Abstract

Domestic natural gas production has increased markedly in the United States, and now compressed natural gas (CNG) has the potential to become a cleaner and less expensive energy source than diesel fuel for use in the public transportation sector, especially for city bus fleets. This paper provides an economic analysis of possible CNG conversion for Lafayette, IN CityBus Corporation. It uses benefit–cost analysis to compare the total cost of three potential options for bus replacement: standard diesel, hybrid diesel-electric, and CNG. A spreadsheet model was used to estimate the total cost of these three fleet options over a 15-year project horizon. Results suggest that the CNG option has the lowest net present value (NPV) cost, and that cost savings would be larger if the corporation could obtain a grant for the CNG fueling station or if the project life span could expand to 20 years. From the environmental perspective, the CNG option would reduce greenhouse gas and particulate emissions particularly in comparison with the diesel option. Monte Carlo simulation was used to examine the inherent riskiness of the three fleet options. CNG is always lower cost than hybrid diesel-electric. Depending on assumptions regarding the underlying price distributions, the CNG option has a 51–100% chance of being lower cost than the standard diesel option.

Introduction

Natural gas is a mixture of hydrocarbon compounds, primarily composed of methane (CH₄) [1]. In recent years, US natural gas production has increased dramatically. The extraction of many unconventional natural gas sources consisting mainly of tight gas, coal-bed methane, and shale gas now has significantly increased total domestic production [2]. According to Annual Energy Outlook, the total natural gas production in the United States was 21.6 trillion cubic feet in 2010 and is expected to increase significantly until 2035. Because of the recent increases in natural gas production, especially the rapid growth of shale gas production, the domestic natural gas price in the United States in 2013 is notably lower than crude oil price on an energy equivalent basis [3]. The price difference between crude oil and natural gas has become larger since 2009. Previously, the prices were linked, but today they are largely decoupled.

The transportation sector uses about 28% of the total energy in the United States [4]. Natural gas has the potential to be an alternative fuel to replace some uses of crude oil. For public fleet companies, only when all the additional capital costs of vehicles and natural gas fueling stations for compressed natural gas (CNG) are fully compensated by the savings of fuel costs over vehicle lifetimes will companies make the decision to switch to natural gas vehicles.

The purpose of this study is to perform an economic and environmental analysis of a bus system using CNG, diesel, and diesel-hybrid buses. We use a case study of a real municipal bus company, CityBus Corporation of Lafayette/West Lafayette, IN, to do the analysis. While many of the assumptions are somewhat specific to CityBus, the general approach should apply to similar municipal bus systems around the country. The main goal of CityBus Corporation is to reduce the total cost of maintaining and operating its fleet. One of the biggest parts of the total cost
is fuel cost. Most of the transit buses in the United States use diesel for fuel [5]. CNG and diesel electric hybrids are being explored as means of decreasing fuel cost.

CityBus Corporation has already implemented on a limited basis of the hybrid diesel-electric bus, which has a higher fuel economy than a standard diesel bus, but considerably higher capital costs. Thus, for CityBus the options being considered are CNG, hybrid diesel-electric, and standard diesel. We will compare some of our results with those from recent literature in the results section.

**Material and Methods**

Most of the data analyzed in this study was provided by CityBus Corporation. CityBus is the operating name of the Greater Lafayette Public Transportation Corporation (GLPTC). GLPTC is a nonprofit corporation serving the adjacent cities of Lafayette and West Lafayette. It also provides bus service for students and faculty of Purdue University on a contract basis with the University. By facing the rise of fuel cost and the increasing concerns of emissions caused by fleet operations, CityBus Corporation expects to find a long-term solution to maintain the current level of services. This study aims to help them to find the most effective way to reduce operating cost as well as make the fleet “greener.” The data provided by CityBus were analyzed using Microsoft Excel to estimate the total present value cost of three fleet options. Cost estimates section explains parameters used and the resulting estimates for operating cost, capital cost in the base case study, and environmental cost in the sensitivity analysis.

In order to compare the total cost over the full lifetime of the project, the net present value (NPV) is used. NPV is defined as the sum of the present values of the project cash flow [6]. Due to the fact that the benefits and costs in the future have a lower value than the flows today, cash flows need to be discounted at a certain “discount rate” to calculate the NPV. In our study, the nominal discount rate and the inflation rate are assumed as 0.05 and 0.025, respectively, and sensitivity analysis was done on the discount rate. All of the analysis was done in nominal terms.

The cost estimates explained in the Cost estimates section were based on a number of assumptions and parameters. Some of these assumptions and parameters could change over time. In order to assess the uncertainties that might affect our benefit–cost analysis, this study applies Monte Carlo simulation to produce distributions of key inputs that reflect the inherent uncertainty in input values. Monte Carlo simulation is a stochastic method that takes input distributions for key inputs instead of fixed values. It then calculates the spreadsheet many times, each time drawing from the input distributions. For each iteration, it stores the output values (NPV, etc.) and creates a distribution of values for the outputs based upon the spreadsheet calculations and the uncertain inputs [6]. Monte Carlo simulation section explains the process of using Monte Carlo simulation in price projections for diesel and CNG fuel and the corresponding results of the total cost of these three fleet options. Results section explains the results of this study and the conclusions are provided in Conclusions section.

**Calculations**

**Cost estimates**

There are mainly two kinds of costs for this analysis: operating cost and capital cost. Environmental cost is also included in the study to evaluate the environmental effect of these three fleet options.

**Capital costs**

There are three main components of capital cost: the costs of purchasing new buses, rebuild cost, and the cost of building a new CNG fueling station for the fleet option with CNG buses.

The base case project period (vehicle lifetime) of three kinds of buses is the same at 15 years. We used the actual CityBus vehicle replacement schedule, so the analysis is not a head to head comparison of pure systems, but a comparison of how CityBus would be impacted by the decision to replace buses with each alternative bus type. Each year, some of the existing buses need to be retired and replaced by the same number of new buses to keep the total number of buses in the fleet the same. CityBus provided us the price which CityBus Corporation would pay for each type of new bus, which is $600,000 for hybrid diesel-electric bus, $450,000 for CNG bus, and $400,000 for standard diesel bus, respectively, in 2012 dollars (Personal communications with the CityBus Chief Executive Officer, Marty Sennett, and other CityBus officials, 2012). Meanwhile, based on the recent data from CityBus Corporation, they predicted the annual price increase rate of bus price is 5% in nominal terms (Personal communications). In the life span of the project, 65 of the existing buses in the fleet (73 buses) need to be replaced. However, because of the limited budget of the CityBus Corporation and the higher price of hybrid buses, if the corporation wants to change to hybrid buses, fewer hybrid buses can be added to the fleet, and the rest need to be replaced by standard diesel buses. So in the hybrid bus option, or option 1, only 32 hybrid buses will be purchased, and the remaining 33 will be replaced by standard diesel buses. The details of the replacement for the three fleet options are shown in Table 1.
Moreover, due to the environmental benefits of using CNG buses, CityBus Corporation may have the opportunity to get a grant from the federal government or Indiana State government to cover part of the cost of building the CNG fueling station. The study evaluates three different grant fractions, 10%, 50%, and 100% in the sensitivity analysis.

### Fuel cost

In the fuel cost part, the total mileage of the fleet is fixed at 1.8 million miles every year. After communicating with CityBus, the distance of the route from the fuel station is usually not so long that each kind of bus can finish the route without coming back to the fuel station (Personal Communications). So in this study we assumed that all these three kinds of transit buses in the fleet traveled the same distance, which means the percentage of each kind of bus in the fleet equals the percentage of mileage travelled by each kind of bus every year. Fuel cost of each type of bus is calculated by the price of the fuel multiplied by the fuel used for that type of bus. The annual fuel cost of each fleet option is calculated as the summation of each kind of bus’s fuel cost in that year.

In this analysis, the initial diesel and CNG price in 2012 are $3.11 per gallon and $1.5 per DGE, respectively (Personal communications). After regressing the historical annual prices of diesel and crude oil from 2000 to 2011 [7], the correlation between them is 0.996, which means crude oil price and diesel price have the same price growth rate. We used U.S. Department of Energy (DOE) [4] projections of crude oil price from 2010 to 2035. DOE also forecasts retail diesel prices, but we wanted to use the wholesale value, without taxes and distribution costs, so it was better to calculate the rates of change directly from the crude oil forecast. The DOE reference case was used as the growth rate of diesel price in the base case study. The CNG price is mainly comprised of two parts: natural gas wellhead price and transmission/distribution cost. After regressing the U.S. historical annual transmission/distribution cost, which equals CNG retail price minus natural gas wellhead price, from 2000 to 2011[7] and the consumer price index (CPI) from 2000 to 2011[8], the result shows that the correlation between transmission/distribution cost and CPI is 0.939, which means the growth rate of transmission/distribution cost is highly correlated with the general inflation rate. The growth rate of the wellhead price is taken from the Henry Hub spot natural gas price projections from U.S. Energy Information Administration (EIA) Annual Energy Outlook 2012 [4]. According to Clean Cities Alternative Fuel Price Report, the conversion factor between CNG price and wellhead price is 7.236, which means 1 mmBtu natural gas converts to 7.236 diesel gallon equivalent (DGE) CNG fuel [9]. Using this factor we can

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**Table 1. Number of buses purchased each year for the three fleet options.**

| Year | Option 1 hybrid project | Option 2 CNG project | Option 3 diesel only |
|------|-------------------------|----------------------|---------------------|
| 1    | 4                       | 3                    | 7                   |
| 2    | 2                       | 1                    | 3                   |
| 3    | 2                       | 1                    | 3                   |
| 4    | 2                       | 2                    | 4                   |
| 5    | 2                       | 2                    | 4                   |
| 6    | 2                       | 2                    | 4                   |
| 7    | 2                       | 2                    | 4                   |
| 8    | 2                       | 2                    | 4                   |
| 9    | 2                       | 2                    | 4                   |
| 10   | 2                       | 2                    | 4                   |
| 11   | 2                       | 2                    | 4                   |
| 12   | 2                       | 3                    | 5                   |
| 13   | 2                       | 3                    | 5                   |
| 14   | 2                       | 3                    | 5                   |
| 15   | 2                       | 3                    | 5                   |
| Total| 32                      | 33                   | 65                  |

CNG, compressed natural gas.

For every transit bus, in the middle of its life span, at the eighth year after it is purchased, the engine and transmission need to be rebuilt. Although the rebuild cost of engine and transmission system in the hybrid bus is the same as the other two types, which is $19,000 in 2012, the battery in the hybrid diesel-electric bus also needs to be replaced at this time. So the fleet needs to pay the additional battery replacement cost for hybrid diesel-electric buses, which is $40,000 in 2012. For all these three types of buses, the annual increase rate of rebuild cost provided by CityBus Corporation is 3% in nominal terms (Personal communications). We did not reduce the battery replacement cost through time, as we do not have confidence in the available projected rates of technical change in battery costs. However, as will be clear below, even if we had used battery replacement costs half the stipulated value, it would not have changed the basic results.

Another important capital cost is the cost to build a new CNG fueling station. Before the CNG transit bus is implemented in the fleet, a CNG fueling station must be built. This cost, which is estimated at $2 million (Personal communications), would happen at the beginning of the first year and needs to be amortized under a certain amortization rate to evaluate the annualized cost. Because the discount rate and the amortization rate used in this study are the same at 5%, the amortization of this cost has no impact on the NPV calculation of the cost in the CNG option. If more favorable financing terms were to become available to CityBus, it would make the CNG option more attractive.
which are CO2, CH4, and N2O. In order to convert them to study, three of the main Greenhouse gases are calculated, 

\[ \text{GWP of CH}_4 \text{ and N}_2\text{O are 21 and 310, respectively} \] \cite{12}.

According to data from U.S. EPA, CNG transit bus releases 1.966 g CH4 per mile and 0.175 g N2O per mile. For the diesel bus, the factors are 0.0039 and 0.0037, respectively.

We use the shadow price of avoiding these two pollutants to calculate the environmental cost. For CO2 equivalent emissions, a carbon tax could be applied as its shadow price. Currently, there is no carbon tax leveled nationwide in the United States. Previous studies \cite{13, 14} suggested a carbon tax at a range from $55 to $110 per ton of carbon, which is equivalent to $15 to $30 per ton of CO2 when divided by the factor 3.67. For PM10 emission, the report “Transit bus life cycle cost and emissions estimation” \cite{15} estimated that the shadow price of PM10 emission is $6367 per ton in 2006 dollars. After adjustment by the historical inflation from 2006 to 2011, the social cost of PM10 is $7384 in 2012.

**Environmental costs**

Two kinds of emissions included in this study are carbon dioxide (CO2) equivalent and PM10 (particulate matter [PM] with a diameter of 10 \( \mu \text{m} \) or less). CityBus Corporation uses ultra-low sulfur diesel (ULSD) as the fuel to follow a mandate which took effect in 2010 in the United States requiring all the diesel fuel refined to be ULSD (Personal communications). An important emission caused by transit buses is PM. Passengers and bus drivers are among the most vulnerable groups of people with immediate and long-lasting exposure to these small particles \cite{10}. In our analysis, we decide to use the PM10 emission estimates by Wayne \cite{11}, which is from the average PM10 emissions for the buses during 2007 to 2009. The PM10 emissions for hybrid, CNG, and standard diesel bus are 0.020, 0.013, and 0.022 g/mile, respectively.

With these emission factors, the amount of Greenhouse gas and PM10 emissions of each fleet option could be estimated. Greenhouse gas emissions are typically calculated in the units of carbon dioxide equivalent (CO2e). In this study, three of the main Greenhouse gases are calculated, which are CO2, CH4, and N2O. In order to convert them to CO2e, the gas’s global warming potential (GWP) need to be used. From the 2011 report of U.S. Environmental Protection Agency (EPA), if the GWP of CO2 is set at 1, the GWP of CH4 and N2O are 21 and 310, respectively \cite{12}.

According to data from U.S. EPA, CNG transit bus releases 1.966 g CH4 per mile and 0.175 g N2O per mile. For the standard diesel bus, the emission factor is 0.0051 g per mile for CH4 and 0.0048 g per mile for N2O \cite{12}. For the diesel hybrid bus the factors are 0.0039 and 0.0037, respectively.

Monte Carlo simulation

The software @Risk is used to perform the Monte Carlo simulation in this study. It is a widely used software package operating as an add-in to Microsoft Excel. A key source of uncertainty in this analysis is the trajectory of diesel and natural gas prices. The technology development of extracting shale gas, its transportation, and storage cost as well as the speed of economic recovery of the United States may all influence on the growth rate of CNG prices. For the diesel price, the fluctuation of the crude oil is the key driver of diesel price. Uncertainties of diesel and CNG price may also appear when the regulations and policies on fuel emission standards change in the future.

Our analysis uses the projected price growth rate of diesel and CNG calculated from the reference case of price projection from U.S. DOE and U.S. EIA, respectively. The range of the projected growth gate in the Monte Carlo simulation comes from the low case and high case of these projections.

In this study, two methods are used in the Monte Carlo simulation to estimate the price growth rate, which are named Monte Carlo 1 and Monte Carlo 2. The method Monte Carlo 1 is that a certain year’s price change is only related to the price in that year and the price in the base year, or the price at the beginning of 2012. In Monte Carlo 2, 1 year’s price is related to the price of the previous year. In other words, Monte Carlo 2 is a lag price structure, which would be expected to have higher variance. The basic reason is that prices from year to year are highly correlated, so low draws early on will result in low prices throughout the sequence and vice versa for high draws. When prices are not correlated from year to year, variance is expected to be lower because there is a greater chance of offsetting random draws.

The normal distribution is used in both of these two methods \cite{10, 16}. The price growth rate of the reference
case is used as the mean in the distribution. Standard deviation is calculated by the range of price growth rate from high and low case of the projection, while using the range as the 99% confidence interval.

In Monte Carlo 1, the range of price growth rate between high case and low case is used as the truncation. But in Monte Carlo 2, each year’s price is based on the price of the previous year, which would make the standard deviation quite large. In order to make the result more realistic, we decide to narrow down the truncation of the distribution and use 70% of the confidence interval to estimate the truncation each year. The results of Monte Carlo simulation will be shown in the Results section.

Results
The benefit–cost analysis in this study was done for a base case and five alternative cases. The base case study compared the operating cost and capital cost of three fleet options over a 15-year project life span, while both environmental cost and investment cost grant are excluded. The five cases for sensitivity analysis were the following:
- Environmental cost included
- Investment Grant included
- Monte Carlo simulation on fuel price projection
- Twenty-year project life span
- Breakeven analysis on CNG price growth rate and discount rate.

Base case
Figure 2 summarizes the fuel cost of these three fleet options each year in nominal terms. The fuel cost in option 2 is much lower than the fuel cost in the other two options. Fuel cost savings of CNG bus is one of the biggest advantages for choosing it as alternative vehicle of the fleet. In option 1, although the hybrid bus has a much higher fuel economy than a standard diesel bus, because only 32 of the hybrid buses can be purchased in the next 15 years, the fuel cost savings is not as much as CNG option. Toward the end of the planning horizon, the total fuel cost for the CNG option actually falls because the fraction of CNG buses in the total is steadily increasing. This fact indicates that the fuel cost differences between option 2 and the other two options will become even larger beyond the 15-year planning horizon. Meanwhile, in the last year of the project, the cost savings between option 1 and option 3 is only $283,651, while in option 2, the fuel cost in the last year is almost 1.4 million ($1,394,091) less than option 3, which saves almost half of the cost of option 3. This is a huge cost savings, and the tendency of Figure 2 also points out that in the years after the project life span (after 2028) fuel cost saving in using CNG buses would be even higher than $1.4 million per year.

The total cost is the sum of fuel cost and capital cost. Figure 3 provides the total cost of these three fleet options over the project life span. These costs assume the CNG capital cost is amortized. At the beginning of 2014, seven of the existing standard diesel buses will be retired, while in the remaining years, the number of retired buses will be only 3–5 each year. The higher capital cost for purchasing new buses in 2014 leads to the fact that there is a surge in the total cost at the beginning and then a drop. In all project years, the total cost of option 1 is higher than the cost of the other two options, which is mainly due to the higher price of the new hybrid diesel-electric buses. Compared with option 3, option 2 has a higher annual total cost in the first several years of the project. However, because of the lower price of CNG fuel, the difference between the annual total cost of these two options decreases. After 2020, the total cost of option 2 becomes lower than that of option 3. Moreover, the cost savings of using CNG buses increase in the years after 2020.

Figure 4 summarizes the components and NPV of the total cost of these three fleet options in the project. NPV of the total cost in option 1 is more than $5 million higher than the other two options. Because of the lower price and price growth rate of CNG fuel, option 2 has the

Figure 2. Fuel costs of three fleet options in the project life span in nominal term.
Figure 3. Total costs of three fleet options in the project life span in nominal term.
lowest total cost, for which NPV is $468,404 lower than that of option 3. Thus, without consideration of other factors, the CNG option is the least cost.

These results are consistent with existing literature in this area. We used the Transportation Research Board NRC [17] bus life-cycle model to do a comparison of the three systems. That model does a one to one comparison of the CNG, diesel, and diesel electric hybrid buses. Thus, one would expect to get different numbers as our comparison is tailored to the CityBus specifics. However, we used the same default values as in this study to come as close as possible. The NPV cost results from that model for 65 buses were $62,857,667 for diesel, $62,668,509 for CNG, and $74,724,408 for diesel-electric hybrid. Thus, CNG was the lowest cost system, and the diesel-electric hybrid the highest. We were not able to project the differential growth rates of diesel and CNG prices in that system, which is one reason the CNG-diesel difference is not as large. Also, we did not include base maintenance costs for any system as they are about the same, but this system included all the maintenance costs, leading to higher total costs. However, the important thing is that the general order of the conclusions is the same.

Also, another important study in the recent literature is Krutilla and Graham [18]. They concluded that the diesel electric hybrid technology is not competitive under most assumption with the standard diesel, the same as our conclusion. They also included a reduction in battery replacement cost over time in their analysis.

Environmental cost
The results in this section estimate how much Greenhouse gas and PM emissions are reduced when the fleet changes to use alternative buses in the next 15 years. CO\(_2\)e and PM10 emissions of all three fleet options in the project are estimated and shown in Figures 5 and 6. These two figures have similar results on the emission amounts of CO\(_2\)e and PM10. Thus, one would expect to get different numbers as our comparison is tailored to the CityBus specifics. However, we used the same default values as in this study to come as close as possible. The NPV cost results from that model for 65 buses were $62,857,667 for diesel, $62,668,509 for CNG, and $74,724,408 for diesel-electric hybrid. Thus, CNG was the lowest cost system, and the diesel-electric hybrid the highest. We were not able to project the differential growth rates of diesel and CNG prices in that system, which is one reason the CNG-diesel difference is not as large. Also, we did not include base maintenance costs for any system as they are about the same, but this system included all the maintenance costs, leading to higher total costs. However, the important thing is that the general order of the conclusions is the same.

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over the 15-year project lifespan are 62,754, 61,432, and 66,560 tons, respectively.

Using the shadow price of CO$_2$e described in Cost estimates section, at the lower bound of the range, $15 per ton of CO$_2$e, the NPV of environmental cost of these three fleet options are $791,358, $776,051, and $836,325, respectively. At the upper bound, which is $30 per ton of CO$_2$e, the environmental cost NPV are $1,582,716, $1,552,102, and $1,672,650, respectively. In other words, the environmental cost NPV for CNG option ranges between $60,274 to $120,548 less than the diesel-only option and $15,307 to $30,614 less than the hybrid/diesel option. Although the environmental cost is not paid by CityBus Corporation under the current policy, they are a true cost to society. The results quantify the health benefits and air pollution reductions to society, as the fleet replaces standard diesel buses with alternative buses.

Monte Carlo simulation

The simulation results of total cost of these three fleet options in the base case study are shown in Tables 2 and 3 by using the method Monte Carlo 1 and Monte Carlo 2, respectively. Option 2, or CNG option, has the lowest mean value of total cost in both of these two simulation methods, which are consistent with the results in the base case study. Because of the relative stability of CNG future price compared with diesel price, CNG option has smaller variance than the other two options. This smaller variance also means a smaller risk of investing in CNG buses.

Moreover, in both Monte Carlo 1 and 2 simulation methods, the probabilities that the total cost of option 1 is lower than that of option 2 are zero, which means the cost difference between them is so large (the mean value is about $6.2 million) that option 1 has zero probability of being lower than option 2. This result indicates that from an economic perspective, the CNG option is always preferred over the hybrid/diesel option. For the cost difference between option 2 and option 3, the possibility of changing its sign is different between these two simulation methods. In the Monte Carlo 1 method, the probability that the total cost of diesel-only option is lower than CNG option is 21%. But in Monte Carlo 2, the number is 49%, which means diesel-only option has a higher probability of costing less than the CNG option while using Monte Carlo 2 simulation method.

Compared with Monte Carlo 1 method, Monte Carlo 2 seems more plausible, because it develops a price trajectory in which each year’s price is dependent on the price of previous year. Monte Carlo 1 has a smaller variance and seems a little bit conservative. However, the range of diesel price in the last year of the project is from $1.13 to $24 in the Monte Carlo 2 method. The higher variance in Monte Carlo 2 is also reflected in the NPV output distributions as would be expected, which could explain why option 3 has a higher possibility to cost less than option 2 in the Monte Carlo 2 method. Although the probability of these extreme cases is very small, the price variability in Monte Carlo 2 may be high, and in the real world, the price variability would fall in between these two methods.

Total cost with grant included

The base case did not consider any grant or subsidy the company might get for investment in the CNG fueling sta-
tion. One of the most likely grants CityBus Corporation can get is for building a new CNG fueling station, which would reduce the total cost of option 2. This section analyzes the impact on total cost if the company can get a grant for building the CNG fueling station. Three scenarios of grant fraction for the capital cost of CNG fueling station are assumed in the analysis: 10%, 50%, and 100%.

In the base case study, without any grant, the NPV of the total cost in option 2 is lower than the other two options. If the corporation can get a grant, option 2 would become more attractive in the final decision. Essentially the present value of total cost gets reduced by the amount of the grant as the capital cost for CNG is at the beginning of the project. In other words, the 10% grant reduces CNG cost $200,000 and similarly for the other percentages.

Table 4 shows the probabilities that the total cost of option 3 is lower than that in option 2 if the grant is included into the analysis. As the grant fraction for the capital cost becomes larger, the total cost in option 2 becomes smaller, which, in turn, causes the probability in Table 4 to become smaller. The probability that diesel is cheaper than CNG in Monte Carlo 1 even becomes zero in the 100% grant scenario.

### Twenty-year project life span

Compressed natural gas fueling stations have a lifetime of 20–25 years. In this section, we choose 20 years as the lifespan of the project, instead of the 15 years selected by the CityBus Company. In this sensitivity analysis, the capital cost of CNG fueling station is annualized over 20 years. The vehicles’ lifetime remains 15 years. The bus replacement cycle and rebuild for the last 5 years is assumed to be continued as it was done for the first 15 for all three fleet options.

Total cost savings of the CNG option compared with diesel-only option is $2,923,355 in the 20-year project lifespan, which is a lot larger than the cost savings in the base case study at $468,404. The result reinforces the economic advantage of using the CNG buses in the fleet.

The simulation results of the mean values in the 20-year project lifespan case are consistent with the results shown previously. Table 5 presents the probabilities that the total cost of option 3 is lower than option 2. Due to the fact that the cost savings of the CNG option is larger over a 20-year lifespan, the probabilities in Table 5 become smaller in the 20-year lifespan. In Monte Carlo 1, the diesel-only option has zero probability of being lower than the CNG option in the 20-year lifespan case. Because the 20-year lifetime more closely matches that of the fueling station, we believe the results for the 20-year lifetime are more realistic.

### Additional sensitivity analysis on price projection

#### Breakeven analysis on CNG price and discount rate

Breakeven analysis is a technique for conducting sensitivity analysis on key variables. In this section we do sensitivity analysis on the breakeven rate of CNG price increase and on the discount rate used for the analysis.

In the base case study, the average annual growth rate of diesel and CNG price are 3.9% and 4.9%, respectively. The total cost difference between CNG option and diesel-only option is $468,404. In this section, we assumed that the average annual price growth rate of diesel remains the same at 4.9%, and solved for the breakeven annual price growth rate of CNG which can make the NPV of the total cost of the CNG option and diesel-only the same. After using what-if analysis in our spreadsheet model, we get a breakeven trajectory of CNG price and we can find out that the last year CNG price increases from $2.669 to $2.999. It indicated that when CNG price has an average annual growth rate of 4.7%, the total cost of CNG fleet option and diesel-only option would be the same. In other words, CNG would have to go up almost as fast as diesel for the two options to have the same NPV total cost.

We assumed that the base case nominal discount rate in this study is 5%. In order to find out the breakeven discount rate which causes the total cost of CNG fleet option and diesel-only fleet option to be the same, what-if analysis is used. The breakeven discount rate is 6.8%. This result indicates that if the discount rate in this study increases to 6.8%, the total cost savings of CNG fleet option compared with diesel-only fleet option would become zero. At a higher discount rate, the diesel option would become preferred.

All the results of the breakeven analysis in this section exclude the environmental benefits of the CNG option.
Conclusions

Because of the lower fuel price and pollution reduction, the CNG bus is considered to have good potential as an alternative vehicle used in the public fleet in the United States. Among the three candidate fleet options for the CityBus Corporation to choose, hybrid/diesel option, CNG option, and diesel-only option, the total cost of CNG fleet option is the lowest over the project life span of 15 years, even in the case with no grant for building the CNG fueling station. Due to the higher cost of purchasing a new hybrid bus, which is 50% higher than a standard diesel bus, hybrid/diesel option is easily the highest cost, about $6.2 million higher than CNG option and $5.7 million higher than diesel-only option in the base case study.

Moreover, from the environmental perspective, the implementation of CNG buses in the fleet would also produce less emission and provide benefit to the environment of the local society. In our analysis, CNG option would reduce about 5128 tons CO₂e emissions compared with diesel-only option over the whole 15-year project lifetime. For the hybrid/diesel option, however, due to the fact that only 32 of the hybrid diesel-electric buses are purchased in the project, the effect of emission reductions is not as good as that in the CNG option.

The wide range of NPV generated by the Monte Carlo simulation reflects the high uncertainty of the total costs of these three fleet options due to the uncertain future diesel and CNG prices. However, because the future price of CNG is likely to be more stable than the price of diesel, the total cost of CNG option has the smallest variance, which would help the fleet to decrease the chance of financial losses in the future.

Over the project lifespan of 15 years, the total cost of the CNG option is $468,404 lower than the diesel-only option in the base case, and has a range of 51–79% probability of a lower system cost. Moreover, if CityBus can get a grant for the CNG fueling station or the project life expands to 20 years, the probability would increase significantly. Meanwhile, a higher discount rate or a higher growth rate of CNG price would make the diesel-only option become preferred.

Based on all these results from our analysis, the CNG option is somewhat preferred from both a financial and environmental perspective. It is possible that other factors not included in this analysis also could play in the decision.

Conflict of Interest

None declared.

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