for new diesel and new electric school buses and for existing school buses in model years 2000 to 2009. The AFLEET (Alternative Fuel Life-cycle Environmental and Economic Transportation) tool was developed by the US Department of Energy's Argonne National Laboratory based on Argonne's GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model and is widely used to calculate the costs and benefits of fleet emissions.

The output values include emissions related to vehicle operations and the fuel production for diesel fuel and electricity. This is especially important when considering different fuels. Production, refining, and transportation of liquid fuels emit pollutants. Electric buses emit no propulsion-related emissions from the electric motor.[1] However, air pollution is generated when fuels such as natural gas and coal are burned to generate the electricity used to power the bus. VEIC's calculations take this into account by using Xcel Energy's 2017 grid resource mix as the basis for calculating emissions related to electric bus use. (AFLEET, by default, also includes non-propulsion emissions such as tire and brake wear.)

Electricity emissions will ultimately be based on the marginal unit of electricity used to charge an electric bus's batteries. Bus charging will typically occur at night, when solar generation is unavailable and baseload fossil fuel dominates on the grid, resulting in higher marginal emissions than the annual average.

Xcel reported that its 2017 grid resource mix consisted of 44% coal, 28% natural gas, and 28% carbon-free generation (wind, solar, etc.). In terms of greenhouse gases, and specifically carbon dioxide (CO_2), Xcel has publicly committed to reducing its carbon intensity from a 2005 base level to 45% of base by 2020, 80% by 2030, 90% by 2040, and 100% by 2050.

The analysis acknowledged that higher nighttime charging marginal emissions is offset against the utility's expected progress towards cleaner power sources over the life of the electric vehicle. Xcel's 2017 grid resource mix balances these factors and was used as the basis of emissions for the electric bus.

Vehicle Efficiency

The analysis used AFLEET's default vehicle efficiency metrics for diesel school buses, at 7.7 miles per gallon for diesel. VEIC used 1.3 kilowatt-hours per mile for electric buses, a value based on VEIC's recent measurements of actual school bus energy use.

Fuel Costs

Fuel costs are based on US Energy Information Administration (EIA) data from the Rocky Mountain Region. The EIA diesel cost was adjusted to eliminate state and federal taxes, and blends wholesale energy, demand charges, and fixed charges based on November 2018

[1] Some electric buses are equipped with diesel auxiliary heaters.

electricity costs for transportation customers in Colorado. The Northeast Bus Terminal is served by Xcel's SG-1 rate. While overnight bus charging is unlikely to occur at times of high demand on the electric grid, DPS should plan to mitigate possible demand charges by using timed charging for time-of-day rate options.

Table 1: Fuel Costs and Fuel Mix used in the Analysis

Key Input	Diesel Bus	Electric Bus
Annual mileage	8,100	8,100
Miles per gallon (per diesel gallon equivalent)	7.7	19.6
Fuel price	$2.39 / gal.	9.18¢ / kWh
Electricity grid fuel mix		Xcel Colorado (2017)

Maintenance Costs

Electric buses lack maintenance costs related to diesel engines and diesel pollution control systems. While the first electric buses delivered to customers may incur higher costs as personnel become familiar with electric technology, lower overall costs are possible and included in the analysis.

Based on DPS fleet data, VEIC found that maintenance costs per mile increase rapidly with bus age. Maintenance savings occur by displacing expensive maintenance for old-bus miles with inexpensive new-bus miles.

Analysis Results

Emissions Comparisons Among Fuel Types

Including upstream emission related to fuel production (diesel) and power generation (electricity), AFLEET analysis indicates that an electric school bus will emit lower levels of greenhouse gases and nitrous oxides (NOx) than a new diesel school bus. However, electric school buses contribute to higher levels of sulfur oxides (SOx) emitted at power plant emissions. Electric school buses have zero propulsion-related emissions. Some particulate matter is created due to tire and brake wear, and buses equipped with auxiliary diesel space heaters will emit when those units are operation. We include both types of auxiliary emissions in our analysis.

Table 2: Annual Emissions for a New Diesel Bus and a New Electric Bus

Pollutant (Pounds)	**Emissions Type**	**New Diesel Bus**	**New Electric Bus**
NOx	Upstream	8.77	12.73
	Vehicle	15.33	2.16
CO	Upstream	4.10	8.14
	Vehicle	18.41	0.54
SOx	Upstream	4.48	39.87
	Vehicle	0.16	0.02
PM2.5	Upstream	0.50	1.48
	Vehicle	0.47	0.51
PM10	Upstream	0.61	3.95
	Vehicle	2.11	2.22
VOC	Upstream	2.41	2.12
	Vehicle	1.79	0.04

Table 3: Annual Greenhouse Gas Emissions for a New Diesel Bus and a New Electric Bus

Pollutant (Short Tons)	**Emissions Type**	**New Diesel Bus**	**New Electric Bus**
GHG (CO_2e)	Combined Upstream & Vehicle	14.7	11.6

Table 4: Annual Nitrous Oxide Emissions for New Buses

Pollutant (Pounds)	**Emissions Type**	**New Diesel Bus**	**New Electric Bus**
NOx	Upstream	8.77	12.73
	Vehicle	15.33	2.16[2]

Avoided Emissions Through Early Replacement

Greater improvements in emissions are possible by replacing an existing diesel bus with a new electric bus. As described above, among the buses eligible for replacement through VW mitigation funds (i.e., 2009 and earlier), model year 2006 buses offer the best potential due to (1) the opportunity to displace miles during their remaining years of operation, and (2) more stringent emissions controls required for buses beginning with the 2007 model year. When comparing between a new electric bus beginning operation immediately, and the "base case" of a 2006 bus continuing to operate and then served by a new diesel bus, the analysis finds that:

- the base case diesel scenario leads to societal costs totaling $41,332, and

[2] Vehicle NOx emissions are entirely from the optional on-board oil-fired space heater.

- the electric scenario leads to societal costs totaling $16,982 over 20 years.

These societal costs consist mainly of impacts on human health, as well as other expenses (e.g., impact to agriculture, deterioration of building materials, climate change damages) not borne directly by the vehicle owner.

Further, in terms of NOx pollution,

- the base case diesel scenario has NOx emissions of 1,038 pounds over 20-years, of which 80% are emitted directly from the vehicle;
- the electric scenario has NOx emission of 235 pounds over 20-years, of which 18% are emitted directly from the vehicle (specifically, the on-board heater).

Table 5: 20-Year Emissions from Electric and Diesel Buses[3]

Pollutant (Pounds)	Electric		Diesel		Reduction		
	Vehicle	Upstream	Vehicle	Upstream	Vehicle	Upstream	Total
NOx	43.2	191.7	831.2	207.2	788.0	15.5	803.6
CO	10.8	122.6	648.3	96.7	637.5	-25.9	611.6
SOx	0.5	600.6	3.9	105.8	3.4	-494.7	-491.3
PM 2.5	10.7	0.0	52.6	11.7	41.9	11.7	53.6
PM 10	48.7	59.6	92.8	14.4	44.1	-45.1	-1.0
VOC	0.7	31.9	120.4	57.0	119.7	25.1	144.7

Negative numbers represent an increase in pollutants.

Financial Savings

By replacing a model year 2006 diesel bus with an electric bus, VEIC estimates that:

- Fuel savings will total $44,508 over twenty years,
- Operational savings will total $67,845, which is comprised of $40,828 of maintenance cost savings (such as eliminated diesel engine service), $33,267 of *avoided* maintenance costs (through early retirement of the 2006 bus), both net of foregone resale revenue of $6,250 (as the vehicle must be scrapped).

Values are reported in 2019 dollars using current costs.

[3] Including 2026 replacement with new diesel.

Total Benefits

Under this scenario, AFLEET estimates the value of total benefits through cleaner air and lower expenses are:

- $112,353 in benefits to Denver Public Schools
- $13,044 in societal benefits related to reduced emissions

Notably, electric buses reduce the harm of air pollution posed by diesel buses to students (who are both vulnerable and more exposed to bus exhaust) as well as to school staff and Denver's dense residential neighborhoods. Electric buses also advance the sustainability goals of Denver Public Schools, the objectives of Colorado's electric vehicle plan, and the principles of Colorado's climate plan.

Conclusions

This analysis determined that electric buses offer a variety of benefits to Denver Public Schools, most notably far-lower emissions of harmful pollutants at the vehicle level. It is especially beneficial to replace an existing diesel bus before its expected end-of-life.

This report acknowledges that shifting from diesel buses to electric buses is not without downsides related to sulfur dioxide emissions, although the AFLEET analysis demonstrates that benefits outweigh concerns. DPS can further mitigate off-site emissions by purchasing renewable energy to charge its electric buses, such as by enrolling in Xcel's wind power purchase option (currently a premium of 1.5¢ per kilowatt hour) or by participation in other solar projects. DPS indicates that the Northeast Bus Terminal has sufficient space and layout to accommodate multiple charging stations in existing bus parking areas, and that transformer capacity is sufficient for an electric bus pilot project.