TRANSPORTATION ELECTRIFICATION: CATALYZING A RAPID ELECTRIFICATION OF SCHOOL BUSES

ABSTRACT

New York City (NYC) has over 10,000 school buses providing student transportation to the city's schools. To reduce the climate impacts and air pollution associated with diesel fuel emissions from these buses, NYC has set aggressive electrification targets for its school bus fleet. The City aims for all new school bus purchases to be electric starting in 2027 and a fully electric school bus fleet by 2035. This transition will reduce the harmful health impacts of fuel emissions on children who ride the school buses, while also improving local air quality and reducing greenhouse gases that contribute to climate change.

However, electric school buses have high incremental upfront costs relative to internal combustion engine (ICE) vehicles and require charging infrastructure to be installed. This study examined the lifetime costs and benefits of electric school buses compared to conventional diesel buses, with the goal of providing implementation recommendations to the City and its bus operators. Key topics examined in this analysis include the ability of buses to manage charging, potential feasibility of revenue from vehicle-to-grid (V2G), charger sharing, power level of chargers, and the timeline for the electrification transition.

RESEARCH AREA OVERVIEW AND OBJECTIVE

New York City has nearly 10,500 school buses supporting student transportation via almost 9,000 different routes to the City's schools. To reduce the climate impacts and air pollution associated with these buses, New York City has issued aggressive electrification targets for its school bus fleet. The New York State Budget requires all new school bus purchases to be zero emission vehicles starting in 2027.[i] Per Local Law 120 of 2021, New York City is required to have a fully electric school bus fleet by September 1, 2035.[ii]

School bus electrification in routes that serve low-income and disadvantaged communities can also work to reduce the disproportionately high amounts of air pollution in these communities. Within New York State, African American, Latino, and Asian American residents are all exposed to nearly twice as much PM2.5, a form of air pollution, as white residents.[iii] Childhood exposure to PM2.5 pollution is linked to slowed lung function and development of asthma, and exposure to PM2.5 pollution from vehicles contributes to an estimated 320 premature deaths each year in New York City alone.[iv] Children from low-income families are also more likely to take the bus to school, and air pollution inside a school bus can reach up to ten times the ambient pollution levels outside.[v] This makes emissions from school buses an equity concern.

Electrifying the City's entire school bus fleet will require significant upfront costs to purchase or lease electric buses relative to the cost ICE buses. An electric school bus can cost three to four times as much as its diesel ICE counterpart. Transitioning to electric buses will also require charging infrastructure, which will further increase costs. While various grant programs exist from the federal and the state governments, available funds will likely not cover the entirety of the city's required investment to electrify by 2035.

To balance upfront costs, various savings are expected to be realized throughout the lifetime of the electric buses. Electric vehicles typically require lower maintenance costs than ICE vehicles. The lower price of electric fuel compared to diesel allow for fuel cost savings, while further savings can be realized by charging the buses during the lowest cost hours of the day (also referred to as "managed charging"). In addition, bus operators can consider the feasibility of having buses share charging stations or use lower powered chargers to reduce cost of charging infrastructure.

Vehicle-to-grid, or V2G, may enable the school buses to generate revenue from dispatching energy back to the grid when the bus is inactive, such as during the middle of the day, in the evening, or during the summer. Electric school buses may be prime candidates for V2G because of their predictable routes and driving patterns, as well as the significant time that they may be parked and available to discharge back to the grid, especially during the summer when the grid is constrained. Utilities and school districts across the country have started to successfully test V2G with school buses, including a recent pilot between Con Edison and White Plains School District.[vi] The Value of Distributed Energy Resources (VDER or "Value Stack") tariff provides revenue to technologies in New York State that provide energy to the grid, and V2G was included as a new technology eligible to access the Value Stack under the Public Service Commission's December 2018 Order. V2G charging may present a potential revenue stream for electric school buses to improve cost-effectiveness. Further, testing V2G with school buses may help inform future use of V2G to support the electric grid as more vehicle types electrify across the City.

The research included a cost-benefit assessment for electric school buses in NYC which compared lifetime costs of electric school buses relative to the conventional diesel counterpart. This included the upfront cost of the bus, maintenance costs, charger costs, fuel savings from using electricity instead of diesel, and reductions in greenhouse gases and air pollution. Benefits also included potential revenue from V2G that could help offset the high upfront cost. Sensitivities were completed considering charger sharing and using higher powered chargers to understand how costs and benefits may change under different assumptions. The goal of the analysis was to quantify costs and potential savings to provide recommendations for efficient implementation.

METHODOLOGY

This study evaluated the lifetime costs and benefits of school bus electrification in New York City and provides implementation recommendations based on detailed charging analysis for the City's school bus fleet. Two main analyses were conducted as part of this research area. First, school bus travel data for New York City's fleet was used to model the associated charging behavior needed once the buses are electrified, as well as the potential for vehicle-to-grid discharging. Second, costs and benefits of school bus electrification were calculated based on the charging load behavior and other inputs.

School Bus Charging Analysis

The first part of this study analyzed driving data for New York City's school bus fleet and evaluated the charging patterns that may occur when the buses are electrified. The NYC school bus fleet is comprised of approximately 10,500 school buses. Of that number approximately 2,000 buses are spares located at vendor lots and do not drive regularly unless needed. About 7,500 buses drive regular routes and then typically return to the vendor lots or garages to park overnight. The remaining 1,000 school buses are "park outs," which means the bus drives its route and then returns home with the driver, and therefore does not regularly park at one of the vendor lots.

The analysis leveraged detailed route data for NYC's school buses from the Department of Education Office of Pupil Transportation (DOE OPT). The DOE OPT dataset included location pings and bus speeds for 24-hour periods. This data was converted into distance traveled in 15-minute intervals for each school bus. Location pings were mapped to locations of bus operator lots and garages to flag when a bus is parked at a vendor location versus when a bus is parked or idle elsewhere. The dataset was aggregated to produce driving profiles for the City's fleet of school buses, showing driving time, distance, parked time, and location type for four day-types: a weekday and weekend day during the school year, and a weekday and weekend day during summer service.

The driving profiles were then analyzed to create electric vehicle charging profiles based on when the vehicle needs to be driving and when the vehicle is parked and has access to charging. The majority of the school bus fleet that parks at bus operator or vendor lots/garages were assumed to have access to charging at those locations. Park outs were also assumed to have access to charging at parked locations, since the bus will need to be able to charge regularly once electrified.

There were three charging types modeled: unmanaged, managed, and managed with V2G charging. In unmanaged charging scenarios, the school buses charge immediately upon arriving at a charging location. In managed charging scenario, bus operators consider the time-of-use rates and manage their charging to minimize their cost of charging. This means that the bus drivers may not charge as soon as they arrive at back at the vendor lot but may instead wait until lower-priced hours to charge. Under managed charging, drivers still charge the amount needed to satisfy the driving patterns for NYC's school bus routes.

In V2G charging scenarios, in addition to charging from the grid, the school buses can sell energy stored in their vehicle battery back to the grid. These cases assume that bus operators pay the same electric rate as in managed charging for charging the vehicle but receive compensation from the Value of Distributed Energy Resources (VDER) tariff for selling energy back to the grid. Similarly to the managed charging scenario, the school buses will only perform V2G if allowed by driving patterns: buses will still charge the amount needed to satisfy routes and will not discharge back to the grid if this would not meet travel needs. This may mean that charging takes more time than in the other scenarios, since the vehicle may deplete a portion of its battery to perform V2G, but charging will still be complete before the vehicle needs to drive its route.

The greatest revenue potential for V2G occurs in July and August. Additional months may also be beneficial for V2G, but the energy arbitrage model that provides most V2G revenue also comes with challenges. Route changes, vehicle downtime, or other complications may result in losses or mean that buses are not able to perform the primary duty of transporting students when needed. In order to take a more conservative approach and align with when V2G revenue can most reliably be achieved, this modeling limits V2G behavior to July and August. All other months in the V2G scenarios follow the normal managed charging optimization. Therefore, this analysis presented a low-end estimate of potential V2G revenue. Additional revenue could be achieved with careful planning from operators and optimization of V2G with VDER compensation during the school year.

For the base set of scenarios, it was assumed that each bus would have its own dedicated charger of 20 kW. A sensitivity scenario was conducted to explore the impact of increasing charger power to 50 kW. An additional sensitivity scenario examined the impact of sharing chargers between two buses. In implementation, it may not be possible to consistently apply these sensitivities (i.e., Park out buses may not be able to share a charger), so the analysis conducted describes book-end results. The key scenario parameters are shown in Table 1.

Table 1. Scenario Parameters

Scenario	Buses per Charger	Charger Power
Base Scenario	1	20 kW
Higher Powered Charger Sensitivity	1	50 kW
Charger Sharing Sensitivity	2	20 kW

In the analysis, the school bus fleet was segmented into two main bus types: Type A, which represent smaller school buses, and Type C, which are larger school buses. Based on fleet data from DOE OPT, we assume 60% of the fleet is Type A or similar and 40% of the fleet is Type C or similar. The specifications for each bus type are shown in Table 2. The school buses were also assumed to have rated driving efficiencies between 0.67 miles/kWh and 0.93 miles/kWh, with the efficiency reduced seasonally based on expected temperature impacts.

Table 2. Electric Bus Specifications

Bus Type	Battery Size (kWh)	Driving Efficiency (mi/kWh)	Electric Range (miles)	Percent of Modeled Population
Type A	128	0.93	118	60%
Type C	203	0.67	137	40%

Cost-Benefit Assessment

Once the charging profiles were created for each scenario, lifetime costs and benefits of the City's school bus electrification transition were evaluated. The costs and benefits were evaluated from a societal perspective for New York City: cost components include the incremental upfront cost of electric school buses compared to diesel buses, charging infrastructure costs, and energy supply costs, whereas benefits include avoided diesel costs, vehicle O&M savings, and emission savings. Results were calculated as a lifetime net present value (NPV), using a nominal discount rate of 6 percent, for the total fleet as well as on a per-vehicle basis.

The analysis first considered the overall timing for electric buses to be procured by the City's vendors. The assumed adoption trajectory is shown in Figure 1 and the number of electric buses that will be purchased in each year are shown in Figure 2. Based on discussion with DOE OPT, electric school bus purchases in 2023-2024 were assumed to be limited to the buses that the City will receive through the EPA Clean School Bus grant program. The City will be establishing new contracts with its school bus vendors in 2025, and electric bus adoption is assumed to ramp up after that point. This scenario assumed the City meets New York State's goal of new school bus purchases to be zero-emission starting in 2027, and for the entire school bus fleet to be zero-emission by September 1, 2035. This scenario also assumed that the total number of buses in the fleet remains constant through 2035. School buses are assumed to have a 16-year lifetime, consistent with typical vendor contracts for the City.

Figure 1. School Bus Electrification Trajectory

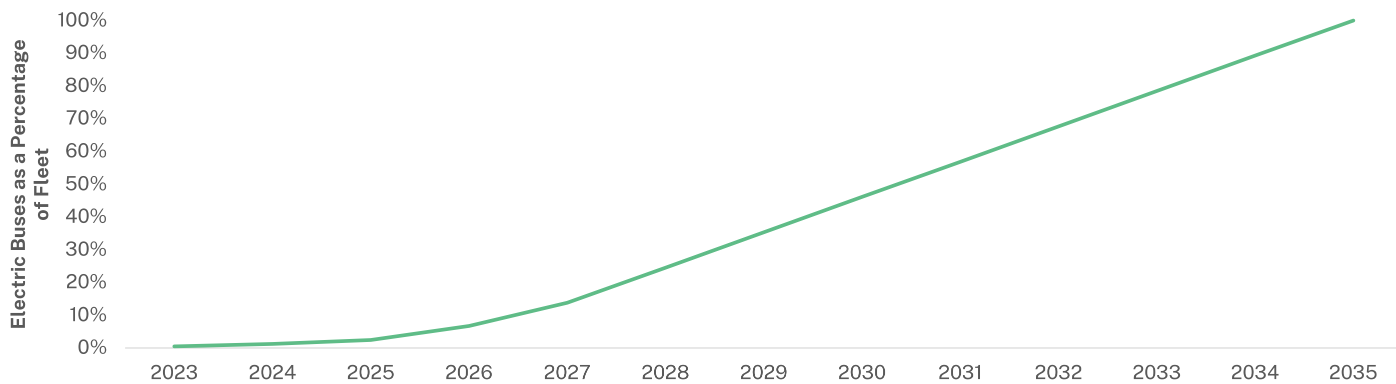
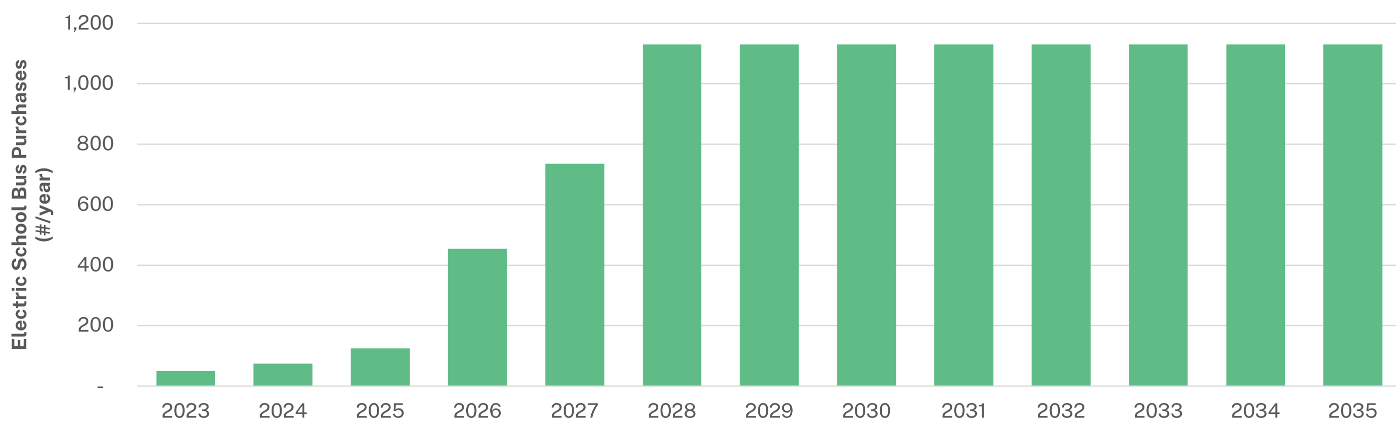


Figure 2. Annual electric school bus purchases



Electric school bus costs used in this study are based the September 2022 New York State Office of General Services' Award Summary for comparable bus types.[vii] Values were adjusted off the source's median price for the presence or absence of V2G capabilities and some additional expected wear on the batteries for buses that perform V2G. The incremental upfront costs of electric school buses compared to similar diesel models are shown in Table 3. These values were compared with a 2022 market study by the World Resources Institute[viii] and assumptions provided in the Argonne National Lab AFLEET tool.[ix] Electric school bus costs were also reviewed with DOE OPT and NYCSBUS to ensure this research represents the range of costs they've seen in the field.

Electric school buses currently have higher upfront costs than their ICE counterparts, primarily due to battery costs. This incremental purchase price of electric vehicles over ICE vehicles is generally expected to decline as battery costs decrease.[x] However, recent pricing trends and conversations with school bus fleet operators and electric bus manufacturers have both indicated that this may not be the case for electric school buses. Even as current supply chain constraints eventually ease, the need for manufacturers to rapidly scale production to meet demand is instead expected to hold real dollar prices steady. This corresponds to an increase in nominal prices over time and is held as the conservative assumption in this modeling.

In this analysis, buses equipped with V2G functionality are assumed to cost more than a non-V2G capable electric school bus. However, there is some uncertainty around additional costs for V2G due to the nascency of the market.

Some bus manufacturers include V2G functionality in all buses, whereas others do not. Therefore, the analysis represents a more conservative outlook on potential added costs for V2G.

Table 3. Incremental Upfront Cost per Bus of Electric School Buses over ICE Buses. Prices in Nominal $.

Vehicle type	2023	2030	2035
Type A	$246,529	$303,200	$351,492
Type C	$244,122	$300,239	$348,059
Type A (with V2G)	$313,479	$385,540	$446,947
Type C (with V2G)	$311,072	$382,579	$443,514

Charging infrastructure costs in this analysis are based on three components: Electric Vehicle Supply Equipment (EVSE or "charger") hardware costs, costs associated with the electrical infrastructure ("make-ready" costs), and the O&M costs for continued operation of the charger over its lifetime. These upfront costs were based on a separate ICCT report, with L2 make-ready costs matching DCFC make-ready to align with the increased charger power used and recently observed costs in New York City.[xi] O&M costs were conservatively assumed from the U.S. Alternative Fuels Data Center.[xii] In addition, increased load from EV charging was assumed to incur distribution upgrade requirements. These values were based on general assumptions from previous E3 studies and reviewed by local utilities. Charger costs assuming 2 ports per charger and associated distribution upgrade costs are shown in Table 4. Charger lifetime was modeled to align with the expected lifetime of the buses.

Table 4. Charging Infrastructure and Distribution Upgrade Costs (2022$/charger)

Charger Type	EVSE Cost	Make-ready Cost	O&M Cost	Distribution Upgrade Cost
20 kW AC charger	$6,104	$38,665	$400/yr	$4,244
50 kW DC fast charger	$62,069	$38,665	$400/yr	$13,792

For avoided fuel costs, the amount of fuel an ICE vehicle would have used under the same circumstances and over the lifetime of the vehicle was calculated from the bus fuel economy. This fuel consumption was multiplied by the costs of fuel in each year to determine avoided fuel costs. The average annual fuel consumption avoided per EV per year was assumed to decrease over time as ICE fuel efficiency improves. The initial fuel economy used was based on the U.S. Department of Transportation statistics for buses,[xiii] and the change in efficiency over time comes from the Transportation Energy Efficiency tables of EIA's Annual Energy Outlook.[xiv] Diesel price forecasts were derived from the EIA 2022 Annual Energy Outlook. Fuel inputs are shown in Table 5. Note that the near-term prices reflect the current market shocks.

Table 5. Fuel Inputs for ICE Vehicles

Year	Fuel Economy (miles per gallon)	Diesel Price (nominal $/gallon)
2023	7.6	$4.29
2030	8.3	$4.39
2035	8.7	$5.01

To calculate avoided operations and maintenance (O&M) costs, the annual mileage for the school buses was multiplied by an estimated per-mile difference between maintenance costs for ICE and electric vehicles. Maintenance costs are considered significantly less expensive for electric buses due to the relatively simple drive system compared to diesel buses. Maintenance costs were assumed to be $0.56 per mile for battery buses and $0.93 per mile for diesel buses, drawn from the Argonne National Lab AFLEET tool.[xv]

All buses were assumed to charge in Consolidated Edison's service territory on the SC 9 Rate III, which provides service to commercial customers with EV charging between 10 kW and 1,500 kW.[xvi] This rate includes a monthly customer charge, a time-varying demand charge ($/kW), and time-varying energy charges ($/kWh). The rate schedules used in the analysis are summarized in Table 6.

For V2G, buses were assumed to receive revenue from New York's Value of Distributed Energy Resources (VDER) Value Stack for standalone storage. This compensation was based on day-ahead energy prices, capacity value, and demand reduction value as determined by the timing and availability of the buses to discharge energy back to the grid.1 V2G buses were assumed to be ineligible for other VDER compensation components based on their nature as an energy resource and the constraints of their schedule.

Table 6. Rate Inputs

Charging Type	Does the bus operator consider rates when choosing to charge?	Charge Rate	Discharge Rate
Unmanaged	No	SC 9 Rate III	N/A
Managed	Yes		N/A
Vehicle-to-Grid	Yes		VDER tariff

Electricity supply cost estimates were used to calculate the utility's cost of procuring additional electricity to serve the electric buses' charging needs. Cost components were included for energy, generation capacity, distribution, and monetized greenhouse gas emission costs. The energy component is based on the forecast produced by the New York Independent System Operator (NYISO), [xvii] and included estimated losses of 7 percent. The NYISO forecast also includes a carbon price forecast for the Regional Greenhouse Gas Initiative (RGGI), which was applied to electricity CO2 emission factors (described below) to produce the monetized greenhouse gas emission costs. The generation capacity component was based on the New York Department of Public Service (DPS) forecast for the NYISO Installed Capacity Market (ICAP).[xviii] Distribution costs were based on ConEdison's marginal cost of service study submitted for the VDER tariff.[xix]

Avoided emissions were calculated based on the difference between electricity grid emissions associated with an electric vehicle's charging load and comparable emissions from a bus's diesel combustion. Avoided carbon emissions were calculated for ICE vehicles based on 0.01098 metric tons CO2 per gallon of diesel, drawn from U.S. EIA factors.[xx] Emissions from electric vehicles were calculated based on the recommended emission intensities for electricity in NYC from Local Law 97 analysis.2 This resulted in an initial emission factor of 0.289 metric tons per MWh of electricity, decreasing to 0.145 metric tons per MWh beginning in 2030. From 2035-2040 the emissions intensity is reduced linearly down to 0 to align with the New York State commitment to achieve zero-emission electricity by 2040. To convert avoided greenhouse gas emissions to a societal cost, New York State's recommended societal cost of carbon was used, which is based on federal values using a 2% discount rate.[xxi]

Avoided NOX and PM2.5 emissions for diesel vehicles come from the Bureau of Transportation Statistics, converted to metric tons per gallon and applied via the fuel economies listed in Table 5.[xxii] Only exhaust values were included as brake-wear and tire-wear are expected to remain to some degree with electric vehicles. New York electric grid

[1] Because the VDER tariff compensation is a combination of day-ahead forecasts and current or historical data, actual rates and the schedule of optimal discharge is expected to change over time. The V2G load shapes in this study combine smoothed energy price forecasts, but actual energy, capacity, and demand reduction values are not locked in and will vary.

[2] Note that the electric grid emissions intensities for Local Law 97 and used here are flat across all hours of the year and do not vary in response to the share of renewable energy generation available in different seasons or times of day. As a result, the charging periods and emissions values used are simplified estimates and may not reflect an ideal societal scenario.

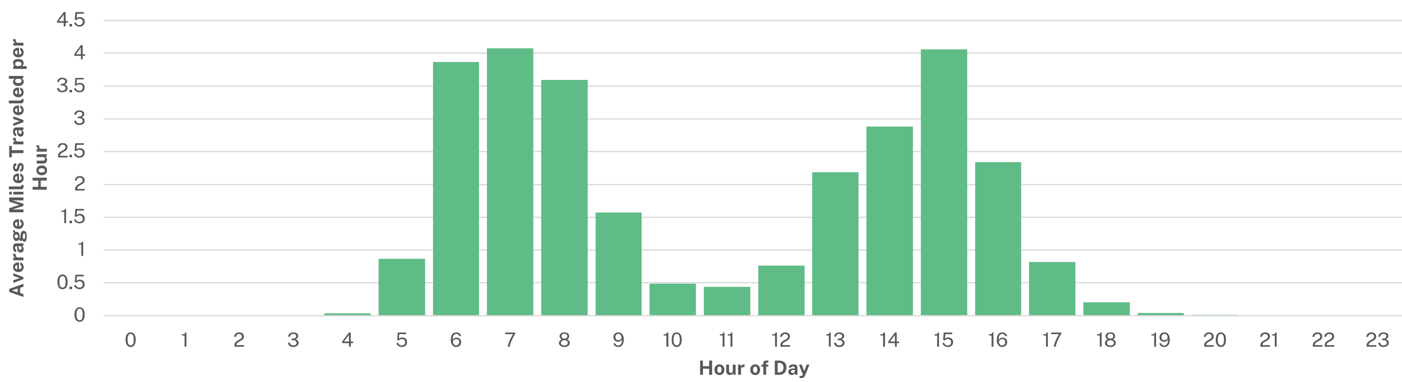
NOX and PM2.5 emissions for electric vehicle charging come from the U.S. EPA eGRID dataset.[xxiii] Social costs were assigned to each of these pollutants based on an EPA Technical Support Document valuing reductions in PM2.5 precursors from avoided mortality and morbidity rates. This analysis used the midpoint of the on-road mobile source values provided.[xxiv]

KEY FINDINGS

School Bus Charging Analysis

Based on the analysis of the City's fleet route data, the average fleet driving profile is below in Figure 2. This shows the average miles traveled per hour across the entire school bus fleet (including spares, which do not drive on a typical day). In general, the City's school buses drive two routes a day: one in the morning hours to take students to school and one in the afternoon to take students home. This is shown by the two discrete bumps in driving profile, with peak driving occurring around 7:00 AM and 3:00 PM on a typical school day.

Figure 3. School Year Weekday Driving Profile

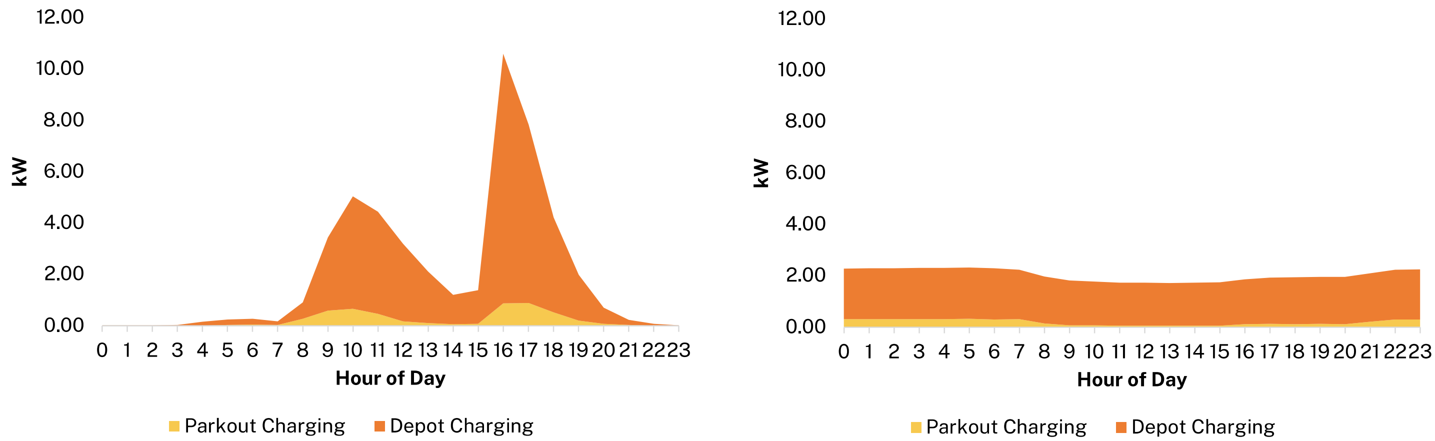


Based on the driving profile, potential charging behavior for the buses was modeled. Charging load shapes were averaged across the entire school bus fleet and shown as average fleet power consumption (kW) per bus in Figure 4.[3] Because these load shapes are averaged across the fleet, they do not necessarily represent exact charging behavior for any one individual bus based on its routes. In the managed charging shape, for example, any given bus would not be charging at all hours of the day, but across the bus fleet, at least some portion of buses would be charging at any given time.

In the unmanaged charging case, bus operators plug in the buses to charge as soon as a bus reaches its parked location. This results in significant charging during the afternoon and early evening as buses return to vendor lots or depots for the night, with a peak of around 10 kW per bus at 4:00 PM. In the managed charging case and V2G case, bus operators consider TOU rates as well as demand charges to decide when to charge. This results in a shifting of charging behavior to overnight when rates are lower and load is flatter. The average peak in the managed charging case is around 2 kW per bus. During the school year, the V2G shape is identical to this managed charging case as this analysis focused on V2G availability in the summer months.

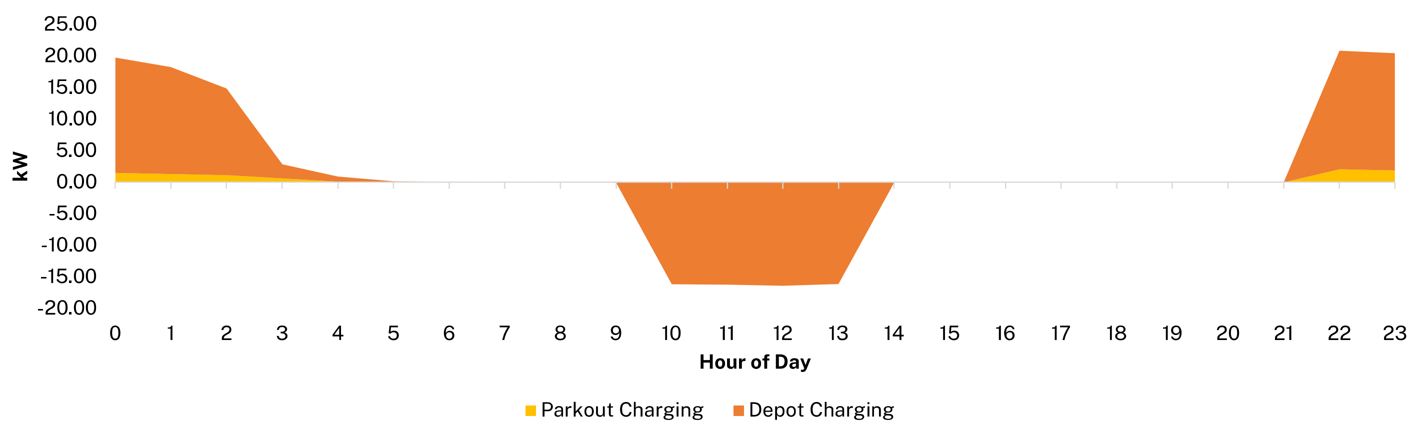
Figure 4. Charging Profiles for Typical School Day in the Base Scenario Unmanaged and Managed (including V2G) Cases

[3] This means that the average per bus power consumption (or output) shown will be less than the nameplate capacity of the charging station, since only a portion of the fleet's buses will be charging (or discharging) at any given time. The fleet average charging shapes include the approximately 2,000 buses that are spares and therefore do not require regular charging.



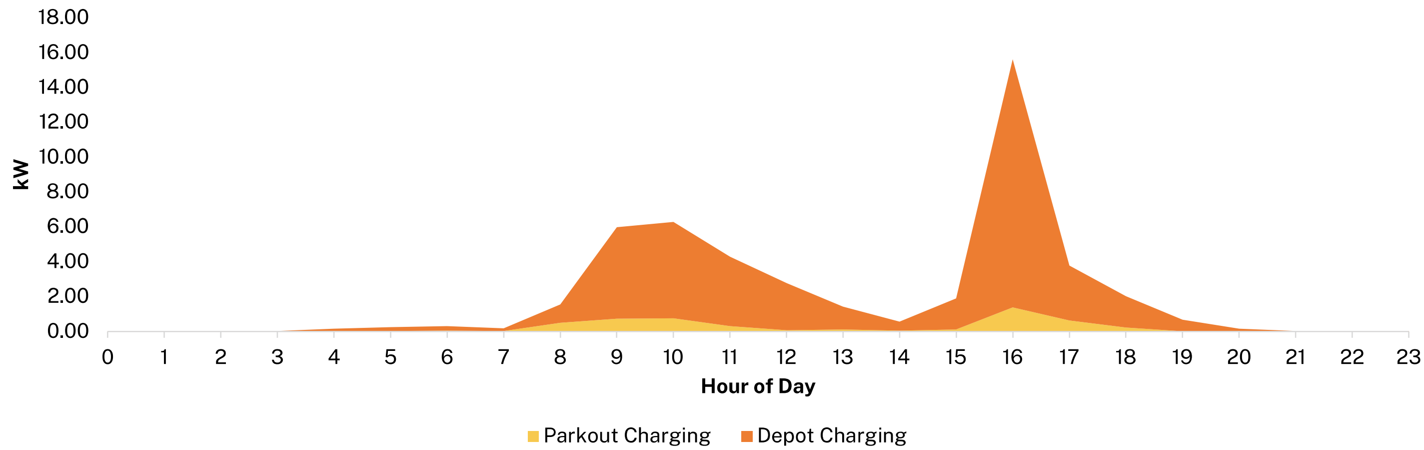
The summer season presents the primary opportunity for school buses to earn revenue from V2G. During the summer, approximately 3,000 buses out of 10,500 conduct routes. This means that many buses in the City's fleet are otherwise idle and can support discharging back to the grid at key times to earn additional revenue. The Demand Reduction Value (DRV) component of the VDER tariff would offer especially high value to the City's school bus fleet between 10am and 1pm of July and August. A sample summer day of V2G charging is shown in Figure 5.

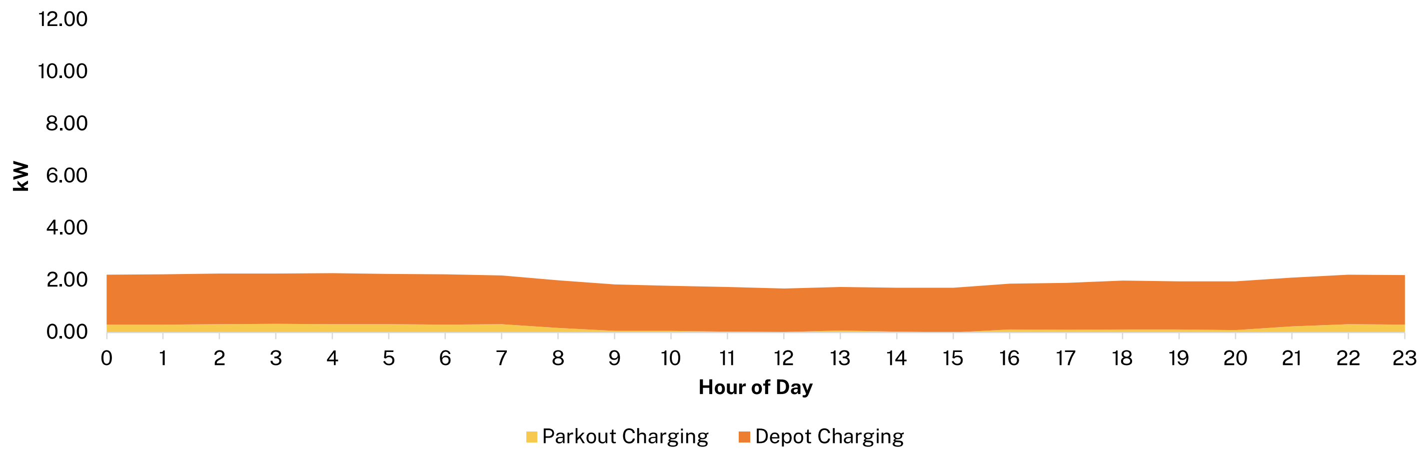
Figure 5. Summer Season Vehicle-to-Grid Load Shape

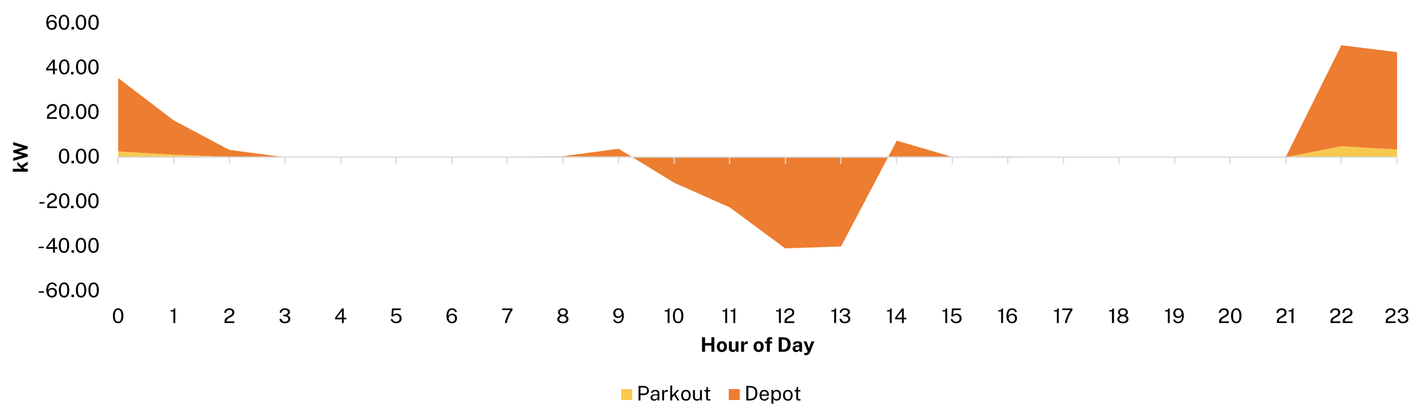


Two sensitivities were analyzed for the charging study. First, the charger power was increased to 50 kW, which allows buses to charge faster and therefore allows for additional V2G potential in the summer, as seen in the charging profiles in Figure 6.

Figure 6. Charging Profiles for the High Power Charger Sensitivity







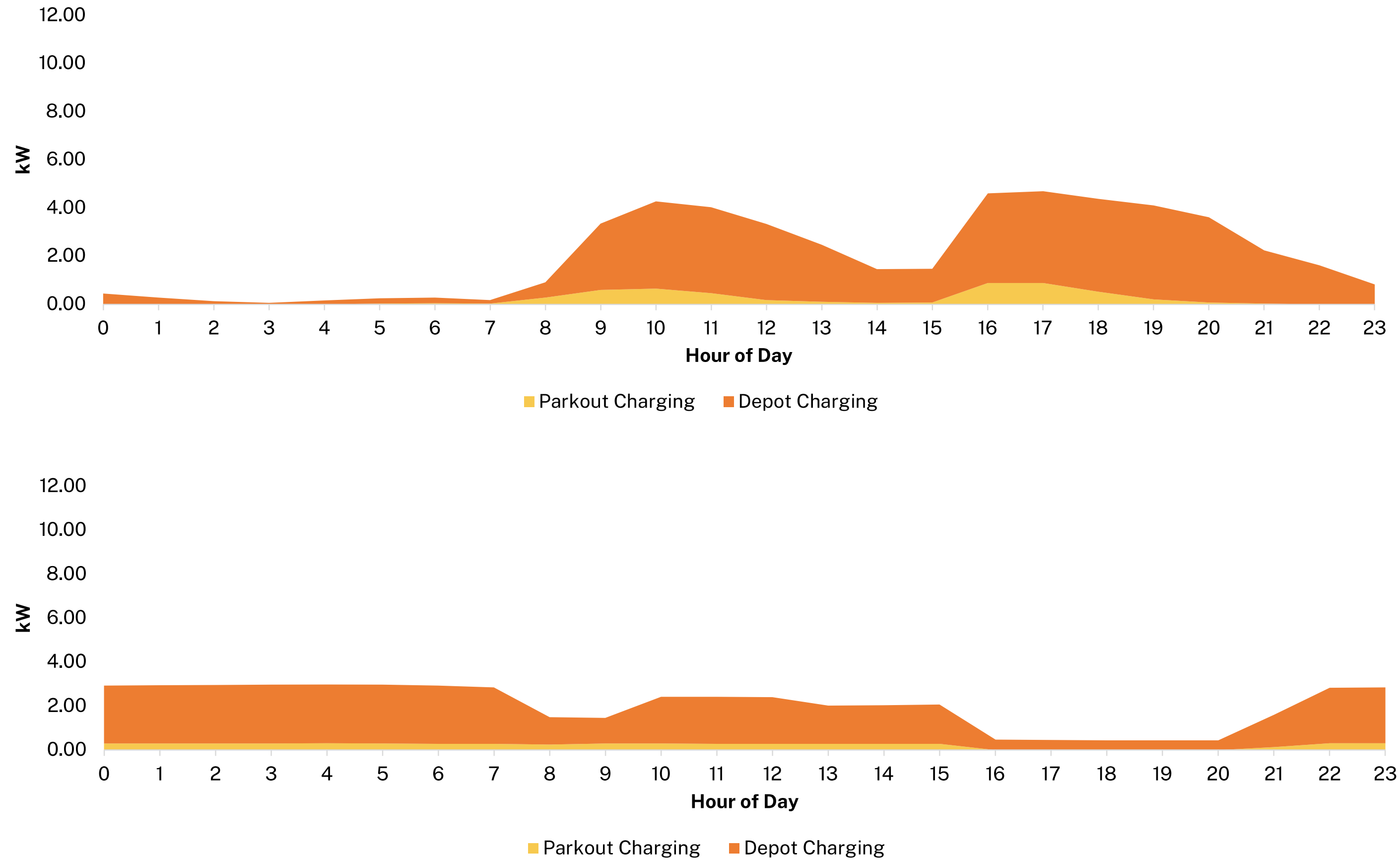
In this sensitivity, unmanaged charging increases the average peak demand by 50 percent. This is a function of buses simply charging to full in a much shorter period by using higher capacity chargers. The managed charging scenario did not show a significant change in charging shapes with the higher-powered chargers. This is because charging was optimized to minimize costs, including the demand charges embedded within the electricity rates. The V2G charging followed the same managed shape to optimize during the school year, but in the summer the magnitude of charging and discharging doubled to maximize revenues when export rates were high.

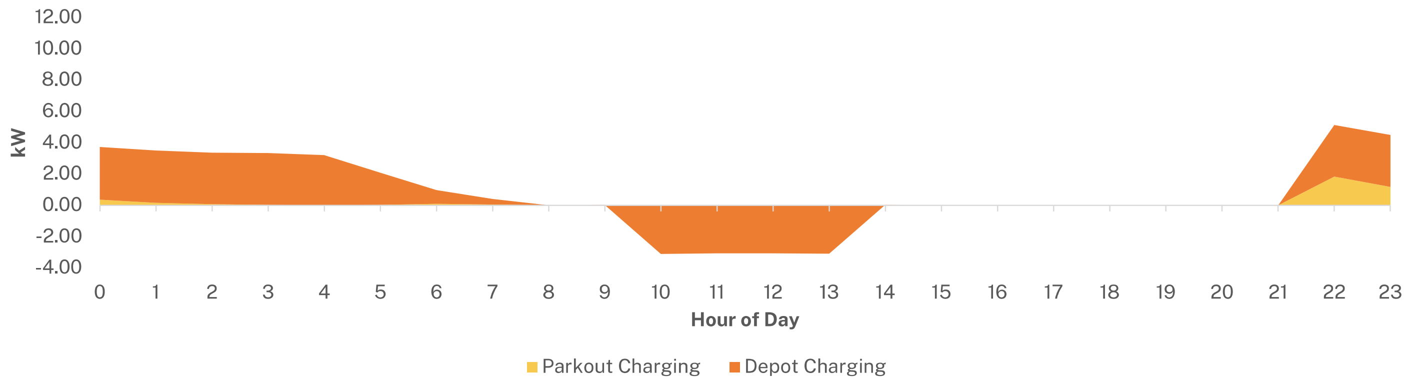
In the second sensitivity, buses were assumed to share charging stations with 2 buses per charger. This requires additional planning for bus operators to ensure that each bus has an opportunity to charge and adds an additional constraint for managed and V2G charging optimization. As shown in Figure 7, this forces the unmanaged charging peak to flatten out compared to the base scenario, decreasing to less than 5 kW average per bus. This is because only half of the fleet has access to chargers immediately upon returning to the vendor lot, and the others must wait instead of charging concurrently.

For managed charging, the limited number of chargers mean that buses cannot schedule charging as freely to flatten coincident demand throughout the day – which would normally be the priority since demand charges outweigh the incremental cost of charging in higher $/kWh periods. This limitation causes the peak demand to increase. However, since demand charges are based on the magnitude of that peak rather than its duration, the buses then shift even more charging to extend that duration and instead reduce costs by not charging under the higher $/kWh early evening rates.

This same constraint has the opposite effect on the V2G summer shape, spreading out and reducing the averaged magnitude of both charging and discharging. Having chargers as a bottleneck on the ability to recharge in-service buses or export back to the grid during a limited number of hours means that the revenue gained by rapidly charging and discharging is no longer able to outweigh the accompanying demand charges. As a result, optimized V2G loads look relatively flat in this sensitivity.

Figure 7. Charging Profiles for the Charger Sharing Sensitivity





Cost-Benefit Assessment – Base Scenarios

Using the charging shapes, costs and benefits from both the bus operator and societal perspective were calculated for the lifetime (16 years) of each school bus during the electrification transition. The results for the base scenarios from the bus operator perspective are shown in Table 7 and Figure 8. The corresponding results from the societal cost test are displayed in Table 8 and Figure 9.

Table 7. Cost-Benefit Results for Base Scenarios - Bus Operator Perspective (Values as Net Present Value in $M)

	Unmanaged		Managed		V2G	
	Costs	Benefits	Costs	Benefits	Costs	Benefits
Electricity bills	$ 637	$ -	$ 239	$ -	$ 868	$ -
Incremental upfront vehicle cost	$ 2,067	$ -	$ 2,067	$ -	$ 2,630	$ -
Charging infrastructure cost	$ 194	$ -	$ 194	$ -	$ 194	$ -
Avoided diesel	$ -	$ 303	$ -	$ 303	$ -	$ 303
Vehicle O&M savings	$ -	$ 266	$ -	$ 266	$ -	$ 266
Totals	**$2,897**	**$ 569**	**$2,500**	**$ 569**	**$3,692**	**$ 569**
Ratio of Benefits/Costs	**0.20**		**0.23**		**0.15**	

Figure 8. Cost-Benefit Results for Base Scenarios - Bus Operator Perspective

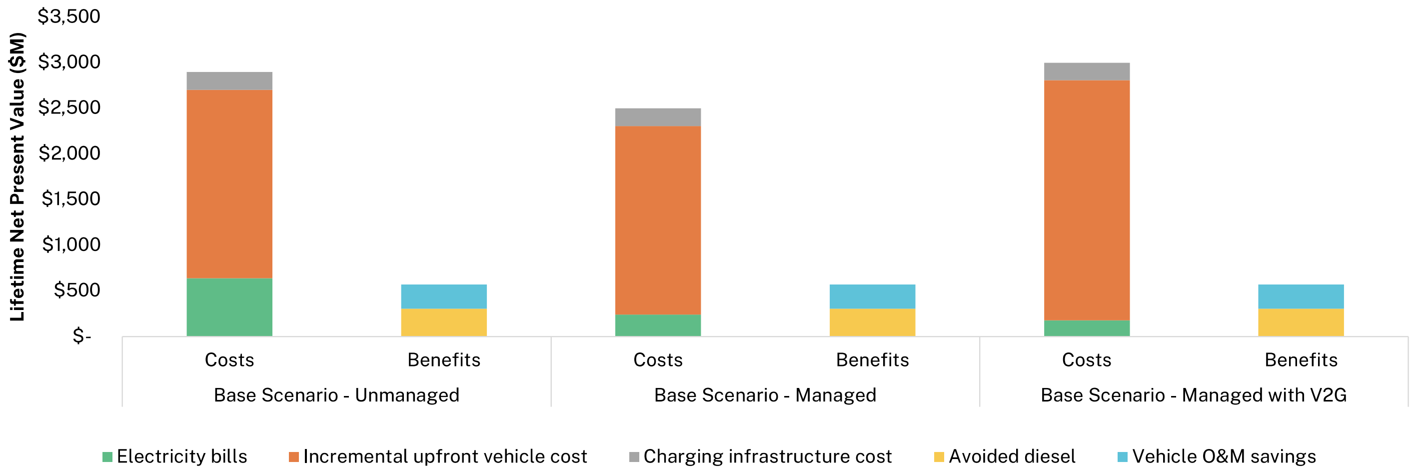
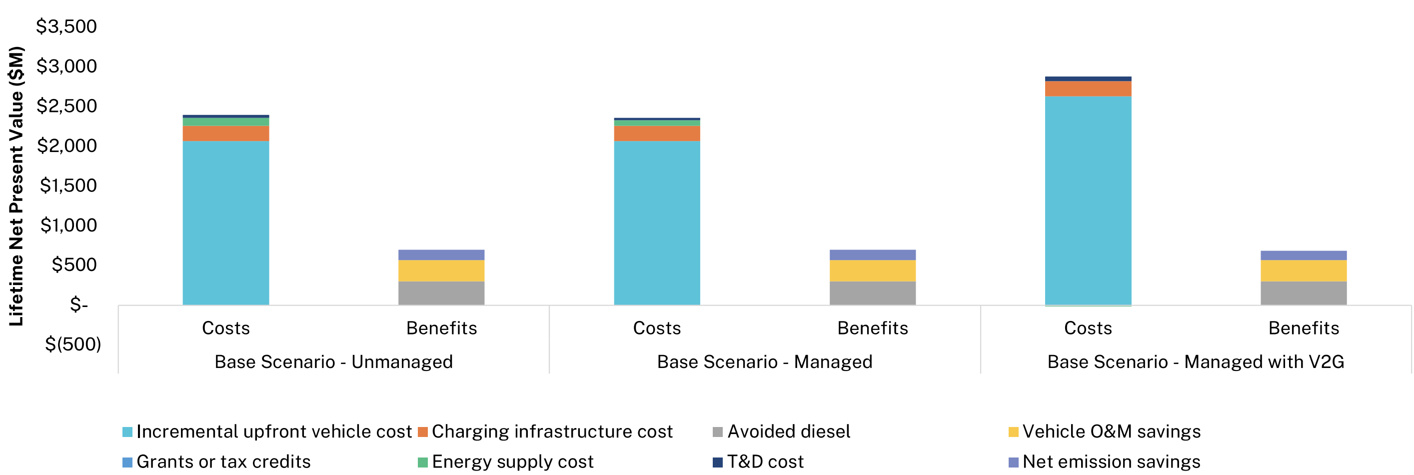


Table 8. Cost Benefit Results for Base Scenarios - NYC Societal Perspective (Values as Net Present Value in $M)

	Unmanaged		Managed		V2G	
	Costs	Benefits	Costs	Benefits	Costs	Benefits
Incremental upfront vehicle cost	$ 2,067	$ -	$ 2,067	$ -	$ 2,630	$ -
Charging infrastructure cost	$ 194	$ -	$ 194	$ -	$ 194	$ -
Avoided diesel	$ -	$ 303	$ -	$ 303	$ -	$ 303
Vehicle O&M savings	$ -	$ 266	$ -	$ 266	$ -	$ 266
Energy supply cost	$ 97	$ -	$ 71	$ -	$ (16)	$ -
T&D cost	$ 40	$ -	$ 29	$ -	$ 55	$ -
Net emission savings	$ -	$ 131	$ -	$ 130	$ -	$ 116
Totals	**$2,398**	**$ 700**	**$2,360**	**$ 699**	**$2,683**	**$ 685**
Ratio of Benefits/Costs	**0.29**		**0.30**		**0.24**	

Figure 9. Cost-Benefit Results for Base Scenarios - NYC Societal Perspective



Across all scenarios and both perspectives, upfront vehicle costs make up the single largest financial component of the transition. As noted in Table 3, the incremental costs of an individual electric bus over its diesel equivalent already exceeds $240,000 in 2023. Collectively, this means the City and its bus operators must plan in advanced for approximately $2 billion of expenditures for this component of the transition. This expense could increase by up to half a billion dollars in a scenario where V2G capabilities are required across the bus fleet and require additional costs. For the sake of illustrating the total expense, this modeling makes a conservative assumption that the incremental bus costs are born in full. When implementing, EPA grants and other federal funding may cover some portion of this cost.

From the bus operator's perspective, electricity bills are the second greatest cost, though this can be mitigated by managing charging or implementing V2G. Between the unmanaged and managed charging scenarios, bus operators see a 62% decrease in electricity bills. With unmanaged charging, bus operators would pay approximately twice as much for electricity over the lifetime of the buses as they would have in continuing to fuel diesel buses. With managed charging, operators could achieve net reduction in fuel costs. Across New York's school bus fleet, this would mean a savings of approximately $397 million compared to the unmanaged scenario. V2G reduces net utility bills even further because of compensation from the VDER tariff, albeit not enough to match the additional capital cost for V2G in this analysis. However, the additional cost for V2G used in this study is a conservative assumption, and V2G was only demonstrated for summer months, showing a low-end estimate for potential revenue. If the buses purchased have V2G capabilities, that cost is removed and year-round VDER compensation may be realized through very attentive V2G management.

Though utility bills were not included in the societal costs (since these bills are a transfer, representing a "cost" to the bus operators but a "benefit" to the utility), managed charging translates to a modest reduction in the utility's energy supply costs (energy, capacity, and monetized greenhouse gas costs). Effective use of V2G results in a net benefit for the energy supply system.

Altogether, the electrification transition will be a significant financial undertaking. In these base scenarios, the present value of total net costs is between $1.9 and $2.5 billion for bus operators, or between $1.6 and $2.2 billion for the City. The Benefit-Cost ratio of electrification ranges from 0.19 to 0.23 for operators and 0.24 to 0.30 for the City as a whole. This does not fully incorporate many of the non-economic benefits of school bus electrification and a net cost is not intended to indicate that a project should not be pursued, especially where it may enable market transformation or equity benefits that would not occur independently. However, this does underline the need for maximizing efficiency in this transition through means such as managed charging.

Cost-Benefit Assessment – Sensitivities

The two sensitivities considered for this analysis adjusted assumptions around the electric vehicle chargers. As the load shape results indicated, the choice of charger power and allocation of chargers between buses affects expected charging behavior. This results in shifts not only in upfront charger cost but also ongoing electricity expenses.

The financial impacts of each sensitivity and the managed charging scenario are shown in Table 9 and Figure 10.

Table 9. Cost-Benefit Results for Managed Charging Sensitivities - Bus Operator Perspective (Values as Net Present Value in $M)

	Managed - Base		Managed - 50kW		Managed - 2 Buses per Charger	
	Costs	Benefits	Costs	Benefits	Costs	Benefits
Electricity bills	$ 239	$ -	$ 239	$ -	$ 262	$ -
Incremental upfront vehicle cost	$ 2,067	$ -	$ 2,067	$ -	$ 2,067	$ -
Charging infrastructure cost	$ 194	$ -	$ 437	$ -	$ 97	$ -
Avoided diesel	$ -	$ 303	$ -	$ 303		$ 303
Vehicle O&M savings	$ -	$ 266	$ -	$ 266		$ 266
Totals	**$2,500**	**$ 569**	**$2,743**	**$ 569**	**$2,426**	**$ 569**
Ratio of Benefits/Costs	**0.23**		**0.21**		**0.23**	

Figure 10. Cost-Benefit Results for Managed Charging Sensitivities - Bus Operator Perspective

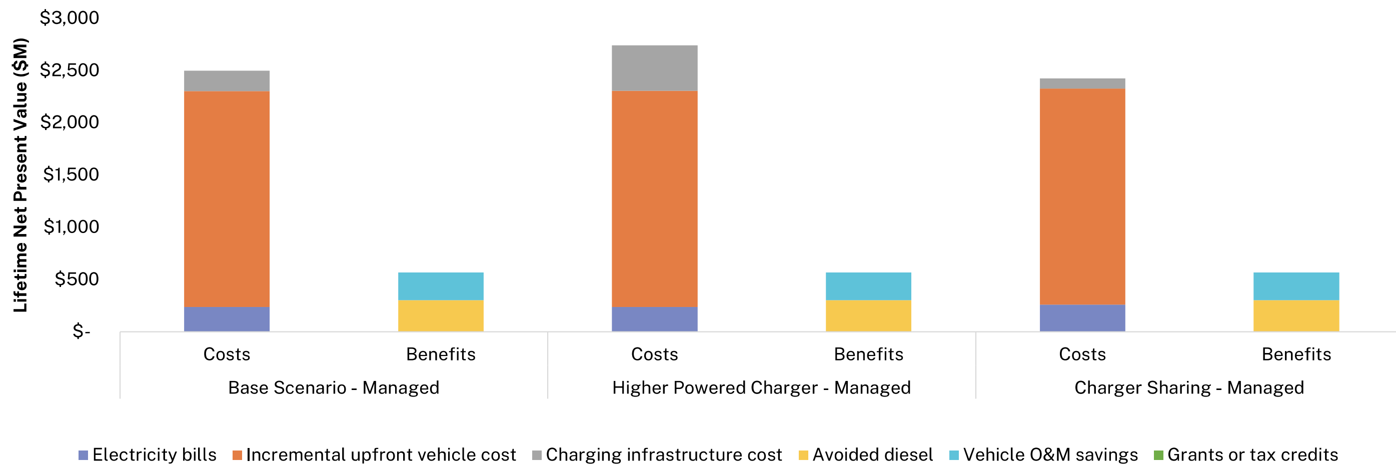


Figure 10 shows the greatest impact of the sensitivities that is common across all scenarios: that the use of higher powered 50kW chargers doubles charging infrastructure costs, while installing only half of the chargers in the two-bus per charger sensitivity decreases these costs, as expected. The use of higher-powered chargers also increases electricity bills in the unmanaged scenario, as peak charging demand and related demand charges roughly double. In the managed scenario shown, there is minimal impact because load shapes remain very similar. For V2G, the increased magnitude of charging and discharging that was observed in the load shapes is tied to additional revenues and a net benefit of $112 million in utility bills.

With two buses per charger, the managed scenario faces more constraints around how charging can be optimized, resulting in a moderate increase in electricity bills. This holds true for the V2G scenario. In contrast, having two buses per charger decreases unmanaged electricity bills by about one-third. Because this implementation would require half of the buses to wait for an available charger, the charging load becomes spread out by necessity, meaning reduced peak demand charges and a slight shift in the charging schedule to lower-cost charging periods.

Table 10 displays impacts of each sensitivity on the societal cost tests for all charging scenarios.

Table 10. Cost-Benefit Results for All Sensitivities - NYC Societal Perspective (Values as Net Present Value in $M)

	Unmanaged			Managed			V2G		
	Base	50kW	2 Buses per Charger	Base	50kW	2 Buses per Charger	Base	50kW	2 Buses per Charger
Total Cost	######	######	$ 2,284	######	######	$ 2,253	######	######	######
Total Benefit	$ 700	$ 700	$ 700	$ 699	$ 699	$ 699	$ 685	$ 684	$ 685
Net Cost	######	######	$ 1,585	######	######	$ 1,554	######	######	######
Benefit-Cost Ratio	**0.29**	**0.26**	**0.31**	**0.30**	**0.26**	**0.31**	**0.24**	**0.23**	**0.24**

While the use of 50kW chargers might allow for greater flexibility in charging and more efficient use of V2G for operators, it also results in higher charging infrastructure costs and marginal transmission and distribution costs. The energy supply benefits from V2G are also less than the utility bill benefits to bus operators, and do not cover the increased infrastructure cost. Sharing one charger between every two buses reduces charging infrastructure and distribution cost components with either unmanaged or managed charging, improving the benefit-cost ratio as compared to the respective base scenarios. For V2G, the changes to optimal charging shape for bus operators means that sharing chargers among buses increases the overall energy supply cost. This makes it a slightly less favorable prospect than maintaining the 1-to-1 ratio. Across all sensitivities, the potential range of net present costs for electrification widens to $1.5 billion to $2.3 billion for New York City. The overall least-cost pathway is to pursue managed charging and share chargers between buses where possible.

Emissions and Air Quality Impacts

The reduction of vehicle-related pollutants is a core benefit of transportation electrification but cannot be perfectly quantified in an economic cost-benefit assessment. As outlined in the methodology section, this analysis incorporates available emissions factors for vehicles and the electric grid, and assigns economic value based on RGGI carbon pricing and EPA air-quality impact studies. The monetized value of CO2 emissions from the electricity grid is included in the energy supply costs, whereas non-monetized societal value of CO2, NOx, and PM2.5 emissions are valued at societal impact rates as the net emission savings component in the societal cost test. This valuation results in around $130 million of net benefits.4 This corresponds to a total of approximately 1.2 million metric tons of net avoided CO2 emissions, 3.4 thousand metric tons of net avoided NOX emissions, and 38 metric tons of net avoided PM2.5 emissions over the lifetime of the bus fleet. As the City's electric grid decarbonizes, these savings will grow.

The greatest air quality impacts will be felt by the children riding the buses and by those along the routes that the school buses travel. This means that the transition can be made to directly prioritize environmental justice initiatives in the selection of which routes to electrify first. There is also an expected initial increase in pollution from fossil-fuel plants serving the electric grid, as additional electricity is needed to serve the school buses. While this impact is minor compared to the vehicle fuel emissions avoided, and will decrease as the electric grid transitions away from fossil fuels, these communities should also be recognized.

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[i] Source: New York State
[ii] Source: The New York City Council
[iii] Source: "Inequitable Exposure to Air Pollution from Vehicles in New York State." Union of Concerned Scientists
[iv] Source: "The Contribution of Motor Vehicle Emissions to Ambient Fine Particulate Matter Public Health Impacts in New York City: A Health Burden Assessment." Environmental Health
[v] Source: "School Buses, Diesel Emissions, and Respiratory Health." Journal of Health Economics
[vi] Source: Con Edison
[vii] Source: "School Buses: Award Summary." New York State OGS
[viii] Source: "Electric School Bus U.S. Market Study and Buyer's Guide." World Resources Institute
[ix] Source: Argonne National Laboratory
[x] Source: "Update on Electric Vehicle Costs in the United States Through 2030." The International Council on Clean Transportation (ICCT)
[xi] Source: "Estimating Electric Vehicle Charging Infrastructure Costs Across Major U.S. Metropolitan Areas." The International Council on Clean Transportation (ICCT)
[xii] Source: U.S. Department of Energy Alternative Fuels Data Center
[xiii] Source: U.S. Department of Transportation Federal Highway Administration
[xiv] Source: U.S. Energy Information Administration
[xv] Source: Argonne National Laboratory
[xvi] Source: Con Edison
[xvii] Source: "2019 Congestion Assessment and Resource Integration Study (CARIS) Report." New York Independent System Operator
[xviii] Source: New York State Department of Public Service
[xix] Source: New York State Energy Research and Development Authority

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[4] Note that these savings may be slightly lessened (to approximately $116M) by the use of V2G under the current VDER schedule. This is expected due to increasing the buses' total demand on the electrical grid in order to export during summer hours when rates are beneficial to bus operators but the potential for clean energy generation would also be at a peak.

[xx] Source: U.S. Energy Information Administration
[xxi] Source: "Establishing a Value of Carbon: Guidelines for Use by State Agencies." New York State Department of Environmental Conservation
[xxii] Source: U.S. Bureau of Transportation Statistics
[xxiii] Source: U.S. Environmental Protection Agency
[xxiv] Source: "Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors." U.S. Environmental Protection Agency