

## **GFO-17-607 Cost Effectiveness Model**

### **Battery Electric School Buses**

#### **Abstract**

The cost effectiveness model presented in this document is being applied to the California Energy Commission's solicitation GFO-17-607: School Bus Replacement for California Public School Districts, County Offices of Education, and Joint Power Authorities. The model is used to determine the cost effectiveness of the solicitation as a whole (calculating the cost effectiveness of total awarded buses), and not the cost effectiveness of each individual awarded bus. As a criteria of GFO-17-607, each awardee of an electric bus will be required to submit a final report at the conclusion of the project that includes data collection. Based on the data collected, the actual cost effectiveness of each awardee will then be determined.

Please note, this model does not necessarily represent the cost effectiveness of electric school buses outside of this program or funding solicitation.

This model examines new battery electric school buses to determine the cost effectiveness of purchasing school buses for public school districts, County Offices of Education (COE), and transportation Joint Power Authorities (JPA). The model sets baseline costs for the bus, estimates annual miles traveled by school buses in California, and calculates the benefits for school districts, COEs and JPAs receiving new all electric school buses by determining lifetime savings due to fuel cost, fuel efficiency, vehicle maintenance, health benefits, economic multipliers due to manufacturing and construction, and reduction of carbon emissions. Lifetime savings are calculated by comparing new all electric school bus costs to the relative costs of an old diesel school bus. Based on the methodology explained in this paper, the analysis demonstrates that the Energy Commission's GFO-17-607 funding for battery electric buses will prove to be a cost effective program.

#### **Methodology**

The cost effectiveness model used is a simple ratio between project benefits and project costs. The results of this model will be used to determine the cost effectiveness of the program as a whole. Benefits for this project are defined as fuel cost savings, maintenance cost savings, greenhouse gas emission reductions, health benefits, and economic benefits. These benefits will be explained in greater detail in later paragraphs and are determined by comparing the cost of a new battery electric school bus to the diesel bus being replaced. Other potential benefits such as job creation, scrappage of the replaced bus required by the legislation, safety benefits and vehicle-to-grid (V2G) ability are not included in the model. The only defined costs associated with this project are the cost of a purchased school bus and the cost of infrastructure. These costs include 100 percent of the school bus cost and \$60,000 for infrastructure that will be borne by the Energy Commission.

The cost effectiveness ratio places benefits in the numerator and costs in the denominator as displayed below in Figure 1. A quotient of 1 or greater indicates that the benefits are greater

than the costs. Any quotient under 1 indicates that the costs are greater than the benefits. To be cost effective, the quotient will need to be greater than 1.

### FIGURE 1: Cost Effectiveness Equation

$$\frac{\text{Sum of Benefits}}{\text{Sum of Costs}} = \text{Cost Effectiveness Score}$$

The benefits in this model are incremental whereas the costs are determined based on assumed actual costs. Incremental benefits will compare savings to awardees by comparing lower operational costs of a new battery electric school bus to operational costs of an old diesel school bus. Both costs and benefits are explained in greater detail throughout this paper.

Because this model uses assumed costs and benefits to determine a cost effectiveness score for the program as a whole, a final assessment to measure and evaluate actual cost effectiveness is built into the program design. Part of the grant agreement between the Energy Commission and local educational agencies (LEAs) will be a final report stating realized costs and benefits over the course of the first year of operation. This information will allow for a review of the cost effectiveness for both individual LEAs and the School Bus Replacement Program as a whole. Compiling the cost effectiveness of each funded bus may also be used to accelerate adoption of fully electric fleets by LEAs.

Figure 2 below shows the cost effectiveness model with the defined benefits and costs. FC is the abbreviation for fuel costs, MC is the abbreviation for maintenance costs, and GHG is the abbreviation for greenhouse gas emissions costs. 1 signifies the costs associated with a diesel bus and 2 signifies the new battery electric bus costs. For example, FC1 represents the fuel costs of the diesel bus and FC2 those of the electric bus.

### FIGURE 2: COST EFFECTIVENESS MODEL WITH DEFINED BENEFIT INPUTS

$$\frac{(FC1-FC2)+(MC1-MC2)+(GHG1-GHG2)+\text{Health Benefits}+\text{Economic Benefits}}{\text{Sum of Costs}} = \text{Cost Effectiveness Score}$$

Annual costs are determined using expected mileage inputs and all benefits are then calculated using a present worth analysis of annual benefits. Total fuel costs, maintenance costs, and emissions reductions are calculated using this present worth analysis. The equations for each can be found below in Figure 3. The same abbreviations used for Figure 2 will be used in Figure 3 with the addition of CI to represent a specific fuel type's carbon intensity (gCO<sub>2</sub>e/MJ) as defined by California Air Resources Board (CARB) with MJ standing for mega joules.<sup>1</sup> It is important to note that as California moves towards its goals of 100% renewable energy generated and sold in the state, the carbon intensity of electricity will decrease. This adjustment was not accounted for in this model, but it will increase the emission reductions benefit in the future.

Using the expected annual mileage, the equations in Figure 3 are used to compute present worth analysis of both the bus being replaced and the requested bus using the expected annual

<sup>1</sup> <https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm>

mileage, time period, and discount rate. The comparison of these calculations is displayed in Figure 2 with the differences between the bus to be replaced (variables FC1, MC1, and GHG1) and new bus (variables FC2, MC2, and GHG2) being the benefits.

FIGURE 3: PRESENT WORTH CALCULATIONS FOR BENEFITS

$$FC = \frac{\text{Annual Mileage}}{\text{Fuel Efficiency (MPG)}} \times \text{Fuel Cost per mile} \times \frac{(1 - (1 + \text{discount rate} + \text{price growth rate})^{-\text{period}})}{(\text{discount rate} + \text{price growth rate})}$$

$$MC = \text{Annual Mileage} \times \text{Maintenance Cost per mile} \times \frac{(1 - (1 + \text{discount rate})^{-\text{period}})}{\text{discount rate}}$$

$$GHG = \frac{\text{Annual Mileage}}{\text{Fuel Efficiency (MPG)}} \times 134.47 \frac{\text{MJ}}{\text{DGE}} \times \frac{\text{Fuel CI} \left( \frac{\text{gCO}_2\text{e}}{\text{MJ}} \right)}{1,000,000 \left( \frac{\text{gCO}_2\text{e}}{\text{MT CO}_2\text{e}} \right)} \times \frac{\text{Price of CO}_2}{1 \text{ MTCO}_2\text{e}} \times \frac{(1 - (1 + \text{discount rate})^{-\text{period}})}{\text{discount rate}}$$

This model is for the lifecycle cost of ownership over a 20 year period with a 2% discount rate and expected fuel cost growth rates attained using the U.S. Energy Information Administration’s (EIA) Annual Energy Outlook 2018 modeled projections.<sup>2</sup> Cost of growth for diesel is 3.9% annually and 3.1% annually for electric.

Additionally, the main variable that dictates cost effectiveness for individual buses is expected annual mileage since benefits associated with this project are calculated in units of dollar per mile. For this model 13,666 was the expected annual mileage. This comes from data provided by CARB and South Coast Air Quality Management District (SCAQMD).<sup>3</sup>

### Costs

Costs of school buses vary depending on manufacturer and bus type. Type D electric buses retail for approximately \$415,000 each whereas Type C electric buses retail for approximately \$350,000. Costs for small, Type A electric buses have not yet been determined and are expected to vary by manufacturer. There are programs run by other state agencies that can be used in addition to this replacement program to offset the purchase cost of electric buses. Programs such as the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) could lower the price of an individual electric school bus by as much as \$235,000 in the form of manufacturer vouchers (up to \$220,000 for electric school buses and an additional \$15,000 provided to districts that service a disadvantaged community).<sup>4</sup> Applying for and receiving this kind of aid would dramatically decrease the amount the Energy Commission is responsible for reimbursing and make this an even more cost effective purchase. However, stacking the funds from this program with those of other programs is not guaranteed and, therefore, not considered in this analysis.

<sup>2</sup> <https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2018&region=1-9&cases=ref2018&start=2016&end=2050&f=A&linechart=ref2018-d121317a.3-3-AEO2018.1-9&map=ref2018-d121317a.4-3-AEO2018.1-9&sourcekey=0>

<sup>3</sup> <https://www.arb.ca.gov/regact/scschl05/appc.pdf>

<sup>4</sup> <https://www.californiahvip.org/eligible-technologies/#your-clean-vehicles>

For the purpose of this model, the expected cost of a battery electric school bus was determined to be \$415,000. The expected cost of a battery electric school bus is the full retail price of a Type D electric school bus without stacking funds from other sources. This model seeks to analyze a bus at its highest assumed cost to ensure that the program is cost effective on its own.

The Energy Commission is also providing grant funding for electric infrastructure for each awardee. Every awarded bus is eligible for up to \$60,000 for electric infrastructure, defined as charging equipment and site upgrades necessary to charge electric buses. To be consistent with the methodology for expected electric bus cost, the expected cost of electric infrastructure will be \$60,000, the full amount of eligible grant funding. Adding the highest expected costs of a school bus and infrastructure results in a total project cost of \$475,000. The benefits need to add up to a sum higher than this cost to be cost effective.

### Benefits

Benefits for this project include fuel savings, maintenance savings, emissions reductions, health benefits, and economic benefits. Full breakdowns of benefits due to fuel savings, maintenance savings, emissions reductions, and health benefits are available in Appendix B.

#### *Fuel Savings*

Fuel savings are determined using vehicle fuel efficiencies provided by the AFLEET tool and fuel costs provided by the EIA.<sup>5</sup>

Fuel costs were calculated in terms of dollar per diesel gallon equivalent (DGE). A gallon of diesel gas in California at the time this model was built was \$3.71.<sup>6</sup> The price per DGE for electric buses was calculated using average costs for electricity used in the transportation sector in the state of California. The average cost of electricity for transportation purposes is 8.74 cents per kilowatt hour (kWh) between March 2017 and February 2018.<sup>7</sup> Even with those low average costs, school districts will be instructed to charge buses at off-peak hours to minimize fuel costs. This model uses the cost of \$0.0874 per kWh. Converting kWh to DGE, using the Low Carbon Fuel Standard's (LCFS) energy conversion results in a fuel cost of \$3.26 per DGE for electric buses. The conversion can be seen in Figure 4 below.<sup>8</sup>

FIGURE 4: DOLLAR PER KILOWATT HOUR TO DGE

$$1DGE = 37.35kWh \rightarrow \frac{\$0.0874}{1kWh} \times \frac{37.35kWh}{1DGE} = \frac{\$3.26}{DGE}$$

Fuel efficiency for each bus type is required to calculate fuel cost savings. Fuel efficiencies for school buses were provided by the AFLEET tool. New battery electric school buses have an efficiency of 19.6 miles per DGE according to the 2017 AFLEET tool. The 2017 version of the

<sup>5</sup> <https://greet.es.anl.gov/index.php?content=afleet>

<sup>6</sup> [https://www.eia.gov/dnav/pet/pet\\_pri\\_gnd\\_dcus\\_sca\\_w.htm](https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_sca_w.htm)

<sup>7</sup> [https://www.eia.gov/electricity/monthly/epm\\_table\\_grapher.php?t=epmt\\_5\\_6\\_a](https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a)

<sup>8</sup> <https://www.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm>

AFLEET tool lists diesel bus fuel efficiency at 7.4 miles per diesel gallon and the 2013 version of the AFLEET tool lists diesel bus fuel efficiency at 5.5 miles per diesel gallon. This model analyzes a 20 year period of ownership so using the older, less efficient 5.5 miles per diesel gallon figure to analyze old diesel buses is appropriate. Additionally, staff reached out to fleet managers throughout the state who reported fuel efficiencies of their diesel fleets close to 5.5 miles per diesel gallon.

### *Maintenance Savings*

Maintenance savings are determined using data supplied by the CARB.

Information from the CARB lists the following per mile maintenance costs for the different types of buses evaluated using this model: \$0.85 for diesel and \$0.60 for electric.<sup>9</sup> Those costs are listed in 2016 dollars. Converting to 2018 dollars results in the following per mile maintenance costs: \$0.88 for diesel and \$0.62 for electric. The CARB maintenance costs for diesel buses were used in this model, but the per mile maintenance cost for electric buses was increased to \$0.71. This model analyzes a 20-year lifecycle cost of ownership and the \$0.62 per mile maintenance costs for electric buses does not include battery replacement, as battery replacement is calculated separately.

Battery replacement is expected to occur at or after year 12. Conservative Energy Commission estimates in the 2017 Integrated Energy Policy Report state that the price of a battery in 2030 will at most be \$120/kWh.<sup>10</sup> Assuming the replacement will be a 150 kWh battery and using a 2% discount rate, the future price of replacement equates to just over \$14,000 in 2018 dollars. Figure 5 below shows the battery replacement cost calculation. Dividing the projected cost in current dollars by the expected average miles traveled multiplied by 12 years (when replacement occurs) results in a per mile maintenance cost of approximately \$0.09. Figure 6 shows this equation. The replacement battery cost would become lower for every year after year 12 that replacement is delayed.

**FIGURE 5: COST OF BATTERY REPLACEMENT**

$$\begin{aligned} \text{Cost in 12 years} &= \$120 \times 150 \text{ kWh} = \$18,000 \\ \text{2018 Cost} &= \$18,000 \times \frac{1}{(1 + .02)^{12}} = \$14,192.88 \end{aligned}$$

**FIGURE 6: COST OF BATTERY REPLACEMENT PER MILE**

$$\text{Per mile cost} = \frac{\$14,192.88}{13,666 \frac{\text{miles}}{\text{year}} \times 12 \text{ years}} = \frac{\$0.09}{\text{mile}}$$

<sup>9</sup> [https://www.arb.ca.gov/msprog/bus/tco\\_assumptions.xlsx](https://www.arb.ca.gov/msprog/bus/tco_assumptions.xlsx)

<sup>10</sup> <https://efiling.energy.ca.gov/getdocument.aspx?tn=223205>

### *Emissions Reductions*

Emissions reductions benefits are calculated using the price of carbon dioxide from the Cap-and-Trade program (\$15.10 for every metric ton of carbon dioxide as of March 29, 2018).<sup>11</sup>

The model uses defined fuel efficiencies and carbon intensities for each type of bus and uses the Cap-and-Trade cost of carbon, as of April 11, 2018, to determine the dollar amount of reductions. That cost is \$15.10 per metric ton of carbon dioxide equivalent (MTCO<sub>2e</sub>). It is important to note that the Cap-and-Trade cost of carbon is expected to rise at a rate higher than the discount rate but this model only used the discount rate to project present worth of the annual emissions savings. These benefits are expected to be higher than the ones used in this model.

### *Health Benefits*

Health benefits are calculated using the Diesel Emissions Quantifier (DEQ), a tool made available by the United States Environmental Protection Agency (EPA).<sup>12</sup>

The DEQ estimates health benefits for projects resulting in reduction of PM 2.5. According to the tool, the “benefits include the reduction of premature mortality, chronic bronchitis, asthma attacks, non-fatal heart attacks, and other health problems.” This requires specific inputs to produce annual health benefit outputs. See Table 1 for these inputs.

TABLE 1: DEQ MODEL INPUTS

DESCRIPTION	INPUT
TYPE	ONROAD
TARGET	SCHOOL BUS
CLASS OR EQUIPMENT	SCHOOL BUSES
QUANTITY	1
ENGINE MODEL YEAR	1990
UPGRADE YEAR	2018
REMAINING LIFE	1
FUEL TYPE	BIODIESEL 20
ANNUAL FUEL GALLONS	2,485
ANNUAL MILES TRAVELED	13,666
ANNUAL IDLING HOURS	107
UPGRADE	VEHICLE REPLACEMENT – ALL ELECTRIC
COST PER UNIT	UPGRADE - \$475,000 LABOR - \$158,656

Since this program will be awarding buses in four regions, the county that provides the fewest health benefits for each region was selected with a 25% allocation for each. These counties and their annual benefits are in Table 2. This was done to calculate the lowest average health benefits throughout the state. When the review of this program is conducted, the DEQ will be

<sup>11</sup> <http://calcarbondash.org/>

<sup>12</sup> <https://cfpub.epa.gov/quantifier/index.cfm?action=main.home>

used to calculate benefits in specific counties that are awarded buses. These are expected to closely match or exceed health benefits used in this model since this tool was used in a way designed to attain conservative benefits and the DEQ does not account for in-cabin emission reductions health benefits. The lifetime health benefits amount to more than \$145,000 as shown in Appendix B.

TABLE 2: COUNTY AND REGIONAL INPUTS AND BENEFITS

COUNTY AND REGION	ANNUAL DIESEL PM2.5 REDUCTION (SHORT TONS)	ANNUAL HEALTH BENEFITS
MODOC, NORTH	0.003	\$85
LOS ANGELES, LOS ANGELES	0.003	\$7,800
MONO, CENTRAL	0.003	\$190
IMPERIAL, SOUTH	0.003	\$780
<b>TOTALS:</b>	<b>0.014</b>	<b>\$8,900<sup>13</sup></b>

*Economic Multipliers*

The last benefit used in this model is economic benefits. These benefits are calculated using the Regional Input-Output Modeling System (RIMS II) created by the Bureau of Economic Analysis. This analysis looked only at the changes of economic outputs statewide due to the changes of final demand caused by new purchases of school buses and electric infrastructure construction and manufacturing. The economic multiplier ignores job creation benefits and focuses only on final demand output using RIMS II multipliers.

The output multipliers used to calculate economic benefits were 1.4516 for construction, 1.4105 for motor vehicles, bodies and trailers, and parts manufacturing, and 1.4467 for out of state industry.<sup>14</sup> There was one assumption made for economic benefits: 75% of the expected cost of a bus was for out-of-state profit, of which 10% comes back to the state. It is important to note that 10% is a conservative estimate. The other 25% of the expected cost of a bus is considered in-state. The costs and multipliers for battery electric buses and electric infrastructure are listed in Table 3.

TABLE 3: ELECTRIC BUS ECONOMIC MULTIPLIERS

DESCRIPTION	AMOUNT	MULTIPLIER	PRODUCT
Construction	\$55,000	1.4516	\$79,838
Motor vehicles, bodies and trailers, and parts manufacturing	\$108,750	1.4105	\$153,392
Other out-of-state industry	\$31,125	1.4467	\$45,029

<sup>13</sup> Table 2 Totals not adjusted for rounding

<sup>14</sup> [https://www.bea.gov/regional/pdf/rims/RIMSII\\_User\\_Guide.pdf](https://www.bea.gov/regional/pdf/rims/RIMSII_User_Guide.pdf)

<b>Totals:</b>	<b>\$194,875</b>		<b>\$278,258</b>
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*Total Benefits*

Total project benefits can be seen in Table 4 for battery electric buses. These benefits were calculated using the equations in the Methodology section of this paper, and include: 13,666 assumed annual miles, health benefits listed in Table 2, and economic benefits calculated in Table 3. Appendix B details how benefits for fuel savings, emissions reductions, and maintenance savings were calculated using the equations listed throughout this paper.

**TABLE 4: ELECTRIC BUS BENEFITS**

Benefit	Amount
Fuel Savings	\$78,509
Emissions Reductions	\$5,981
Maintenance Savings	\$37,988
Health	\$145,528
Economic	\$278,258
<b>Total</b>	<b>\$546,264</b>

**Conclusion**

Figures 1 and 2 of the Methodology section displayed the cost effectiveness equation. To recap, the sum of benefits is divided by the sum of costs. If the quotient is 1 or greater the project is cost effective. If the quotient is less than 1 the project is not cost effective.

Figure 7 shows, based on the methodology explained in this paper, that the sum of the benefits of battery electric buses are greater than the costs.

**FIGURE 7: BATTERY COST EFFECTIVENESS**

$$\frac{\text{Sum of Benefits}}{\text{Sum of Costs}} = \frac{\$546,264}{\$475,000} = 1.15 \geq 1$$

Therefore, the Energy Commission’s GFO-17-607 funding for battery electric buses is cost effective.



## Appendix A: Equations, Conversions, and Variables Used

Variables and Abbreviations for Equations Used:

F: Future value

P: Present value

A: Annuity value

I: Inflation rate

N: Number of years

Equations Used:

$$\text{Present value given a future value: } P = F * \frac{1}{(1+I)^N}$$

$$\text{Present value given an annual value: } P = A * \frac{1-(1+I)^{-N}}{I}$$

$$\text{Annual value given a present value: } A = P * \frac{I(1+I)^N}{(1+I)^N - 1}$$

Conversions Used:

$$1 \text{ DGE} = 134.47 \text{ MJ}$$

$$1 \text{ kWh} = 3.6 \text{ MJ}$$

$$1 \text{ DGE} = 134.47\text{MJ}/3.6\text{MJ} = 37.35 \text{ kWh}$$

Fuel Carbon Intensities (gCO<sub>2</sub>e/MJ):

Diesel: 102.01

Electric: 105.16

## Appendix B: Category Costs and Benefits

### Battery Electric Bus Lifetime Costs:

$$\text{Fuel: } \frac{13,666 \text{ miles}}{19.6 \frac{\text{miles}}{\text{DGE}}} \times \frac{\$3.26}{\text{DGE}} \times \frac{1-(1+.02+.031)^{-20}}{.02+.031} = \$28,088.18$$

$$\text{Emissions: } \frac{13,666 \text{ miles}}{19.6 \frac{\text{miles}}{\text{DGE}}} \times 134.47 \frac{\text{MJ}}{\text{DGE}} \times \frac{105.16 \frac{\text{gCO}_2\text{e}}{\text{MJ}}}{1,000,000 \frac{\text{gCO}_2\text{e}}{\text{MTCO}_2\text{e}}} \times \frac{\$15.10}{1 \text{ MTCO}_2\text{e}} \times \frac{1-(1+.02)^{-20}}{.02} = \$2,434.41$$

$$\text{Maintenance: } 13,666 \text{ miles} \times \frac{\$0.71}{\text{mile}} \times \frac{1-(1+.02)^{-20}}{.02} = \$158,655.67$$

### Diesel Bus Lifetime Costs:

$$\text{Fuel: } \frac{13,666 \text{ miles}}{5.5 \frac{\text{miles}}{\text{DGE}}} \times \frac{\$3.71}{\text{DGE}} \times \frac{1-(1+.02+.039)^{-20}}{.02+.039} = \$106,597.34$$

$$\text{Emissions: } \frac{13,666 \text{ miles}}{5.5 \frac{\text{miles}}{\text{DGE}}} \times 134.47 \frac{\text{MJ}}{\text{DGE}} \times \frac{102.01 \frac{\text{gCO}_2\text{e}}{\text{MJ}}}{1,000,000 \frac{\text{gCO}_2\text{e}}{\text{MTCO}_2\text{e}}} \times \frac{\$15.10}{1 \text{ MTCO}_2\text{e}} \times \frac{1-(1+.02)^{-20}}{.02} = \$8,415.49$$

$$\text{Maintenance: } 13,666 \text{ miles} \times \frac{\$0.88}{\text{mile}} \times \frac{1-(1+.02)^{-20}}{.02} = \$196,643.65$$

### Battery Electric Bus Lifetime Savings:

$$\text{Fuel: } \$106,597 - \$28,088 = \$78,509.61$$

$$\text{Emissions: } \$8,415 - \$2,434 = \$5,981.08$$

$$\text{Maintenance: } \$196,644 - \$158,656 = \$37,987.98$$

### Health Benefits:

$$\text{Lifetime Benefit Calculation: } \$8,900 \times \frac{1-(1+.02)^{-20}}{.02} = \$145,527.76$$