Assessing The Economic Feasibility of Converting The Portland Public School District Bus Fleet From Current State to EV

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Acronyms and Abbreviations

PPSD	Portland Public Schools District
PGE	Portland General Electric
EV	Electric Vehicle
ODOE	Oregon Department of Education
V2G	Vehicle-to-Grid
ICE	Internal Combustion Engine
DGE	Diesel Gallon Equivalent
MPDGE	Miles per Diesel Gallon Equipment
CFP	Clean Fuels Program
PEV	Personal Electric Vehicle
CEC	California Energy Commission
USEIA	U.S. Energy Information Administration

1 Abstract

School bus fleets are optimal test beds for V2G integration due to the centralized location of bus depots, their respective infrastructure, and the vehicles limited use during the day. This limited use during the day means that the fleet has a known and predictable charging schedule. The Portland Public School District (PPSD) is ready to retire half their fleet within the next five years, positioning them to take advantage of this timing and evaluate a fleet conversion from primarily diesel to primarily electric. Preliminary research indicates that while the cost of purchasing an electric bus is substantially large, the savings found through reduced maintenance and fuel costs alone cannot offset the large purchase price. Value must be found through other means. Equity analysis, ancillary services, electricity wholesale markets, emissions concerns, utility programs, and recent FERC orders like 745 each have their own way to add unrealized value into the equation. This paper will evaluate the cost and benefits to the PPSD in the Portland Metro area to determine the ideal economic feasibility regarding a fleet conversion from current state to electric vehicle (EV). From this analysis we create a model to evaluate other school district fleets within the Portland General Electric service territory based on current tariffs, technologies, miles driven, and policies in effect today.

2 Introduction

The rise of EV ownership has led policymakers, grid operators, and public utilities to begin addressing their integration onto the grid through V2G. V2G refers to the process of energy transfers between an EV and a recipient that could be the grid, a building, or substation. The technology offers numerous benefits to the consumer and the grid. The consumer will see benefits in the form of reduced electricity costs from charging during non-peak times, and likely through additional financial incentives and storage options. The grid will see these benefits in the form of resiliency, ancillary services, storage ability, reduced need for peak generation facilities and reduced grid stress.[1] Society at large sees the benefit through increased demand for renewable energy, and the ability to further move away from utilizing fossil fuels for electricity production. The Pacific Northwest is somewhat uniquely situated to meet this energy transition. Wind energy production is more abundant during non-peak times when EV's would be charging, and EV's then could provide excess charge to the grid when wind production is not a viable energy source.

V2G fleet services could then be a powerful mechanism for Oregon to meet its goal of reduced carbon emissions by 2030.[2] School bus fleets are optimal test beds for V2G integration due to the centralized location of bus depots, their respective infrastructure, and the vehicles limited use during the day. In addition, their limited summer use helps to

[1] *Utilities and Electric Vehicles: The Case for Managed Charging*, 2017
[2] *Climate Action Plan Summary*, City of Portland and Multnomah County, 2015

further limit uncertainty about availability, and offers increased potential for these services. PPSD is ready to retire half their fleet within the next five years, positioning them to take advantage of this timing and evaluate fleet conversion. This assessment aims to analyze the long term economic feasibility of converting the fleet from current state to EV.

Despite all of the benefits of V2G integration, there are several concerns surrounding the necessary initial investment, specifically for a public school district. It has been shown that operating costs for many EV's are, on average, lower than those using diesel and other fossil fuels.[3] The main obstacles preventing V2G integration reform begin with the sheer complexity of the task. This includes budgetary restraints, legislative reforms, and grid infrastructure compounded with variability in implementation, technology, and available resources. Therefore, restricting the case study to a single school district and utility company is vital, and certain assumptions must be made. For these reasons, this paper shall be focused on evaluating PPSD which lies within the territory of PGE.

3 Overview of benefits to grid

While addressing the economic feasibility for the switch from current state to EV, it is vital to address the benefits to the grid. Although incentive programs are outside the scope of this analysis, it's important to address that they exist, and could mitigate the impact of initial investment if incentives for utility companies to invest in V2G infrastructure existed.

Resiliency of the grid is difficult to value until it's needed but is of the utmost importance. Battery storage has become one of the most cost effective ways to meet this need[4]. PGE has previously developed the Salem Smart Power Center [5] and is currently in development of a wind and storage facility [6] in partnership with NRG Energy. In addition, PGE has started experimenting with V2G technologies at one of their Portland substations. This positions PGE to make the next jump and partner with school districts on similar projects regarding V2G integration. This confluence of events generates interest for investing in V2G infrastructure.

The conversion of the PPSDs bus fleet could further serve as a pilot program for the other districts serviced by this particular utility. If the utility company can better understand the costs and benefits from converting one district fleet, then it can develop a viable framework for future conversion for other districts it serves. As they include investments in V2G infrastructure into the battery development portfolio they may be able to more

[3]Noel, Lance, and Regina Mccormack. 2014. "A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus."

[4]Richardson, David B. 2013. "Encouraging Vehicle-to-Grid (V2G) Participation through Premium Tariff Rates."

[5]The Salem Smart Energy Plant is a battery storage system aimed at integrating more renewable energy, stabilization of grid components, and to provide simulations of a microgrid for tests of grid resiliency.

[6]The Wheat Ridge Project is aimed at providing more solutions to further increase renewable energy production for PGE.

quickly realize return on investment. Pilot programs like this can prepare PGE for the substantial impacts on the grid that transportation electrification poses.[7]

4 Assumptions of V2G implementation

4.1 Technology factors

V2G technology is changing rapidly, and this effectively changes the costs associated with any system implementation drastically. V2G like most new technology is changing rapidly. Undoubtedly, this expected innovation creates an incentive to wait for further market development, as system implementation costs decline. To mitigate this effect, it was necessary to assess the current market and make assumptions based on these findings. Additionally, the age of the fleet provides justification for dismissing the potential savings from future technological advances.

4.1.1 Batteries

The costs of EV battery manufacturing have been steadily declining since the market for EV's started growing, and there is strong evidence that these costs will continue declining in the future.[8] As batteries become more feasible, initial investment expenditure declines as well as expected maintenance costs. In addition, the impact from ancillary services on battery degradation, which is of large concern for long term maintenance, would become less integral in determining long run costs.

[7] Wu, Ye, Zhengdong Yang, Bohong Lin, Huan Liu, Renjie Wang, Boya Zhou, and Jiming Hao. 2012. "Energy Consumption and CO2 Emission Impacts of Vehicle Electrification in Three Developed Regions of China."

[8] *Update On Electric Vehicle Costs In The United States Through 2030*, International Council On Clean Transportation, 2019

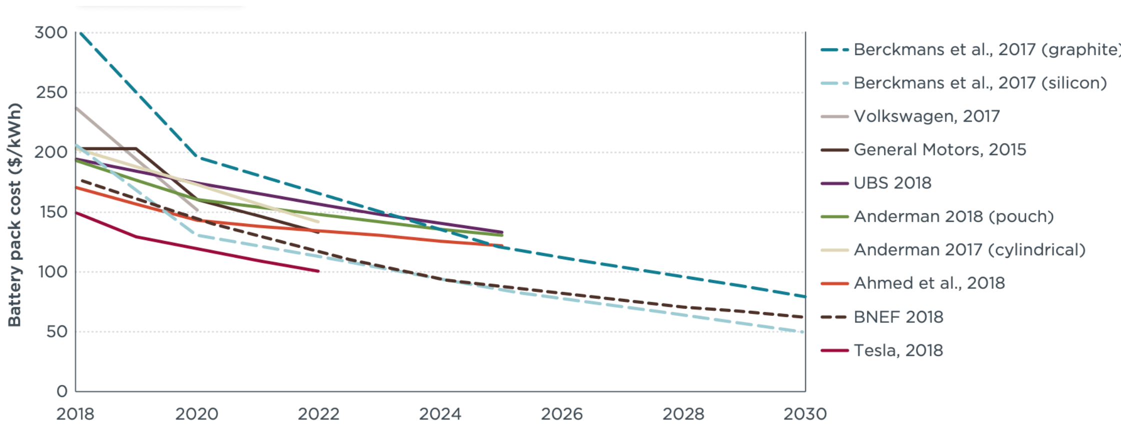


Figure 1 Electric vehicle battery pack costs from technical studies and automaker statements.[9]

The PPSD owns roughly one-hundred buses of similar size with similar daily mileage demands. They also contract out a large number of their services to a third-party that operates larger buses but with similar mileage demands. For this reason, we have limited the scope of this analysis to only buses owned by the district. The variation in bus design and component make up is substantial. One of the largest variances is battery size. This analysis uses the assumption that battery size is fixed to a standard 240 kWh size. It should also be noted that many EV bus models allow for interchanging batteries. In this way, multiple battery packs could be used for each bus so as to not only increase the available size of the on-board battery, but also to provide more capacity for ancillary services later in the day. This significantly increases the initial cost of fleet conversion, and would not be needed for normal bus operation. Beyond just normal operation, there would be additional labor expenses needed to change out batteries, complicating this evaluation without specific data regarding how long it takes to perform this work for a depot full of busses. Therefore, this strategy is not considered in this analysis.

4.1.2 Charging stations

The routes for the current fleet vary significantly in length, thus the required charge for each bus is different. This presents an interesting metric for considering the capacity of infrastructure requirements, namely the size of charging stations, and their relative charging speeds. The grid delivers AC power, but charging stations are required to convert it to DC current. The time required for each bus to charge will therefore be different, so optimizing expenditure on capacity of charging services as well as charging schedules will be important when addressing initial investment requirements. In addition, these systems are evolving quite rapidly, each requiring less investment, space, and distribution legs.

[9] *Update On Electric Vehicle Costs*, International Council On Clean Transportation, 2019

The ability to manage the charging schedules of the school bus fleet will be imperative in designing effective V2G implementation. For the fleet to be adequately charged to meet route demand, as well as to optimize performance for ancillary services, smart charging will need to be integrated into the system. This study acknowledges the fact that a school district would most likely need an external service to manage this. The costs that this adds are variable, and need further assessment. There are a number of options currently available to fill this role, and the market for this technology is growing. For this reason, the charging stations chosen will need to be bi-directional, offering the capacity for V2G operations. This study focuses on current market availability that will allow for V2G participation in the future where level 2 chargers operate at 19.2 kWh.

4.2 Wholesale energy markets

Every local energy market is going to be part of a larger wholesale market that will be able to subsidize its energy demands. These are ancillary services, that can ramp up generation for grid operators for supplementing hourly demand. It would be possible for the PPSD to participate in ancillary services that could be sold to other utility companies. On the wholesale market, it may be possible to garner a higher premium per megawatt (MW) than would be available through the local electric utility. This however would necessarily create the need for a specific department focused on maximizing revenue. By extension, the creation of this department would limit the net gains from its creation, possibly to the point where it was costing more to participate in the wholesale market in the first place. For this reason, this analysis acknowledges the existence of a wholesale market, but focuses on the more realistic assumption that the district would provide and receive compensation for ancillary services through the local electric utility. In addition, the rates established for year round buying and selling of energy from the grid would most likely need to be altered during the Summer months, given that the district would be able to provide more services to the grid, and thus potentially profit significantly. Another solution to variable rates by season would be PGE renting the battery storage systems from the district for a fixed or variable rate, to ensure both parties are fairly earning advantages from implementation.

4.3 Overview of current legislative issues

There are several issues with fleet conversion in terms of OAR's. It should be made clear that EV buses are no less safe than conventional buses. This is why the current rules and regulations aren't focused on restricting EV bus use, yet they simply don't allow for certain mechanical differences between the two. For example, the administrative rules outlined by the ODOE [10], outline the need for regular oil changes at regulated mileage

[10] *Pupil Transportation and Fingerprinting*, Oregon Department of Education, Chapter 581, Administrative Rules (Comprehensive)

intervals. Given that EV engines don't use oil, they would be unable to comply with this rule. Therefore, they would not be eligible to be used for transportation services.

It is possible to submit a variance that could make an exception for one of these current issues. This wouldn't actually change the OAR's, it would just allow this one acceptance. It makes far more sense to change them at the state level, to allow for EV adoption. There are numerous other issues similar to the one detailed above. These include but are not limited to regenerative braking, reliability of EVs, and various ICE components that are not used in EVs. All of these issues are currently being addressed by representatives from the ODOE and PGE, and should all be resolved by the start of the 2020-2021 school year.

5 Limitations of study

There are numerous positive externalities that arise from a relatively small fleet conversion that fall outside the scope of this assessment. It would be difficult to monetize them in an economic analysis, but nevertheless they are abundant.

5.1 Health and wellness of children

Several studies have been conducted evaluating the positive benefits from fleet conversion on children's health and wellness. One study found that children are more likely to test better and hold a greater retention of material when not exposed to carbon emissions.[11] They also found that of the buses studied, the levels of pollutants inside the buses were higher than outside the bus on roadways. This presents a fantastic opportunity in public health and an investment in future generations. In addition, the benefits from less pollution affect a much larger percentage of the community as a whole. This positive externality of fleet conversion is fairly easy to monetize the positive effect on the public, and it directly plays into the economic benefits of conversion. Several studies have quantified the cost of emissions. The per mile cost of diesel health emissions is $0.08. The per mile cost of electricity health emissions is $0.0149, and roughly 80% less than the per mile cost of diesel health emissions. [12]The variance between the two is significant and will be evaluated in the cost component of the analysis.

5.2 Feed in tariffs for ancillary services

While assessing the viability of fleet conversion, a chief economic benefit will be V2G services. As mentioned previously, with smart charging capabilities, it would possible to charge buses overnight while energy is less expensive, and then sell it back to the utility

[11] Austin, Wes, Garth Heutel, and Daniel Kreisman. 2019. "School Bus Emissions, Student Health and Academic Performance."

[12] Noel, Lance, McCormack, "Cost benefit analysis", 4.

company during peak times. This would generate a revenue stream on top of the savings from conversion that would greatly reduce the long run costs of fleet conversion. It also allows greater use of renewable energy like wind overnight, while mitigating the need for fossil fuel energy production during peak times. The cost structures for these feed in tariffs have been well researched in a variety of markets[13] and their implementation will be necessary for fleet conversion. The specific implementation for Portland Public Schools District (PPSD) and Portland General Electric (PGE) are outside the scope of this paper, as these rates would need to be independently negotiated.

5.3 Programs for conversion

Currently in Oregon there are several programs being developed by utility companies to invest in V2G infrastructure to test the feasibility of such programs. One such state program is the Clean Fuels Program (CFP) which aims to reduce greenhouse gases in the transportation sector.[14] Each personal electric vehicle (PEV's) in the state of Oregon generates a carbon credit. PGE will use the credits originating within their territory to fund four electric bus acquisitions, each in a different school district. These electric buses will be the basis for a pilot program and will be vital to assessing initial actual costs of infrastructure building and to find any unforeseen hidden costs of implementation. Oregon is an interesting case however, given that legislative difficulties have largely hindered the development of programs like these. When the legislative issues are resolved next year, further program development can begin and the initial costs of fleet conversion will be further reduced. For this reason, the possibility of future programs are being left out of this analysis. The existing programs are based on a lottery system, so their implementation cannot be relied upon.

On the federal level, there are several programs in the form of tax credits to offset fleet conversion.[15] Given that these programs are still evolving and the particular application for the state of Oregon are unclear, these have also been left out of this analysis. Further research is needed to establish the effectiveness of these programs.

5.4 Conversion vs. replacement

There are two main strategies to electrify a bus fleet; purchasing new buses, or outfitting old buses with EV systems. The latter offers several advantages, and would be

[13] Richardson, David B. 2013. "Encouraging Vehicle-to-Grid (V2G) Participation through Premium Tariff Rates."

[14] Oregon Clean Fuels Program (Department of Environmental Quality), 2019

[15] "Low or No-Emission (Low-No) Bus Program", "Congestion Mitigation and Air Quality Improvement", and State of Good Repair programs are grants which state and local governments apply for on an annual basis. These programs are operated by the Department of Transportation. In addition, the "School Bus Rebate Program" is a program from the U.S. Environmental Protection Agency and is designed to help school districts reduce their diesel emissions.

necessary for fleet conversion of newer diesel buses. If the district were to convert the fleet, it would need to wait until each particular bus is no longer viable for operation. This usually happens when a bus has been in service for thirteen years. Given that almost half of the current fleet is less than ten years old, if immediate conversion was desired, these newer buses would need to be converted, rather than replaced with new EV buses.

The advantages include being able to convert the fleet over a shorter time period, limiting the financial costs of resale (so as to not lose fleet equity), and eliminating other externalities arising from component replacement. It should be noted that it is possible for the entire fleet to be converted without ever purchasing a new bus. In fact, it would be far less expensive to buy buses that are no longer fit for service and convert their systems to re-purpose them for the district. Though this raises new and untested legal concerns. The industry for this type of conversion is still developing and so the exact pricing models are varying quite a bit. In addition, it is unclear if grant money from future program developments could be used for this type of fleet conversion. For all of these reasons, we focus on new vehicle acquisition as the primary means of fleet conversion.

5.5 Future industry innovation

There exists a downward trend regarding system costs. This analysis is assuming current costs and conditions for its evaluation of the cost effectiveness of conversion. Given the level of innovation in only the last few years, it's easy to predict further trends of system costs. An environmental consulting firm recently did a study of market trends and came to a similar conclusion.[16] The study found that battery costs, the battery replacement ratio, and other mechanical systems for EV's will decline in the future. In addition, it found that battery energy density, effective range, battery life, and other mechanical component efficiency to increase significantly. This will change the makeup of the costs already outlined.

Beyond cost of ownership and operation, there exist initial investment opportunities. As mechanical system stability increases, the initial purchase price of EV's will decrease. This will also cause the energy efficiency of the bus to increase, thus lowering fuel costs. Subsequently, the cost of ownership will decrease. In addition the U.S. Energy Information Administration (USEIA) foresees diesel costs relative to electricity costs rising every year in perpetuity. Each of these trends are interdependent, but the overall magnitude of them will be left to further studies.

5.6 Second life batteries

V2G implementation may offset the need for grid scale storage investment, for two reasons. First, fleets have the opportunity to become large scale battery storage systems. These fleets would be made entirely of first life batteries. When designing one of these

[16] *Electric Buses 101* (M.J. Bradley and Associates), 2019

battery systems, the initial round of batteries is made entirely of first life batteries. The usefulness of EV batteries starts declining when the battery can only hold a charge that is roughly 60% that of it's initial capacity.[17] At this point, it can't charge to meet the mileage needs of an average electric bus. A study was conducted though that showed that these batteries could still serve in a storage system setting for much longer and are called second-life batteries.[18] The school district may be able to sell used batteries back to a utility company, thus accomplishing several goals. The cost of battery replacement for a school bus would be reduced given that the selling price of the old battery would offset the cost of a new one. Also, battery waste is reduced by allowing second-life batteries to provide services for the grid beyond just electric bus implementation. This second life reduces the cost of building and developing future storage systems by a utility company.

5.7 Further limitations

There are several other opportunities to make fleet conversion profitable that fall outside the scope of this analysis, but are important to acknowledge. Among these, the most interesting may be the ability to install solar panels on top of EV buses. This presents an interesting way to maximize real estate for renewable energy production. For a fleet consisting of over one hundred buses, the energy produced is significant. These systems represent another investment though that would not be realistic to implement at the initial conversion stage. In addition, energy production in the summer while the bus fleet is not as heavily in use provides another way to generate income for the district. To complicate things, given the decommission rate for a school bus is roughly half the life of a photovoltaic (PV) solar panel, the labor costs associated with relocating used panels onto new buses may make this strategy too costly to implement.

6 Evaluating the costs of system implementation

The cost effectiveness model used for conversion evaluation is based off of a similar study from the California Energy Commission (CEC), which will help to evaluate the economic feasibility of fleet conversion.[19] The monetary benefits realized from conversion include decreased fuel costs and decreased maintenance costs. Though they still hold clear value, ancillary services such as V2G will not be assessed in this model. First, the current and future costs of the current fleet with respect to fuel, maintenance and replacement will

[17] *Encouraging Vehicle-to-Grid (V2G) Participation through Premium Tariff Rates*, Richardson, 2013.

[18] *Reuse and Repower: How to Save Money and Clean the Grid with Second-Life Electric Vehicle Batteries*, Elkind, 2014

[19] *School Bus Replacement for California Public School Districts, County Offices of Education, and Joint Power Authorities* (California Energy Commission), 2018

be evaluated. Second, the cost of purchasing new buses and the resulting infrastructure purchasing will be assessed. Third, health costs will be included in the analysis, but will only have limited application in the final recommendation due to the limited nature of which public agency bears the burden of health costs. Finally, the cost of an EV fleet will be assessed in terms of fuel costs, maintenance, and battery replacement.

This assessment looks at a time period of ten years because this is the expected length of time for total turnover of the current fleet. In other words, the current fleet will be completely replaced inside of ten years, to meet the thirteen year cycle expressed earlier. Given this time frame, the present worth value of any savings will need to be analyzed.

The ODE re-imburses the PPSD for all bus purchases at a rate of 7% of the original purchase price per year. This does not include maintenance expenses. When assessing the added cost of fleet conversion, the original purchase price of the vehicle is reimbursed, however, the battery costs would be thought of as maintenance, and therefore would not be reimbursed.

6.1 Figures and equations used

The model used here to evaluate conversion is based on a similar study done by the CEC and uses several basic assumptions. First, it assumes a discount rate of 2% in all valuations of present value. The fuel cost growth rate is attained from the USEIA at 3.1% annually for electricity and 3.9% annually for diesel. The present worth formulas for future fuel and maintenance costs are given by the following equations,

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

$$\text{Maintenance Costs} = \text{Annual Mileage} \cdot \text{Maintenance Cost per Mile} \cdot \frac{(1 - (1 + \text{discount rate})^{-\text{period}})}{\text{discount rate}}$$

We calculated an average rating of 7.4 miles per gallon for the diesel buses, and assume an average of 2.84 kWh per mile for electric buses.[20] There are two conversions used when comparing EV's to internal combustion engines (ICE). The first is the miles per diesel gallon equivalent (MPDGE) which compares electricity used to fuel economy of an ICE. This would mean that 19.6 is the MPDG equivalent for an electric bus.[21] The second is the e-Gallon conversion, which compares fuel costs to electricity costs. The formula for the

[20] *School Bus Replacement for California Public School Districts* (California Energy Commission), 2018

[21] Eudy, Leslie, and Matthew A. Jeffers. 2018. "Zero-Emission Bus Evaluation Results: County Connection Battery Electric Buses."

e-Gallon is given below.

$$\text{e-Gallon (\$/gal)} = FE \cdot EC \cdot EP^{22}$$

where,
FE = the average fuel economy of a comparable diesel bus

EC = the average electricity consumption (kWh/mile) of the electric bus

EP = the local electricity price (\$/kWh)

This study assumes an energy price of 11.78/kWh.[23] We also assume an average cost of \$3.49 per gallon of diesel. With this, we can calculate the e-Gallon price.

$$\begin{aligned}\text{e-Gallon (\$/gal)} &= (7.4\frac{miles}{gallon})(2.84\frac{kWh}{miles})(0.1187\frac{\$}{kWh}) \\ &= 2.49\frac{\$}{kWh}\end{aligned}$$

This means that the equivalent cost per gallon of operating an EV is 28.6% less than diesel. In other words, fuel expenditure should be 28.6% less on EV's compared to their diesel counterparts.

The public health benefits from carbon abatement and reduction of various other pollutants is considerable. The per mile cost of diesel health emissions was estimated to be \$0.08 while the per mile cost of electricity health emissions is \$0.0149. This represents the relative impact that fleet conversions has on the relative public health for the Portland Metro area.

$$\begin{aligned}\text{Public Health Costs of Diesel Emissions (10 years)} &= \$0.08 \cdot (\text{Yearly Mileage}) \cdot \frac{(1+0.02)^{10}-1}{0.02(1+0.02)^{10}} \\ \text{Fleet Total} &= \$3,039,286.55\end{aligned}$$

$$\begin{aligned}\text{Public Health Costs of EV Emissions (10 years)} &= \$0.0149 \cdot (\text{Yearly Mileage}) \cdot \frac{(1+0.02)^{10}-1}{0.02(1+0.02)^{10}} \\ \text{Fleet Total} &= \$566,067.12\end{aligned}$$

$$\text{Public Health Savings From Fleet Conversion (10 years)} = \$2,473,219.43$$

If the PPSD were to convert their convert, this study estimates the net savings on public health over the next ten years would be \$2,473,219.43.

[23]PGE data based on schedule 38; https://www.portlandgeneral.com/our-company/regulatory-documents/tariff; Will need help citing this document.

6.2 Current fleet costs

The current fleet is composed of approximately 102 type "C" diesel buses and 43 gas powered vans/sedans. This study focuses on the bus portion of this fleet, and in addition restricts the scope to daily operation not including athletic events, field trips, etc. given the variability in demand for bus maximum mileage. The district would most likely need to keep some diesel buses to perform some services for the district like field trips, athletics and other activities demanding longer distance transportation. The PPSD also contracts out a great deal of their daily ridership to a third-party, and much of their transportation for athletic events and field trips are provided with the third party fleet as well. Therefore, the number of average miles driven by one of their buses may be less than that for a typical district. The average length of one of the routes a bus would travel is approximately 14.07 miles, but varies widely. Every bus usually goes out on two routes in the morning and two routes in the evening; AM/PM for middle schools, and AM/PM for elementary. PPSD has a waiver for high school transportation and is not included in their costs, lending to the uniqueness of their district. Over a year, the average number of miles driven by each bus is approximately 5811 miles.

The buses in the fleet are split up into three groups based on how many years they've been in operation. The groups contain buses that have a service life (SL) of less than five years (group one), from five to ten years (group two), and more than ten years (group three), respectively.

6.2.1 Fuel and maintenance costs per bus per year

	$SL < 5$ years	5 years $< SL <$ 10 years	10 years $< SL$
Number of Buses	26	27	49
	$--$	$--$	$--$
Fuel Costs	4778.03	4938.38	4885.64
$p-value$	$--$	0.033566	-0.0106
Maintenance Costs	2580.46	3665.13	4131.15
$p-value$	$--$	0.42034	0.2066

Figure 2 Current fuel and maintenance costs per diesel per year summarized.

This shows that the age of the bus has no statistically significant impact on fuel costs given that the relative p-values are less than 5%. However, as age increases so do maintenance costs given a p-value greater than 5%. This also shows that the district decreases costly repairs for older buses, so as to limit investment before they retire a bus.

6.3 Current fleet costs over next ten years

In analyzing the expected costs for the next ten years for the diesel fleet, the largest factor would be bus acquisition. As shown, the average age of the fleet is over ten years of age. Over the course of the next ten years, the school district will need to replace 76 buses. This represents a significant investment in the current diesel fleet, but also a fantastic opportunity to invest in electric buses. If over the next five years the district purchased new diesel buses, fleet conversion would become more difficult and certainly take longer. As the number of buses that need replacing would be significantly less, the sunk costs on the diesel fleet would inhibit investment in EV conversion. The district wouldn't invest in new buses and then also pay to convert them to electric. So the process of fleet conversion would take a significant amount of time.

The present worth evaluation of fuel costs over the next ten years is given by the following formula.

$$\text{Fuel Costs (per bus)} = \frac{\text{Yearly Mileage}}{7.4\frac{mi}{dge}} \cdot \frac{\$3.49}{dge} \cdot \frac{1-(1+0.02+0.039)^{-10}}{0.02+0.039}$$

$$\text{Total Fuel Costs (of fleet)} = \$1,783,384.53$$

Calculating the perceived maintenance costs for the next ten years of the diesel fleet is more complicated given that age has a statistically significant impact on that cost. Given that each group is separated by approximately five years, it's necessary to calculate the perceived maintenance costs for each group in five year increments, using the appropriate maintenance cost per mile figure. Maintenance cost per mile MCM_i (for $i =$ group number) is then given for each group.

$$\begin{aligned} MCM_1 \text{ } (SL < 5 \text{ years}) &= \frac{\$2580.46}{5810.66 \ mi} \\ &= 0.4441 \frac{\$}{mi} \end{aligned}$$

$$\begin{aligned} MCM_2 \text{ } (5 \text{ years} < SL < 10 \text{ years}) &= \frac{\$3665.13}{5810.66 \ mi} \\ &= 0.6308 \frac{\$}{mi} \end{aligned}$$

$$\begin{aligned} MCM_3 \text{ } (10 \text{ years} < SL) &= \frac{\$4131.15}{5810.66 \ mi} \\ &= 0.7109 \frac{\$}{mi} \end{aligned}$$

The present worth evaluation of maintenance costs (MC) then is evaluated for each bus in each group. For example, a bus in group one would be evaluated for five years with a maintenance cost per mile of \$0.4441/mi, and then five years with a maintenance cost per mile of \$0.6308/mi. The third group will be evaluated for five years of maintenance costs at \$0.7109/mi. Then, given that it will be replaced with new diesel buses, the new group will be evaluated for five years of maintenance costs at \$0.4441/mi.

$$\begin{aligned} MC_1 &= 5810.66\ mi \cdot \frac{\$0.4441}{mi} \cdot \frac{1-(1+0.02)^{-5}}{0.02} + 5810.66\ mi \cdot \frac{\$0.6308}{mi} \cdot \frac{1-(1+0.02)^{-5}}{0.02} \\ &= \$29,439.69 \end{aligned}$$

$$\begin{aligned} MC_2 &= 5810.66\ mi \cdot \frac{\$0.6308}{mi} \cdot \frac{1-(1+0.02)^{-5}}{0.02} + 5810.66\ mi \cdot \frac{\$0.7109}{mi} \cdot \frac{1-(1+0.02)^{-5}}{0.02} \\ &= \$36,749.89 \end{aligned}$$

$$\begin{aligned} MC_3 &= 5810.66\ mi \cdot \frac{\$0.7109}{mi} \cdot \frac{1-(1+0.02)^{-5}}{0.02} + 5810.66\ mi \cdot \frac{\$0.6308}{mi} \cdot \frac{1-(1+0.02)^{-5}}{0.02} \\ &= \$31,633.49 \end{aligned}$$

The total maintenance costs for the diesel fleet over the next ten years, in present value, is included in the following table.

	$SL < 5$ years	5 years $< SL <$ 10 years	10 years $< SL$
MCM_i	$\$29,439.69$	$\$36,749.89$	$\$31,633.49$
Number of Buses	26	27	49
Total Maintenance Costs	$\$765,431.94$	$\$992,247.03$	$\$1,550,041.01$

Figure 3 Projected maintenance costs per bus per year for next ten years.

6.2.2 New diesel bus acquisition

Given that the majority of the fleet will need to be replaced in the next ten years, this poses a significant impact on the costs of the current fleet. The PPSD only owns and operates type "C" buses. The average retail price for one of these new buses is \$150,000. The district will aim to replace 76 buses in the next ten years. This amounts to \$11,400,000 for new diesel bus acquisition. However, they will see a return of 7% on those purchases every year over the next ten years. Therefore, if a diesel bus costs \$150,000 initially, the state will see a return of \$8,076.92 per year for ten years. Over the course of ten years, the district will see a return of \$72,551.65 for each new diesel bus purchased. For the purposes of this analysis, we can say that the real cost to the district will be the original price minus the reimbursement amount. This cost will be \$77,448.35 per bus. To conclude, to replace 76 buses at \$150,000 per bus, the district will need to spend \$5,886,074.74.

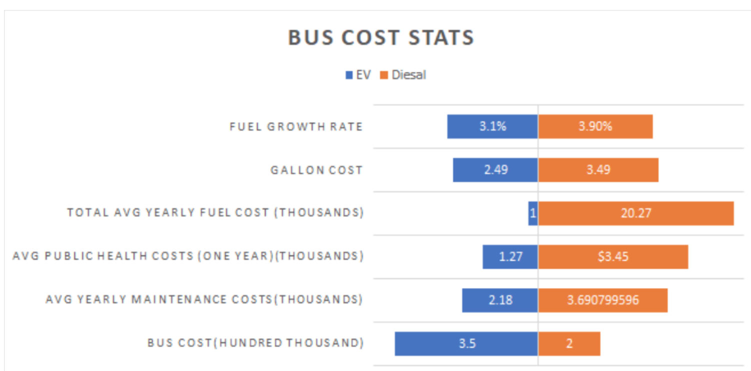
In total, the district is set to spend \$10,977,179.25 on the current diesel fleet over the course of the next ten years in present dollars. In other words, the district will spend approximately $1,097,717.93/year for the next ten years.

6.4 Cost of conversion

Fleet conversion would entail the phasing in of electric buses over approximately ten years and building infrastructure over similar time periods.

6.4.1 Infrastructure for bus depots

The infrastructure needed for fleet conversion consists of transformer installation, general electrical and construction improvements per site, as well as chargers, charger maintenance and software for smart charging. The whole of the fleet is currently located at two distinct bus depots. Assuming that composition doesn't change, many costs are mitigated in terms of distribution system upgrades for the utility. We assume an equal share of the fleet for two distinct bus depots during fleet conversion. The local utility company has provided the following data outlining these costs per depot.



Number of Buses	50/*depot*	
Capital Expenses		
Transformer + Installation	$40,000	
Electrical/ Construction	$200,000	
Chargers	$125,000	
O & M		
Charger Software	$25,000	/*yr*
Charger maintenance	$20,000	/*yr*
Total Cost	**$365,000**	
	+$45,000	**/yr**

Figure 4 Initial infrastructure investments, summarized.[24]

In total, two bus depots will require an initial investment of $730,000. Then for the next ten years, the district would spend an additional $80,432.66 (present value) per year, in maintenance, software costs, and support for the system.

6.4.2 New electric bus acquisition

Electric buses cost approximately $200,000 more than their diesel counterparts, even for the relatively small buses comprising the school district fleet. If the district was to replace 76 buses over the next ten years, it would require an additional investment of $7,848,099.66 (present value). This is also assuming the cost of EV's wouldn't decrease in the next ten years, which is contrary to what has been forcasted.[25]

6.5 EV bus fleet electricity and maintenance costs

A similar study found that the maintenance cost per mile of an electric bus is 29.54% lower than the maintenance cost per mile of a diesel bus.[26] Given that the average cost per mile of the diesel fleet is $0.594, we infer that the average maintenance cost per mile of an electric bus is $0.418. Then the maintenance cost for a single electric bus over ten years in present value is given by the following formula.

$$\text{Maintenance Cost (per electric bus)} = \text{Yearly Mileage} \cdot \frac{\$0.418}{mi} \cdot \frac{(1+0.02)^{10}-1}{0.02(1+0.02)^{10}}$$

Expanding this number to an entire fleet yields the following result.

$$\text{Maintenance Cost (fleet)} = \$1,919,931.96$$

The electricity cost of the fleet can be evaluated using the e-Gallon as a fraction of total expenditure on fuel for the diesel fleet. The total fuel cost of the fleet was estimated to be $1,783,384.53 with a diesel cost growth rate of 3.9%, in present dollars. Then using the e-Gallon metric, the district should expect to spend 28.6% less on fuel consumption than it would on the diesel fleet. So the district should expect to spend $1,273,336.55. Using a more accurate measure of fuel costs yields similar results.

$$\text{Fuel Cost (electricity consumption per bus)} = \frac{\text{Yearly Mileage}}{19.6\frac{mi}{dge}} \cdot \frac{\$4.39}{dge} \cdot \frac{1-(1+0.02+0.031)^{-10}}{0.02+0.031}$$

[24] PGE information on infrastructure building, 2019

[25] *Electric Buses 101* (M.J. Bradley and Associates), 2019

[26] *Electric Buses 101*, 2019

$$\text{Total Projected Fuel Cost For Fleet} = \$880,086.00$$

6.5.1 Battery degradation and replacement

Battery degradation will be minimal if the fleet is only used for current transportation needs. Although battery life is improving consistently from year to year, the newly purchased electric buses will house batteries with similar performance to those available currently. The same study referenced above concluded that batteries will need to be replaced at or near 12 years of use. The cost of the initial battery is included in the initial cost of the EV, and so is not included as an additional cost. In addition, the battery replacement would happen outside of the scope of this study. However, it is important to note that degradation needs to be included in this analysis to account for ten years of in use service. The Conservative Energy Commission estimates that the price of an EV battery will at most be \$120/kWh.[27] Therefore, we use this metric in determining the cost of battery degradation over ten years as a loss of equity in the battery. Also, we continue to assume a battery size of 240 kWh.

$$\begin{aligned}
\text{Cost of Battery Replacement (10 years)} &= \$120 \cdot 240kWh \\
&= \$28,800 \\
\text{Present Value Cost} &= \$28,800 \cdot \frac{1}{(1+0.02)^{10}} \\
&= \$23,626.00 \\
\text{Per mile Cost} &= \frac{\$23,626.00}{(\text{Yearly Mileage}) \cdot 10 \text{ years}} \\
&= \$0.46/mi
\end{aligned}$$

Then the approximated loss of value in the bus batteries can be seen as a cost of \$2,448,000.00. Therefore, the total cost of operating an electric bus fleet for ten years can be estimated to be \$29,927,744.78. In the subsequent analysis, this will be compared to the cost of the current diesel fleet, which is \$16,491,104.51.

6.6 Cost intersection

This represents a 44.89% increase in operating costs for the school district. This is largely due to the increased initial investment for the electric vehicles.

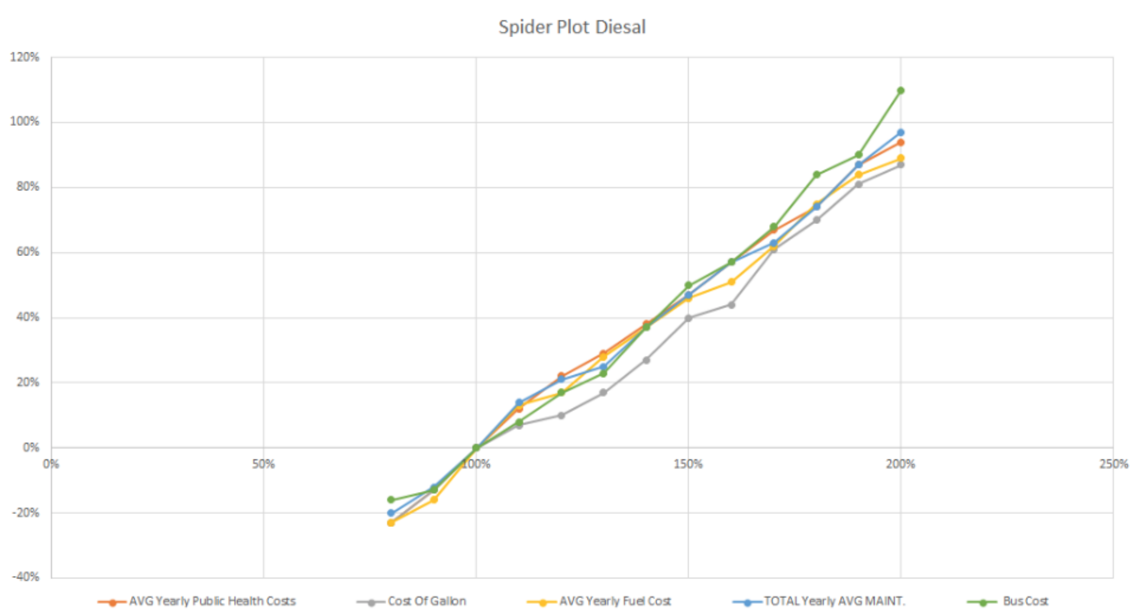
[27] See figure 1.

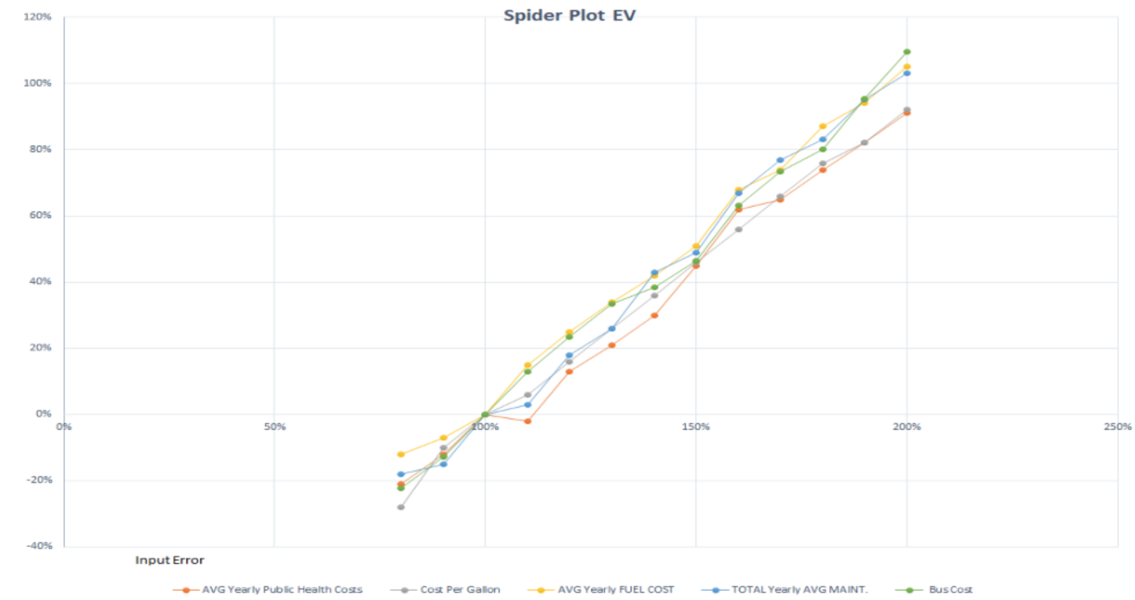
7 Analysis

7.1 Summary of cost effectiveness

	Diesel Fleet	**Electric Fleet**
Fuel Costs	$\$1,783,384.53$	$\$880,068.00$
Maintenance Costs	$\$3,307,719.98$	$\$1,919,931.96$
New Bus Acquisition	$\$5,886,074.74$	$\$13,734,174.40$
$\boldsymbol{MCM_i}$	$\$0.594$	$\$0.418$
Charging Time	$--$	$--$
Infrastructure Investment	$--$	$\$730,000$
Retraining	N/A	✓
Possibility for Future Programs	X	✓
Public Health Costs	$\$3,039,286.55$	$\$566,067.12$
Total Cost	$\$10,977,179.25$	$\$17,264,174.36$
Cost per Student (*per year*)	$\$22.22$	$\$34.94$

Figure 5 Total projected costs of both diesel, and electric fleet, summarized.





The 'fuel' and maintenance costs for an electric bus are clearly substantially lower than that of a diesel bus. Electric Fuel cost approximately 49.3% less than diesel, or \$903,316. Maintenance for an electric bus cost 42% less than diesel, or \$1,387,788. The major difference in price comes when evaluating purchase price. An electric bus cost %133 more than a diesel bus with a price difference of \$13,506,640 for an entire fleet conversion. This cost alone for an electric bus is approximately thirteen times as much as the individual differential cost of fuel or maintenance when compared to that of a diesel fleet. The total difference between the two types of fleet when looking at total hard costs is \$32,729,743 - \$21,510,207 = \$11,217,536. When breaking it down to what PPSD will actually pay, the difference is smaller: \$6,286,955. The rest of the analysis will focus on true cost as it will filter down to the district at approximately %70.

There are some places where this cost differential can be closed. The above numbers are based off of tariff schedule 38 with the average kWh costing 11.78. Given the amount of energy an entire fleet would consume could put the district in to tariff schedule 89 and could cut their electric bill in half to nearly 6, saving them an additional \$440,034 in electricity 'fuel' costs. Additionally, There is the potential this change in schedule could have ripple effects throughout the district on the price they currently pay for electricity throughout the district and save money elsewhere. Though the potential savings in energy and maintenance cost is substantial, is not nearly enough to completely make up for the extra cost to purchase brand new electric busses. This could bring the total down from \$11,217,536 to \$10,777,502, still not enough to justify converting an entire fleet to EV based on these costs and benefits alone.

There is room for additional factors, which we have explicitly noted we will not be addressing in this paper but may be able to address in a future version regarding the value of providing ancillary services back to the grid. These have been valued by FERC at nearly $28 / MWh. With busses sitting dormant for most of the summer during peak periods they have the ability to provide value some additional value to the grid and receive compensation for doing so. But this value is not substantial. The PPS fleet had 75 busses, each with a battery availability of 192kWh (80% capacity a of 240kWh battery) and equates to 14.4 MWh available to dispatch for ancillary services. During the summer when busses are sitting Idle for peak times, they still do not add a great deal of value (14.4 MWh * $28 = $403 / day). If this was done all 60 days of summer, this is only worth an additional $24,000 and doesn't come close to closing the $10,000,000 gap on the cost of electrifying the fleet. Additionally, if EV busses are able to last longer in service compared to a diesel bus due to maintenance or regulatory differences, this could allow the value of these busses to amortize at a different schedule due to the wear and tear differentiation between diesel and EV bus.

As noted above, the cost to purchase an EV instead of a diesel vehicle is $200,000 more per bus. This is the largest factor in determining the feasibility electrifying the entire fleet. It is possible that a district would be able to negotiate lower prices with a bus provider. That difference would need to be approximately $149,567 lower than initially thought. To be clear, the purchase price would need to come down from $350,000 per bus to $199,567 per bus. That is that point at which an electric bus becomes more cost competitive against the diesel choice and is the largest factor regarding whether it makes economical sense to electrify the entire fleet for PPS. Purchase price is by far the largest determining factor, even above energy costs within the PGE area. If this can be brought down through contract negotiation or converting older vehicles rather than purchasing new vehicles are the two ways which this issue can be mitigated, but future efforts should be focused on understanding the initial cost or retro-fitting existing busses and extending their current life at a much higher value if this would be legislatively palatable.

The final number to be considered and understood are the impact of emissions on children's health. The difference in health costs between the two fleets are $2,473,219 d. What makes this calculation difficult to incorporate is who pays for the health costs. In Oregon, typically the county (in this case Multnomah County) bears the weight of health costs and would never fall on the shoulders of the school district. There is reasonable an argument to be made whereas if kids are healthier (due to lower diseel emissions in their ride to school), they will be in school more often, their learning will be positively impacted in this way, and district incomes might rise in the future at some point. However, when it comes to evaluating the hard dollars/cents of the issue of health costs, PPSD wouldn't likely take this health cost in to consideration even though the cost is over 2 million. Also, just like many of the other costs, this one still doesn't tip the scale in favor of choosing an electric fleet.

7.2 Limits of cost estimates

There are several limits to the comparison of cost effectiveness that deserve to be mentioned. First of all, although long run savings have been realized, there are several other factors present that might mitigate the magnitude of these savings. Retraining will play a large role in conversion and future stability of the system. The investment of the district in employee retraining or hiring of new staff will undoubtedly lead to increased cost over time. There are federal grant opportunities for employee education in these fields, but they are competitive and take time.

A similar study found that carbon abatement, and its effects on public health are substantial when evaluating the cost of electric bus conversion. This fact may drive for more public funding and grants to help mitigate initial costs. As more and more programs become available the total cost of ownership will diminish. This case study is unique in that Oregon does not have any state government policy in this respect. Similar studies conducted in California and Delaware have had the aid of state agencies to offset costs. The long run costs associated with conversion will undoubtedly be offset in the future, while further grants and funding for diesel fleet acquisition will likely decline.

Electricity prices are generally lower in the Pacific NW than in other parts of the world given our available hydroelectric capacity and ability to generate cheap wind. This presents a unique opportunity for Oregon to develop a strong framework for future EV integration and to stimulate demand for renewable energy. This demand will surely lead to new innovation and further decreases in energy production, which will be realized further in the costs of fleet operation costs.

There exist economic multipliers to the extent that increased demand in one industry like electric buses will lead to increased demand in similar industries, leading to economic stimulation and further development of current resources and technology factors.

Finally, the infrastructure presented in this study is compatible with V2G integration and presents an incredible opportunity for further savings on fleet conversion. These services fall outside the scope of this study, but will be evaluated further in other research. The existing body of research shows strong motivation for participation and clear pathways for development of strategies to further incentivize fleet conversions of similar magnitude.

8 Conclusions

It is the recommendation at this point that additional research be done to understand the exact implications that ancillary services and feed-in tariffs could play to bring additional income to justify the cost of electrifying the fleet of PPS short busses. The cost of the bus conversion does not make sense as the numbers suggest currently without substantial contract negotiation lowering the initial e-bus purchase price by nearly $150,000. In the

PGE territory (and likely the larger pacific northwest pricing structure) pricing tariffs are low enough on average that they do not play as much of an important role as initial cost does. Given this information, it is beneficial to understand where other revenue streams can be found, but not if the initial price is substantially higher for an EV than it is for a traditional diesel ICE bus.

8.2 The future of fleet conversion

The availability of energy from the utility may become an issue for any fleet conversion, even outside of the PPSD. The demand on the grid from a single fleet conversion represents nearly a 1% gross increase in electricity demand. The local utility serves 52 cities, each with at least one school district. The demand for electricity generation will grow rapidly in the future.

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