Hybrid Electric School Bus

Business Feasibility Report

by
Advanced Energy

Hybrid Electric School Bus
Feasibility Study Funded by:

State Energy Office
ENERGY
www.energync.net 1-800-662-7131
N.C. Department of Administration "Ensuring a sustainable energy future"

HYBRID ELECTRIC SCHOOL BUS
PRELIMINARY BUSINESS FEASIBILITY REPORT

Ewan Pritchard, P.E.

Bob Zickefoose

Ken Dulaney, P.E.

Hybrid Electric School Bus Program
Advanced Energy
Raleigh, N.C.

Revision 1.4
June 3, 2005

ACKNOWLEDGEMENTS

The Hybrid Electric School Bus Project is a team effort and would not be possible without participation of the Advisory Group and the Buyers Consortium. The Advisory Group is composed of school bus manufacturers, funding agencies and school districts. The Buyers Consortium is a select group of school districts that have agreed to pursue funding for this project and purchase a bus. The school districts have created the demand, and the manufacturers have responded.

Funding for this project comes from the United States Department of Energy, the North Carolina State Energy Office, Duke Power, Progress Energy and Advanced Energy.

This project represents a unique coordination among all parties to improve the air quality for our nation's children.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

School buses represent a major percentage of our nation's transportation sector in terms of fuel consumed, miles traveled, passenger trips and emissions generated. As demonstrated in passenger cars and transit buses, hybrid technology holds promise for the school bus market. With two energy storage mechanisms in a single vehicle, hybrids achieve significant gains in fuel efficiency as well as reduced maintenance costs and reduced emissions.

The Hybrid Electric School Bus (HESB) Project is a program designed to bring these vehicles to market by creating the demand among school districts required for a manufacturer to invest in the development of the technology. An initial phase of this project included a Technical Feasibility Study that quantified the improved performance and reduced emissions expected from a hybrid school bus.

This document is the Business Feasibility Study that estimates the lifecycle savings of two hybrid options compared to a conventional, type C, 65 passenger, diesel bus. The hybrid options include plug-in and standard hybrid. This report focuses on the costs to the vehicle owner and does not attempt to calculate manufacturing costs. The report describes a cost model (developed as an Excel workbook) that allows users to input information specific to their operation. The cost categories include initial cost, infrastructure costs, fuel costs and maintenance costs, including battery replacement for hybrid options. The model also allows users to input the value of avoided emissions for several pollutants.

Using the input costs and other vehicle parameters (lifetime, annual mileage, discount rate, etc.), the model calculates the values of several economic factors. These factors are Lifecycle Savings, Savings to Investment Ratio, Adjusted Internal Rate of Return and Discounted Payback.

The Baseline Case described in the report represents average values for many of the inputs. This case shows that the plug-in option at full production levels offers some lifecycle savings over the conventional school bus. The factors also show that using standard investment determinations, the plug-in option offers a payback period less than the life of the vehicle. The sensitivity analyses show how several parameters can have a dramatic impact on the factors. The most influential parameters are initial cost and battery replacement cost.

Users of this model are encouraged to experiment with the model and customize the input values to represent their operations.

1. INTRODUCTION

There are 482,000 school buses in the United States that transport 25 million children on approximately 10 billion student trips each year. These buses consume 1.1 billion gallons of diesel fuel and emit thousands of tons of pollutants per year. School buses represent a major segment of our country's transportation sector in terms of trips delivered, fuel consumed and pollutants emitted.

Emissions from these buses are a problem. The U.S. Environmental Protection Agency (EPA) has responded with the Clean School Bus Program, in which researchers are evaluating the levels of exposure for our children, As a result, many school districts have implemented anti-idling policies to reduce emission during loading and unloading.

In addition to policy changes, there are technological options for reducing these emissions. These options include using different fuels such as biodiesel or natural gas and add on emission control devices such as particulate filters and oxidation catalysts. Hybrid technology is another option. Hybrids are available in the passenger vehicle market as well as the transit bus market. Currently, there are no commercially available hybrid school buses.

This study demonstrates that hybrid school buses provide an economically attractive alternative for school districts seeking to reduce emissions from their fleets. This study is the companion to a Technical Feasibility Study prepared earlier. Both reports are part of the Hybrid Electric School Bus Project administered by Advanced Energy.

1.1 What Is a Hybrid?

A hybrid vehicle is one with two or more methods for storing energy for propulsion. Hybrid vehicles were actually first developed in the 1900s. The focus then was on dual fuel capability and not on optimizing efficiency or performance. The modern hybrid combines an electric motor with a gasoline or diesel engine. Typically, an electric battery stores and supplies energy for the electric motor, and the fuel tank stores energy for the engine. Both the engine and the motor can be small and light weight because they share the load for moving the vehicle.

There are two common configurations of a hybrid vehicle: parallel and series. In the parallel configuration, the engine and/or the motor can drive the transmission at the same time. Electronic controls adjust the balance of power delivery based upon maximum efficiency and battery energy level. In a series hybrid, only the electric motor actually drives the wheels. The engine turns a generator which creates electricity that recharges the batteries. Again, electronic controls adjust the engine load as required to optimize efficiency and minimize emissions. Commercial passenger cars available today are considered parallel hybrids.

Hybrid vehicles can also incorporate regenerative braking. This allows the motor to act as a generator and slow the vehicle while at the same time generating current to charge the batteries. This braking occurs without physical contact of the friction surfaces of the brake pads and therefore extends the life of brake shoes and drums. The vehicle retains the conventional braking system, and the electronic controls adjust the amount of regenerative braking. The amount of regenerative braking that is applied during any individual stopping event depends on many factors, including the energy level of the batteries.

Hybrid vehicles today recharge their batteries using energy from the fuel. This happens in a way similarly to the concept of regenerative braking. The motor acts briefly like a generator while the engine continues to provide power. This transfers energy to the batteries to maintain a certain state of charge determined by the electronic controls. There are also “plug-in” hybrids that charge the batteries partially from engine power but are also equipped to charge their batteries by plugging in to the utility grid. The electronic controls in plug-in hybrids allow more energy to be discharged from the batteries before recharging using engine power. This further increases fuel economy. These plug-in hybrids typically have larger battery packs than non plug-in hybrids to allow greater depth of discharge. Plug-in hybrids can have lower operating costs than regular hybrids especially when they are recharged using inexpensive electricity available during off-peak hours.

1.2 History of Modern Hybrids

There is no doubt that hybrid vehicles are growing in popularity. While many experimental vehicles were built during the ’70s, ’80s and ’90s, Toyota was the first to introduce a production vehicle to the Japanese market in 1997. In 1999, Honda released the two-door Insight, the first hybrid car to hit the mass market in the United States. The Insight won numerous awards and received EPA mileage ratings of 61 mpg city and 70 mpg highway. Toyota followed the next year with the introduction of the Prius to the U.S. market. In 2002, Honda introduced the hybrid Civic.

The Toyota Prius II won 2004 Car of the Year awards from Motor Trend Magazine and the North American Auto Show. Toyota was surprised by the demand for the vehicle and increased its production from 36,000 to 47,000 vehicles per year in the United States. Interested buyers have had waiting periods of over a year for the new model Prius.

Earlier this year, Ford released the Escape hybrid, the first American hybrid and the first Sport Utility Vehicle (SUV) hybrid. In addition, there are plans for more than 20 other hybrid models to be introduced before the year 2010.

For buses, the options are more limited. There are currently about 300 hybrid transit buses in daily operation, the bulk of which are in New York City or Seattle, Washington. These buses demonstrate that hybrid technology works on the bus scale. However, transit buses have drive cycles and operating requirements that are quite different from school buses. Therefore, there is a need for a hybrid project focusing solely on school buses.

1.3 Hybrid Electric School Bus (HESB) Project

Hybrid electric school buses have the potential to reduce emissions and to reduce the overall lifecycle cost when compared to conventional diesel buses. The technology has been demonstrated in passenger vehicles and transit buses. However, to penetrate the school bus market, there must be a demonstration of the technology. School bus manufacturers are hesitant to offer hybrid vehicles without demand from school districts. However, a request for hybrid technology from a single district or state would not sway a manufacturer. Encouraging the demand for hybrid electric school buses requires a coordinated effort among several districts. The HESB Project provides this coordination.

The HESB Project seeks to deploy a fleet of hybrid electric school buses across the United States. This project will connect interested school districts with an interested manufacturer. With the assistance of Advanced Energy, the HESB Buyers Consortium is developing the performance specifications for an early production purchase of hybrid school buses.

One of the initial tasks of the project was to determine if applying hybrid technology to school buses was even technologically feasible. Using a computer model called the Advanced Vehicle Simulator (ADVISOR) to numerically simulate a conventional school bus as well as several different hybrid configurations, Advanced Energy demonstrated that hybrid school buses would offer substantial fuel savings, reduced emissions and increased performance over conventional diesel buses.

1.4 Hybrid School Bus Market

According to industry trade publications, the school bus fleet in the United States has over 482,000 vehicles and adds over 40,000 new buses each year. School buses may be classified as type A/B, type C or type D. The HESB Project focuses on type C buses like that shown in Figure 1. These are also called "conventional" buses.

Figure 1.1. Type C School Bus

According to School Bus Fleet magazine, the current U.S. market for type C buses is approximately 21,000 buses per year. This represented 57 percent of the market in 2003. These buses typically cost between $60,000 and $66,000 each. Therefore, the annual market for type C school buses is approximately $1.3 billion.

There are three major school bus manufacturers in the United States: Thomas Built, International Corporation and Blue Bird. Recent changes in the manufacturing sector, however, show that other vehicle manufacturers are becoming active in the school bus market. For example:

- Thomas Built was acquired in 1998 by Freightliner Corporation, a subsidiary of Daimler Chrysler.
- International Corporation refocused from providing chassis to the other manufacturers to emphasizing their own full line of buses.
- Blue Bird's major shareholder, Henlys Group PLC with 42.5 percent, restructured to transfer power to Peach County Holdings. The other major shareholder, Volvo also with 42.5 percent, is now likely to take a stronger role in their leadership.

There are potentially three levels to national market development for hybrid buses: early adopters, non-attainment fleets and, finally, the national market. Each of these markets has distinctly different drivers and will therefore have different price points.

1.4.1 Early Adopters

Early adopters represent a small number of fleets willing to evaluate different fuel types and other measures to both reduce emissions and reduce fuel costs. This market is likely to be dominated by large purchasing agencies such as the states of North Carolina, South Carolina and Florida. Other early adopters can be found in states with the most severe environmental conditions such as California, New York, Georgia and Texas. While these markets are quite large, they will likely purchase only a small number of hybrid buses. From feedback in the Hybrid Bus Advisory Group and the Hybrid Bus Buyers Consortium, the level of vehicles in this market is less than 100 or 0.25 percent of the market across the country annually. The estimated price point for this market is roughly $200,000 or a price premium of 3.3 times the current cost of buses. The total value of this type C market is estimated to be around $20 million per year.

1.4.2 Non-Attainment Fleets

The U.S. EPA has designated many urban areas around the country as not in compliance with ambient air quality standards for ground level ozone and particulate matter. These non-attainment areas usually receive some federal funding to help correct the problems. School districts in these non-attainment areas are seeking innovative, cost-effective solutions to their local air quality issues.

The newer standard for ozone requires a more stringent eight hour averaging period. Oxides of nitrogen are a family of pollutants collectively called NOx that lead to ozone formation in the presence of sunlight. Over 50 percent of national NOx emissions are generated by the transportation sector. Figure 1.2 shows a national map of counties designated as non-attainment for ozone. Overlaying this map with current school bus fleet information shows that ozone non-attainment counties are home to 173,000 school buses, 36 percent of the entire fleet. The distribution among bus types (i.e., A, B, C or D) in these counties is not known but is assumed to mimic the national fleet.

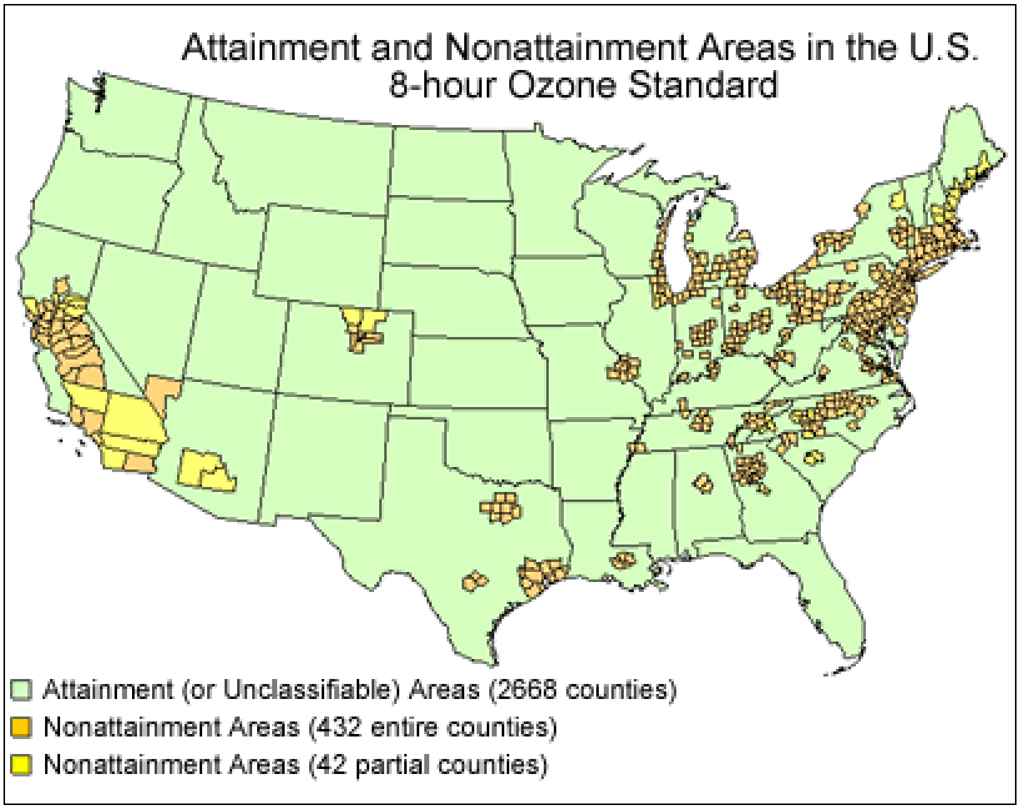

Figure 1.2. Ozone Non-Attainment Areas

The U.S. EPA also revised the particulate matter standard to regulate smaller diameter particles due to their increased health risk. The previous standard governed ambient concentrations of particulates smaller than 10 microns in diameter (PM10). The newer standard governs PM2.5, particles with diameters less than 2.5 microns. Figure 1.3 shows a national map of counties designated as non-attainment for PM2.5. These counties contain 78,500 buses representing 16.3 percent of the national fleet.

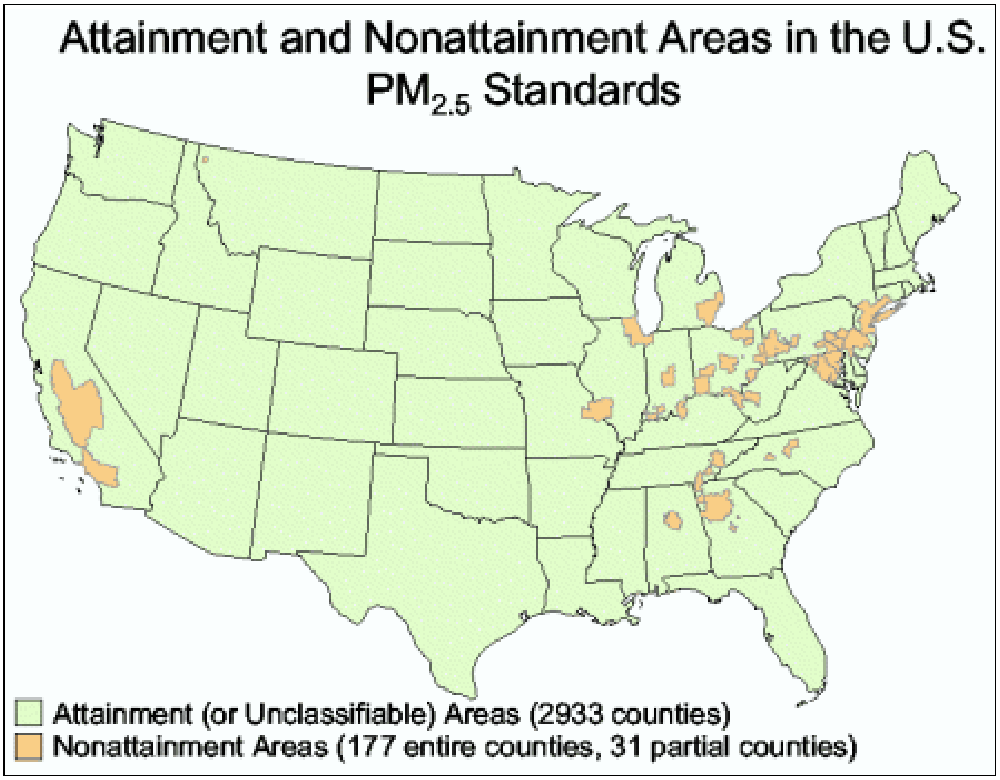

Figure 1.3. PM2.5 Non-Attainment Areas

Because virtually all of the counties that are in non-attainment for PM2.5 are also in non-attainment for ozone. Bus populations in both types of non-attainment counties should not be added together. This does imply that there is a strong incentive to implement NOx reduction strategies in 36 percent of the school bus market and an even greater incentive to reduce emissions in 16.3 percent of the market by implementing PM2.5 reductions. All vehicles operating in these regions are preferentially eligible for various federal and state funding for technologies that reduce emissions.

The estimated price point of hybrid technology for buses in non-attainment fleets is $140,000. In areas where both particulate matter and ozone reductions are required, there would be a slightly greater desire for the technology. Using these figures, the estimated value of the type C hybrid bus market in non-attainment areas would be just over $2 billion annually.

1.4.3 Entire Marketplace

The remaining school bus fleets are searching for safer, more efficient means of transport and are constantly making value judgments regarding the best trade off between operating costs, vehicle safety/health concerns and initial costs. Based on the results of this feasibility study and discussions among the school bus purchasers, it is likely that the price for such a vehicle would be widely accepted at approximately $80,000. This represents a 33 percent premium over current prices for type C buses. At this price range, the value of the national type C hybrid bus market is $1.7 billion per year.

1.5 Purpose of Business Feasibility Study

The Technical Feasibility Study predicted increased fuel economy and decreased emissions for various hybrid school bus options. It did not address economic impacts of those improvements nor did it address initial costs associated with hybrid technology. This Business Feasibility Study addresses those issues.

This study and the accompanying model analyze the differences in lifecycle costs between conventional, hybrid and plug-in hybrid school buses. It compares costs associated with maintenance and fuel as well as initial costs and infrastructure costs associated with each option. The following sections provide more details on the model development and results.

2. MODEL DEVELOPMENT

Hybrid vehicles promise reduced maintenance costs, reduced operating costs and reduced emissions. However, initial costs are expected to be greater than those for a conventional vehicle. Purchasers of these vehicles might ask if the incremental cost is ever repaid over the life of the vehicle. What is the payback? Are there other benefits beyond reduced fuel expenses? What is that incremental cost? What is the payback if fuel prices increase drastically?

Hybrid vehicles manufacturers have answers to these questions that may be based on generic inputs and "industry averages." What if a particular school bus fleet operator knows that expenses are different from those of the manufacturer's example? How would that affect the payback and overall lifecycle cost of the hybrid option?

To answer these questions and provide individual users the capability to modify the analysis, Advanced Energy developed a series of spreadsheets with variables that users can change to reflect their specific operations. This interactive model allows users to analyze various scenarios and compare the economic factors for each scenario. The following sections describe the options, the methodology of the analysis and the inputs to the model.

2.1 Model Outline

As stated earlier, the purpose of this model is to provide a tool for evaluating the economic impact of selecting a hybrid electric school bus over a conventional diesel school bus. To do this, the model calculates a lifecycle cost and several other economic factors. Lifecycle costs include initial purchase cost, operation costs (i.e., fuel) and maintenance costs. There are also benefits associated with reduced emissions for the hybrid options. Each of these costs is evaluated and summed to compare the options. Appendix A contains a printout of the model worksheets.

The Preliminary Technical Feasibility Study conducted earlier in this project required very specific information regarding vehicle technologies, bus configuration, drive cycle and performance criteria. That study used a computer model known as ADVISOR. This software was developed by the National Renewable Energy Laboratory to simulate the performance of hybrid electric vehicle drive systems and is used by many auto manufacturers.

Unlike ADVISOR, this model for the Business Feasibility Study does not require an inordinate level of detail regarding the individual vehicle specifications. However, it does rely on some of the same assumptions used to develop the technical model, and it relies on outputs generated by that model for evaluating the economic impact of the hybrid options. For example, like the Technical Study, this Business Study only compares type C, 65 passenger school buses. The Technical Study required a certain drive cycle and used the City Suburban Heavy Vehicle Cycle (CSHVC) to evaluate the performance of the various hybrid options. This Business Study does not require knowledge of the drive cycle but does require input of average annual mileage and average fuel economy. These values may be changed by the user, but the fuel economy values selected for the hybrid options were derived from the Technical Study. Therefore, the two studies are linked together in some of their common assumptions, and the outputs from the Technical Study can be used as inputs to the Business Study, but the Business Study is an independent tool that does not require detailed knowledge of the specific vehicle configuration.

The Business Feasibility Model is an Excel workbook with several worksheets. Table 2.1 provides a brief explanation of each worksheet. On each worksheet, cells that require user input have a different background color. All other cells contain either explanatory information or calculated values and should not be altered by the user. Some inputs such as bus lifetime, average annual mileage and discount rate are common to all the options while other inputs are specific to a particular option. More detailed descriptions of the various model inputs are provided in the sections below.

Table 2.1. Model Worksheets

Worksheet	Description
Summary	Common Input Variables, Summary of Economic Factors
Infrastructure	Costs for Associated Infrastructure
Fuel	Lifecycle Costs for Diesel and Electric Energy Use
Maintenance	Comparison Lifecycle Costs for Differential Categories
Emissions	Benefits from Hybrid Emission Reductions

Some costs are not considered in this analysis because they would be identical for each option. For example, driver compensation will not be affected by the choice of drivetrain. Primarily, these unconsidered costs fall under maintenance. For example, every school bus will require seat repair, new tires, repairs to the air conditioner, steering adjustments and new exterior paint. However, these costs will be the same regardless of the drivetrain. Costs in this category are not included in the analysis. Therefore, the lifecycle maintenance cost only evaluates areas where there would be a cost differential between the options.

2.2 Options

The three options evaluated in the model are:

- Conventional, powered only by diesel
- Hybrid, but not a plug-in
- Plug-in Hybrid

The Conventional option is a standard, diesel-only school bus available for sale today by all the major manufacturers. As explained above, the model assumes this is a type C, 65 passenger bus, but does not rely on many other specific details. In addition to the common variables such as annual mileage and diesel price, the model allows the user to input the specific capital cost and fuel efficiency for the conventional option. Where the Technical Study required specific details regarding engine type, transmission gear ratios and tire size, this Business Study only requires performance information.

The Hybrid and Plug-in Hybrid option likewise only require performance data. Users may alter this performance data using the Technical Study as a guide and may refer to that document for more details regarding different configurations and specific hardware options for the hybrids. For example, if users desire an all-battery range of 60 miles instead of 30, they may change the fuel economy of the hybrid options appropriately based on information in the Technical Study. Details on the recommended input values for the model are provided in the following sections.

The key difference between the hybrid options is the plug-in feature. As explained in the Technical Study, a plug-in hybrid allows the battery pack to be fully charged while the vehicle is sitting idle. The typical method for recharging is overnight while the bus is parked. Plug-in hybrids typically have larger battery packs than non plug-in hybrids. This additional electric capacity can significantly increase the effective fuel economy. This increase is reflected in the model and explained in more detail under Section 2.4, Model Inputs and Calculations.

2.3 Economic Analysis

The model calculates several economic factors that HESB purchasers may use when comparing the options. The primary factor calculated by this model is the lifecycle cost (LCC). This method emphasizes that all costs arising from owning, operating and maintaining a project are important to the decision to pursue that project. LCC is applicable to a wide variety of projects including energy saving investments, building renovations and equipment purchases. It is particularly suited for projects with multiple options that satisfy the performance criteria but that have different initial investment costs as well as operating, maintenance and repair costs. Lifecycle costing provides a significantly better assessment of long-term cost effectiveness than other methods that focus on first costs or short-term operating costs. Typically, the option with the lowest total LCC is the preferred option.

The lifecycle cost of a project represents the present value of all the costs and benefits associated with purchasing, operating and maintaining an investment over the life of the investment. For this study, the benefits include the value of avoided emissions. Future costs are discounted to their present value equivalent using the investor's Minimum Acceptable Rate of Return (MARR) as the discount rate. This methodology accounts for the time value of money. The federal government issues a recommended discount rate each year that must be used in federal project evaluations that reflects predicted trends in long-term inflation rates and returns associated with government securities. For 2004, this rate was set at the minimum value of 3 percent.

Any sort of discounting method must account for inflation. This model uses the constant dollar assumption. This means that a dollar has uniform purchasing power from year to year, starting from the base year. The price of a good or service in constant dollars is not affected from year to year by inflation. Therefore, the discount rate that represents the investor's MARR should be adjusted to the real discount rate (i.e., a lower rate that ignores inflation). This constant dollar assumption allows future costs to be estimated using today's price quotes assuming that the value of the good or service remains constant. However, some costs may have real escalations even if inflation is ignored. For example, the real cost of many manufactured products has decreased over time due to advances in technology and savings through mass production. This can be accounted for by applying a negative escalation rate to a certain cost.

There are other supplementary measures of economic performance that are consistent with the lifecycle cost method of project evaluation: the Savings to Investment Ratio (SIR), the Adjusted Internal Rate of Return (AIRR) and the Discounted Payback (DPB). The SIR reflects the relationship between a project's savings and its increased investment cost. The SIR is a relative measure of performance and is computed relative to a base case. An alternative is generally considered justified relative to the base case when the SIR is greater than one. The SIR should not be used when choosing among mutually exclusive projects that have different lifetimes or discount rates. The project with the lowest LCC is always the most cost effective but savings to investment ratios may be used to rank alternatives with similar LCCs.

The AIRR is a measure of the annual percentage yield from a project investment over the study period. Like the SIR, the AIRR is a relative measure of cost effectiveness and must be computed relative to a base case. The AIRR is compared to the investor's Minimum Acceptable Rate of Return (MARR) which is usually equal to the discount rate. If the AIRR is greater than the MARR, then the project is economically acceptable. The AIRR is different from the Internal Rate of Return (IRR). The IRR assumes that savings are reinvested at the calculated rate of return instead of the discount rate. This can overestimate the project's yield. The AIRR and IRR are equal if the investment yields a single lump sum payment at the end of the study life. The AIRR is generally considered a more accurate measure of performance and is more consistent with the LCC method.

The Discounted Payback (DPB) is a measure of the time required to recover the initial investment costs. The DPB is the number of years from the start date of the investment to the time at which cumulative discounted savings just equal the initial investment. The DPB is preferred over the Simple Payback factor since it discounts future savings to present values. A DPB that is less than the life of the investment indicates cost effectiveness.

One warning regarding these factors: these are used to evaluate investments. If users do not view the fleet vehicles as an investment that earns a return, then these factors may be less useful.

2.3.1 Economic Factor Formulas

The formulas for calculating the economic factors discussed above are shown in this section. The abbreviations used are explained in Table 2.2.

Table 2.2. Economic Factor Abbreviations

Abbreviation	Name	Description
LCC	Lifecycle Cost	Sum of all the Present Values
PV	Present Value	Value of Future Amount Discounted to Year Zero
F	Future Cash Flow	Future Amount either Positive or Negative
A_t	Annual Amount	Annual Cash Flow Occurring in Year t
t	Year	When the Cash Flow Occurs
n	Life	Total Life of the Investment in Years
N	Study Period	Total Years in the Study Period (Equal to n for this Study)
d	Real Discount Rate	Investor's Minimum Acceptable Rate of Return Without Inflation
e	Real Escalation Rate	Increase in Annual Cash Flow Above Inflation
S_t	Savings	Operational Savings in Year t due to the Option
ΔI_0	Initial Investment	Initial Capital Expenditure for the Option
ΔI_t	Incremental Investment	Additional Investment in Year t Attributable to the Option

The LCC is merely the sum of the Present Value of all of the benefits and costs for an individual option. Therefore, the total LCC for this model is calculated using Equation 2.1.

Equation 2.1. $$LCC = (Initial\,Cost) + PV_{Fuel} + PV_{Maint} + PV_{Emission}$$

The general formula for calculating the Present Value of a single future cash amount in year t for a given discount rate is shown in Equation 2.2.

Equation 2.2. $$PV = F_t \frac{1}{(1+d)^t}$$

For annually recurring non-uniform amounts that have an escalation rate, the Modified Uniform Present Value (MUPV) factor can be multiplied by the Uniform Amount to determine the Present Value. The MUPV factor is calculated according to Equation 2.3.

Equation 2.3. $$MUPV = \left(\frac{1+e}{d-e}\right) \times \left[1 - \left(\frac{1+e}{1+d}\right)^n\right]$$

The Savings to Investment Ratio is the Present Value of each year's savings divided by the Present Value of each year's incremental investment costs. Equation 2.4 defines the calculation. However, in the model worksheet, the summation occurs over a column of values.

Equation 2.4. $$SIR = \frac{\sum_{t=0}^{N} \frac{S_t}{(1+d)^t}}{\sum_{t=0}^{N} \frac{\Delta I_t}{(1+d)^t}}$$

The Adjusted Internal Rate of Return is easily calculated from the Savings to Investment Ratio as in Equation 2.5.

Equation 2.5. $$AIRR = (1+d)\,(SIR)^{1/N} - 1$$

Calculating the Discount Payback period requires an iterative process where the discounted savings are summed over the years until they exceed the initial investment. This comparison is expressed in Equation 2.6.

Equation 2.6. $$\Delta I_0 \leq \sum_{t=1}^{y} \frac{(S_t - \Delta I_t)}{(1+d)^t}$$

2.4 Model Inputs and Calculations

The inputs to the model include a wide range of variables that allow users to customize the analysis. Variables include data specific to the hybrid options, such as battery replacement life, as well as data common to all the options such as annual bus mileage. On the worksheets, inputs are shown as colored cells. The calculations that rely on these inputs are also discussed below. Each option, i.e., Conventional, Hybrid or Plug-in, has a separate column for each input variable or calculated value.

2.4.1 Summary Worksheet

The summary worksheet contains some brief explanatory text and a list of common variables. These variables affect all of the calculations in the model and are the primary variables that should be altered by the user. Table 2.2 shows these variables and the typical ranges.

Table 2.2. Summary Worksheet Inputs

Variable	Range
Annual Mileage	National average is 8,000.
Bus Lifetime	Informal polls show average is 15 years.
Today's Diesel Price	Fuel costs vary widely across the nation and change with time. Section 2.4.3 contains more discussion on an appropriate value.
Real Discount Rate	As explained in Section 2.3, this value should reflect a constant dollar analysis and the user's MARR. The U.S. government recommends a minimum of 3 percent.
Technician Labor Rate	Used to calculate differential maintenance costs. Direct labor only, no benefits.
Initial Cost	Informal poll shows average to be $60,000 for Conventional option. Hybrid and Plug-in values are estimates.
Diesel Efficiency	Default values in the model for each option were derived from the Technical Feasibility Study.
Electric Efficiency	Value of 1.25 mile/kWh is derived in the Technical Feasibility Study.
Residual Value	Will vary widely across the nation and depends on assumed bus lifetime. Hybrid and Plug-in values are estimates but are assumed higher than Conventional.

The Summary worksheet calculates certain values and reads other values that are calculated on the other worksheets. For example, the lifecycle mileage is calculated from the annual mileage and the life of the bus. Values for infrastructure, fuel and maintenance costs are read from those particular worksheets. Values for emission reductions and the associated value of those reductions are read from the Emissions worksheet. All cash flows are discounted to Present Values as explained earlier in Section 2.3.

The columns to the right of the inputs section show the savings from the Hybrid and Plug-in options relative to the Conventional option (see Appendix A). Total lifecycle savings is the sum of the lifecycle fuel savings, maintenance savings and the increase in the residual value. This represents direct operational savings over the life of the bus.

The economic factor calculations are also on the Summary spreadsheet below the variable input area. Section 2.3 contains explanations of these calculations. The Savings to Investment Ratio, Adjusted Internal Rate of Return and the Discounted Payback Period include the benefit from avoided emissions. This reflects the philosophy that the value of a hybrid electric school bus should include the value of the avoided emissions.

2.4.1.1 Assumptions

The Initial Cost of a school bus depends on many factors. There are price variations even for a standard, type C, 65 passenger model. This cost difference partially derives from the varying requirements that different states place on the school districts when specifying a bus purchase. The average cost for a Conventional bus used in the model is based on an informal poll of the HESB Buyers Consortium.

The Initial Costs for the Hybrid and Plug-in Options are based on discussions with school bus manufacturers and a review of hybrid transit bus prices. The costs assumed for the model are also influenced by low volume production for the Early Production Purchase. Because the hybrid bus will have drivetrain components that are not found on conventional buses (e.g., motor/generator, controller, battery pack, battery charger), it is expected that even in mature production, hybrid technology will be more expensive for the buyer than conventional technology. However, this premium is not expected to be excessive. Table 2.3 shows the estimated premium as production volumes increase.

Table 2.3. Hybrid Bus Premium

Production Quantity	Hybrid Premium
20	$140,000
100	$80,000
1,000	$20,000

The national average annual mileage for school buses is 8,000 miles. However, based on discussions with individual state directors and local transportation directors, the national average mileage is skewed toward the low end. This is due to reporting spare buses that are not driven many miles per year. Based on input from the HESB Buyers Consortium, a more realistic value of 12,000 miles per year is used in the model.

Values for diesel efficiency were calculated in the Technical Feasibility Study based upon the City Suburban Heavy Vehicle driving cycle. It is recommended that users not change these values.

2.4.2 Infrastructure Worksheet

Infrastructure costs include any support structure required to service or refuel the vehicle. For conventional diesel vehicles, this would include the maintenance garage, engine diagnostic equipment, the fuel storage tank, fuel pumps and fuel distribution network. These same requirements are present for the hybrid option. The Plug-in option would require additional charging infrastructure. The costs for this additional infrastructure were derived from a review of a technical report published by the Electric Power Research Institute (See References).

The model assumes that infrastructure support for the Conventional option is already present and therefore has zero cost. This same infrastructure would support both the Hybrid and Plug-in options as well. Costs for driver training are assumed to be the same for all options and are therefore not calculated. Technician training costs are typically covered by the manufacturer and not included in this model. Also, both the Hybrid and

Plug-in options are expected to use standard diagnostic equipment that would be used for a new Conventional bus.

All the infrastructure costs are assumed to occur at the beginning of the project. Users should therefore input present values into this worksheet.

2.4.3 Fuel Worksheet

The Fuel worksheet estimates the lifecycle cost of both diesel and electricity associated with the options. Most of the input variables are copied from the Summary worksheet. Users input real escalation rates for both diesel and electricity as well as unit costs for electric energy and peak demand.

Calculations on this worksheet are highly influenced by the cost of diesel input on the Summary worksheet. Users should input the price they actually pay. For school districts, this price typically excludes state and federal taxes. This model uses a long-term analysis to estimate the differences in lifecycle costs. Users should therefore take a long-term approach to estimating the cost of diesel. It may be appropriate to average diesel costs over the last year or even few years to determine a value to put in the model. Fuel prices change daily and over the long term are subject to drastic increases in cost over short-time periods. This model does not have a method for estimating those future "shocks" but instead assumes a steadily changing cost.

As discussed in Section 2.3, this model uses the constant dollar assumption to account for inflation. It assumes that the purchasing power of a dollar is constant over time. Therefore, real changes in the cost of a commodity such as diesel fuel or electricity must be included in the calculation of present value. The real escalation rate reflects an increase (positive value) or decrease (negative value) in the real cost of an item. The baseline analysis presented in Section 3 assumes that the real cost of diesel fuel will increase by 0.5 percent per year. This assumption reflects recent OPEC decisions, growing world demand for oil and the reduction of inexpensive proven reserves.

Electricity costs for the plug-in version depend on several assumptions. Each trip is assumed to drain the plug-in battery pack to a 20 percent state of charge. Therefore, the amount of electric energy assumed to be replaced by the grid is 80 percent of the total pack capacity. Also, the value for peak electric demand is based upon the maximum charger size for the Plug-in option.

This spreadsheet calculates first-year fuel costs and uses this value to calculate lifecycle fuel costs. First-year diesel costs rely on the annual mileage, diesel efficiency and fuel price. First-year electric costs are based on the yearly energy charge and the monthly demand charge. Lifecycle costs are estimated from the first-year cost using the MUPV Factor (see Section 2.3.1). The model therefore assumes that fuel efficiency of the bus does not decrease over time.

2.4.4 Maintenance Worksheet

As mentioned earlier, the lifecycle cost calculation is really an estimate of the differences in lifecycle costs between the options. Therefore, only costs for those maintenance items that are expected to differ between the options are estimated in the model. Tires, painting and upholstery repairs will be the same regardless of the drivetrain configuration. Therefore, the Maintenance worksheet only addresses costs associated with oil changes, brakes and transmissions.

The worksheet copies commonly used variables from the Summary worksheet and has certain cells for user input. The user inputs include material cost, labor cost and schedule associated with each category of maintenance (i.e., oil change, brakes and transmission). The model also allows for separate escalation rates for materials and labor. From the escalation rate and other factors, a MUPV factor is calculated (see Section 2.3.1).

Inputs for the Hybrid and Plug-in options include battery replacement schedule and battery replacement cost. In *Advanced Batteries for Electric-Drive Vehicles*, EPRI reports estimates for battery costs and life in terms of miles traveled. Their analysis documents battery costs on a per kilowatt hour basis at different production levels for nickel metal hydride technology. Exact costs and battery life used in the analysis are detailed in Section 3.

Both the Hybrid and Plug-in options are expected to have significantly longer oil change, brake replacement and transmission repair schedules. Longer oil changes are expected due to lower average engine loads and overall reduced engine operating time due to the absence of idling. Hybrid drivetrains also incorporate regenerative braking. This allows the motor to act as a generator and provide a torque that resists forward motion of the vehicle while at the same time generating current to charge the batteries. Therefore, brake life on hybrid electric school buses is estimated to be twice as long as that for conventional buses. Depending on the configuration of the drivetrain, hybrids may also have reduced transmission wear. The model assumes a 50 percent longer time between transmission repairs.

Lifecycle maintenance costs are estimated from the first-year labor and material costs using the MUPV factor. First-year costs are based on the per event labor and material costs and the number of events per year. Lifecycle battery replacement costs are the sum of the present values of all battery replacement events over the life of the bus. The Maintenance worksheet shows these calculations below the other lifecycle cost calculations.

2.4.5 Emissions Worksheet

The Emissions worksheet estimates the value associated with the reduced emissions from the Hybrid and Plug-in options. The pollutants evaluated by this model are the same as those evaluated by the Technical Feasibility Study: Particulate Matter (PM), Nitrogen Oxides (NOx) and Carbon Dioxide (CO2). That study, using a standard drive cycle, showed significant reductions of these pollutants on a gram per mile basis for the Hybrid and Plug-in options. This Business Feasibility model relies on these emission factors and the annual mileage to estimate lifecycle emissions for each option.

Inputs to this worksheet also include the value per ton of each pollutant. However, the value of emission reductions is far from certain. If all emissions were traded in a market-based system like stocks or bonds, then the value could be clearly assigned. The emerging Greenhouse Gas (GHG) market is approximating this scenario for Carbon Dioxide equivalents. Entities can buy and sell Certified Emission Reductions created through a reduction in actual emissions, avoidance of potential emissions or the creation of emission offsets (through carbon sequestration). These markets are particularly active in Canada, Japan and Europe. Recent values for each ton of Carbon Dioxide equivalent range from $4.50 to $5.50. However, as the market develops, this value is expected to increase.

Despite the lack of a market trading scenario, the federal government and local air pollution control agencies still assign a value to PM and NOx. For example, the Federal

Aviation Administration administers the Voluntary Airport Low Emission program whereby airports may obtain federal funding to implement emission reduction technologies. Guidance for that program indicates that emission reduction programs are considered cost effective at $5,000 to $10,000 per ton of NOx and $25,000 to $50,000 per ton of PM10 (Particulate Matter less than 10 microns in diameter). These values may vary depending upon the local air quality. In an Ozone Non-Attainment area, the value of each ton of avoided NOx emissions may be much higher than $10,000. Users should consult their local air pollution control agency for more information.

As on the other worksheets in the model, the first-year emissions are used to calculate the lifecycle emissions. The value of the lifecycle emission reductions as compared to the Conventional option are then discounted using the MUPV factor (see Section 2.3.1).

Emissions for the Plug-in option include emissions from the electric generating utility. The calculations rely on an estimate of the grams per kilowatt hour emitted by the power plant. These values will be higher for coal-fired utilities than for natural gas-fired utilities and would be zero for electric power generated from renewable sources such as solar panels, hydroelectric or wind turbines. The values used in the model are from the Technical Feasibility Study which relied on the average generation mix of the entire United States. Even coal-fired power plants emit very little PM on a per kilowatt hour basis, and the model assumes this emission factor is zero.

3. RESULTS

The model generates several economic factors that can be used to evaluate the options. Individual users may place more emphasis on a particular factor over another. Therefore, this section of the study will report the values of the factors for a set of input values and leave judgment to the user. As indicated in Section 2.3, the lifecycle cost is clearly applicable to the operation of a fleet vehicle, but the supplementary factors may not be applicable for certain users.

3.1 Baseline

The Baseline case compares the Conventional, Hybrid and Plug-in options with the default inputs described in previous sections. Table 3.1 below shows some of these input values.

Table 3.1. Baseline Case Inputs

Variable	Value	Units
Annual Mileage	12,000	Miles
Bus Lifetime	15	Years
Diesel Price	$1.70	Dollars
Real Discount Rate	3.00%	Percent
Real Diesel Escalation	0.50%	Percent
PM Value	$50,000	$/Ton
NOx Value	$10,000	$/Ton
CO2 Value	$5	$/Ton

Table 3.2 shows some of the input values for the Baseline case for the three options.

Table 3.2. Baseline Case Option Inputs

Variable	Units	Conventional	Hybrid	Plug-in
Initial Cost	Dollars	$60,000	$80,000	$80,000
Diesel Efficiency	mpg	7.4	8.4	18.0
Residual Value	Dollars	$2,000	$10,000	$10,000
Oil Change	Miles	4,500	6,750	6,750
Brake Replacement	Miles	24,000	48,000	48,000
Transmission Repair	Miles	48,000	72,000	72,000
HESB Battery Replacement	Miles	-	150,000	150,000
Battery Cost	Dollars	-	$7,200	$7,200
Charging Infrastructure	Dollars	-	-	$1,400

The values for initial cost and battery cost are based upon full production volumes for the national market (see Section 1.4). Using these values, the economic factors show that the Plug-in option has a lifecycle cost that is less than the Conventional option, but the Baseline Hybrid has a higher lifecycle cost than the Conventional. Table 3.3 shows all the economic factors for the Baseline Case. All dollar values shown are Present Values assuming constant dollars over the lifetime.

Table 3.3. Baseline Case Economic Factors

Factor	Hybrid	Plug-in
Lifecycle Savings	- $8,846	$13,975
SIR	0.55	1.56
AIRR	- 0.01%	0.06%
Discounted Payback	> 25 years	9 Years

These results show that the Plug-in option is a favorable economic investment. The lifecycle savings are positive, the incremental investment (i.e., the higher initial price) earns the investor's minimum acceptable return and the payback period is less than the life of the project. Using the assumptions of the Baseline Case, the Hybrid option does not compare as favorably using these economic factors.

3.2 Sensitivity Analysis

A sensitivity analysis for this model shows how the economic factors change when certain input parameters are adjusted. For this study, the critical factors appear to be the initial cost and battery replacement cost. Other parameters of interest that are included in the sensitivity analysis include diesel price, bus lifetime and discount rate. For the cases discussed below, all other input parameters are held constant while the single parameter is modified.

3.2.1 Initial Cost

The baseline case assumed that the Hybrid and Plug-in option are manufactured at production volumes for the national market. At this level, the hybrid options are assumed to have a cost premium of approximately $20,000. At lower volumes and with current technologies, this cost premium is substantially higher. At the national market level, the operational savings of the Plug-in option recover this higher initial cost. This is not the case for the non-attainment fleet market (see Section 1.4). Table 3.4 compares the results for these higher initial costs.

Table 3.4. High Initial Cost Case Economic Factors

Parameter	Hybrid	Plug-in
Initial Cost	$140,000	$140,000
Lifecycle Savings	- $68,846	- $46,025
SIR	0.14	0.41
AIRR	- 0.10%	- 0.03%
Discounted Payback	> 25 years	> 25 years

3.2.2 Battery Replacement Cost

Battery life and replacement cost have a significant impact on the overall lifecycle savings of the Hybrid and Plug-in options. If the battery is replaced more often or if each battery is more expensive, then this cost decreases the lifecycle savings. Researchers at the Electric Power Research Institute in Palo Alto, California have done extensive market analysis and technology evaluation relative to hybrid and electric vehicles. A 2004 study (see References) indicates that Nickel Metal Hydride batteries in hybrid vehicle applications should have lifetimes of 150,000 miles. That same study provides estimates for battery costs per kilowatt hour at various production volumes. These values are used in the Baseline Case.

However, battery performance and costs have been difficult to predict. Manufacturers point to these uncertainties as a significant hurdle in hybrid vehicle development. This sensitivity analysis therefore varies both battery life and replacement cost. The study referenced above indicates that battery technology for hybrids will improve to the point where the initial battery will last the life of the vehicle. The tables below show the economic factors for both short and long battery life. Also, the battery replacement costs in the Baseline Case are assumed to be the minimum costs. Tables 3.5 through 3.8 show the results.

Table 3.5. Long Battery Life Case Economic Factors

Parameter	Hybrid	Plug-in
Battery Life	180,000 miles	180,000 miles
Lifecycle Savings	- $3,943	$18,878
SIR	0.79	1.78
AIRR	0.01%	0.07%
Discounted Payback	> 25 years	9 Years

Table 3.6. Short Battery Life Case Economic Factors

Parameter	Hybrid	Plug-in
Battery Life	60,000 miles	60,000 miles
Lifecycle Savings	- $15,175	$7,646
SIR	0.23	1.26
AIRR	- 0.07%	0.05%
Discounted Payback	> 25 years	14 Years

Table 3.7. High Battery Cost Case Economic Factors

Parameter	Hybrid	Plug-in
Battery Cost	$15,000	$15,000
Lifecycle Savings	- $14,158	$8,663
SIR	0.28	1.31
AIRR	- 0.05%	0.05%
Discounted Payback	> 25 years	11 Years

Table 3.8. Mid Battery Cost Case Economic Factors

Parameter	Hybrid	Plug-in
Battery Life	$10,000	$10,000
Lifecycle Savings	- $10,753	$12,068
SIR	0.45	1.47
AIRR	- 0.02%	0.06%
Discounted Payback	> 25 years	9 Years

As anticipated, shorter battery life means more replacements and higher lifecycle costs. Higher battery costs increases lifecycle costs as well. However, the Plug-in option has favorable economic factors for all cases. This is due to the economic value of the emissions benefits included in the factor calculations.

3.2.3 Diesel Price

As discussed above, fuel prices vary substantially year to year. Recent events have driven these prices even higher and may reflect a long-term trend. In the same way, new oil field discoveries or political changes may lead to much lower real prices. Therefore, this sensitivity analysis on diesel price includes increases and decreases. The results are shown in Tables 3.9 and 3.10.

Table 3.9. High Diesel Price Case Economic Factors

Parameter	Hybrid	Plug-in
Diesel Price	$2.25	$2.25
Lifecycle Savings	- $7,530	$20,484
SIR	0.61	1.85
AIRR	0.00%	0.07%
Discounted Payback	> 25 years	7 Years

Table 3.10. Low Diesel Price Case Economic Factors

Parameter	Hybrid	Plug-in
Diesel Price	$1.25	$1.25
Lifecycle Savings	- $9,923	$8,649
SIR	- 0.02	1.32
AIRR	- 0.02%	0.05%
Discounted Payback	> 25 years	13 Years

As expected, higher fuel costs improve the economic factors for both the Hybrid and Plug-in options. In the low diesel price case, the Plug-in option still shows favorable factors from an investment perspective.

3.2.4 Vehicle Lifetime

Different school districts have different expectations for vehicle lifetimes. In northern states where road salt is commonly used, vehicle lifetimes may be shorter than the 15 years considered in the Baseline Case. Each district also has a few 30-year old buses that operate as reserves. Tables 3.11 and 3.12 show the impact of these different lifetimes on the economic factors.

Table 3.11. Longer Lifetime Case Economic Factors

Parameter	Hybrid	Plug-in
Lifetime	20 years	20 years
Lifecycle Savings	- $6,761	$21,865
SIR	0.62	1.88
AIRR	0.01%	0.06%
Discounted Payback	> 25 years	9 Years

Table 3.12. Shorter Lifetime Case Economic Factors

Parameter	Hybrid	Plug-in
Lifetime	10 years	10 years
Lifecycle Savings	- $6,304	$9,892
SIR	0.71	1.41
AIRR	0.00%	0.07%
Discounted Payback	> 25 years	9 Years

The longer lifetime allows the Plug-in option to accumulate greater annual fuel savings, but of course, does not change the payback period since it was positive for the shorter lifetime baseline case. For both longer and shorter lifetime cases, the Hybrid option has a higher lifecycle cost than the Conventional option.

3.2.5 Discount Rate

School districts may not necessarily consider buses as an investment option. Typically, a district has a certain funding allocation that must be spent on transportation. The notion of a discount rate representing the minimal accepted rate of return may seem out of place with this reality. Therefore, a discount rate of zero may be more appropriate for some districts. Even with a zero discount rate, the constant dollar assumption still applies, but the discounted payback is now a simple payback. Table 3.13 shows the results.

Table 3.13. Zero Discount Case Economic Factors

Parameter	Hybrid	Plug-in
Discount Rate	0.0%	0.0%
Lifecycle Savings	- $5,450	$23,273
SIR	0.73	2.00
AIRR	0.02%	0.05%
Discounted Payback	> 25 years	8 Years

As expected, this assumption increases the lifecycle savings. If the user assumes a zero discount rate, then the other economic factors have relatively little meaning because the investment is no longer considered an option among other investments.

4. CONCLUSIONS

This study estimated the lifecycle savings of a Hybrid and Plug-in hybrid school bus compared to a Conventional diesel bus. The model developed as part of the study allows users to input costs for the initial purchase, infrastructure, fuel and maintenance. In addition, the model allows users to assign some economic value to avoided air pollution. The model uses a constant dollar analysis to account for inflation and a real discount rate for determining the time value of money.

The Baseline Case result demonstrates that the Plug-in option achieves lifecycle cost parity with the Conventional option. The Hybrid option, however, would require either an increase in fuel economy or a lower initial cost to meet this goal. The Sensitivity Analysis points to several key parameters that could increase lifecycle savings. From a design consideration, the goals include low initial cost and long battery life. These goals may work against one another as longer life batteries usually result in higher initial costs. Optimization is required to meet the necessary performance goals and fuel efficiency.

This Business Feasibility Study supports the conclusions of the Technical Feasibility Study. Not only are plug-in hybrid school buses possible, they also make economic sense when compared to a conventional bus over the lifetime of the vehicle.

REFERENCES

Pritchard, Ewan, 2004, "Hybrid Electric School Bus Preliminary Technical Feasibility Report," Advanced Energy, Raleigh, N.C.

Fuller, Sieglinde and Petersen, Stephen, 1996, *Life-Cycle Costing Manual for the Federal Energy Management Program, NIST Handbook 135*, Building and Fire Research Laboratory, Office of Applied Economics, National Institute of Standards and Technology, Gaithersburg, M.D.

Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options, EPRI, Palo Alto, C.A: 2001. 1000349.

Advanced Batteries for Electric-Drive Vehicles: A Technology and Cost-Effectiveness Assessment for Battery Electric Vehicles, Power Assist Hybrid Electric Vehicles, and Plug-in Hybrid Electric Vehicles, EPRI, Palo Alto, C.A: 2004. 1009299.

APPENDIX A. MODEL OUTPUT FOR BASELINE CASE

This page is intentionally not blank.

Hybrid Electric School Bus Project
Business Feasibility Study

This Excel workbook estimates the lifecycle cost of a conventional, diesel powered, 65-passenger, type C school bus and compares that to the lifecycle costs for two types of hybrid electric school buses: non plug-in and plug-in versions. Costs that are the same for all options are ignored. The values reported are therefore not the complete lifecycle costs but are representative values for comparison. The report that accompanies this tool contains additional details.

This worksheet shows the major input variables to the analysis. Values in shaded cells may be altered to evaluate various scenarios. The other worksheets contain detailed calculations for the categories of costs.

The lifecycle cost (LCC) calculations use the methodology prescribed by the Federal Energy Management Program in Handbook 135 published by the National Institute of Standards and Technology. This methodology applies a real discount rate and does not include inflation adjustments. This is known as a constant dollar analysis.

Common Variables

Annual Mileage	12,000	Miles
Bus Lifetime	15	Years (Must be less than 25)
Lifecycle Mileage	180,000	Miles
Today's Diesel Price	$1.70	Dollars
Real Discount Rate	3.00%	Excludes general price inflation. DOE recommendation is 3.0%.
Technician Labor Rate	$15.00	$/hr

	Conventional	Hybrid	Plug-in		Difference in Value Hybrid	Difference in Value Plug-in
Initial Cost	$60,000	$80,000	$80,000		($20,000)	($20,000)
Infrastructure Cost	$0	$0	$1,400		$0	($1,400)
Diesel Efficiency	7.4	8.4	18.0	mpg	1.0	10.6
Electric Efficiency	-	-	1.25	miles per kWh	-	-
First Year Fuel Cost	$2,757	$2,429	$1,330		$328	$1,427
First Year Maintenance Cost	$387	$240	$240		$146	$146
Lifecycle Fuel Cost	$34,163.70	$30,096.59	$16,482.97		$4,067	$17,681
Lifecycle Maintenance Cost	$8,008.77	$9,868.61	$9,868.61		($1,860)	($1,860)
Residual Value	$2,000.00	$10,000.00	$10,000.00		-	-
Present Value of Residual	$1,283.72	$6,418.62	$6,418.62		$5,135	$5,135
				Total Lifecycle Savings	($12,658)	$956

This workbook also estimates the value of the reduction in emissions associated with operating a hybrid instead of a conventional bus. The values below are referenced from the 'Emissions' worksheet. The value assigned to each ton of pollutant is also found on that worksheet.

Lifecycle PM Emissions	0.04	0.01	0.01	Tons	0.02	0.03
Lifecycle NOx Emissions	2.30	1.95	0.87	Tons	0.35	1.42
Lifecycle CO2 Emissions	253.93	223.70	144.38	Tons	30.23	109.55

Lifecycle Value of PM Reductions	$923.64	$1,223.63
Lifecycle Value of NOx Reductions	$2,763.03	$11,342.78
Lifecycle Value of CO2 Reductions	$124.88	$452.56
Total Lifecycle Value of Avoided Emission	$3,811.55	$13,018.96
Total Lifecycle Savings Plus Emissions Value	($8,846)	$13,975

The economic indicators below are explained in the text of the report. The calculations for each indicator are in the labeled cells below. The indicators include the value associated with the reduced emissions.

	Hybrid	**Plug-in**	
Savings to Investment Ratio	0.55	1.56	Should be greater than 1.
Adjusted Internal Rate of Return	-0.01	0.06	
Discounted Payback	>25	9	

Only Economic Indicator Calculations Below This Row

Hybrid Economic Indicators

Savings to Investment Ratio

Year	Savings	New Battery	Avoided Emissions	Residual	SPV Factor	Present Value Savings
0	$0	$0	$0	$0	1.00	$0
1	$475	$0	$319	$0	0.97	$770
2	$475	$0	$319	$0	0.94	$748
3	$475	$0	$319	$0	0.92	$726
4	$475	$0	$319	$0	0.89	$705
5	$475	$0	$319	$0	0.86	$684
6	$475	$0	$319	$0	0.84	$664
7	$475	$0	$319	$0	0.81	$645
8	$475	$0	$319	$0	0.79	$626
9	$475	$0	$319	$0	0.77	$608
10	$475	$0	$319	$0	0.74	$590
11	$475	$0	$319	$0	0.72	$573
12	$475	$0	$319	$0	0.70	$556
13	$475	$7,200	$319	$0	0.68	($4,363)
14	$475	$0	$319	$0	0.66	$524
15	$475	$0	$319	$10,000	0.64	$6,928
16	$0	$0	$0	$0	0.62	$0
17	$0	$0	$0	$0	0.61	$0
18	$0	$0	$0	$0	0.59	$0
19	$0	$0	$0	$0	0.57	$0
20	$0	$0	$0	$0	0.55	$0
21	$0	$0	$0	$0	0.54	$0
22	$0	$0	$0	$0	0.52	$0
23	$0	$0	$0	$0	0.51	$0
24	$0	$0	$0	$0	0.49	$0
25	$0	$0	$0	$0	0.48	$0

Incremental Initial Investment	$20,000	Note: Initial investment is only investment for this analysis.
Lifecycle Savings	$10,985	
Savings to Investment Ratio	0.55	

Discounted Payback Period

Year	Cumulative Present Value Savings	=1 if > Incremental Investment
0	$0	0
1	$770	0
2	$1,518	0
3	$2,244	0
4	$2,949	0
5	$3,633	0
6	$4,297	0
7	$4,942	0
8	$5,568	0
9	$6,176	0
10	$6,767	0
11	$7,340	0
12	$7,896	0
13	$3,533	0
14	$4,058	0
15	$10,985	0
16	$10,985	0
17	$10,985	0
18	$10,985	0
19	$10,985	0
20	$10,985	0
21	$10,985	0
22	$10,985	0
23	$10,985	0
24	$10,985	0
25	$10,985	0

Plug-in Economic Indicators
Savings to Investment Ratio

Year	Savings	New Battery	Avoided Emissions	Residual	SPV Factor	Present Value Savings
0	$0	$0	$0	$0	1.00	$0
1	$1,573	$0	$1,088	$0	0.97	$2,584
2	$1,573	$0	$1,088	$0	0.94	$2,509
3	$1,573	$0	$1,088	$0	0.92	$2,436
4	$1,573	$0	$1,088	$0	0.89	$2,365
5	$1,573	$0	$1,088	$0	0.86	$2,296
6	$1,573	$0	$1,088	$0	0.84	$2,229
7	$1,573	$0	$1,088	$0	0.81	$2,164
8	$1,573	$0	$1,088	$0	0.79	$2,101
9	$1,573	$0	$1,088	$0	0.77	$2,040
10	$1,573	$0	$1,088	$0	0.74	$1,980
11	$1,573	$0	$1,088	$0	0.72	$1,923
12	$1,573	$0	$1,088	$0	0.70	$1,867
13	$1,573	$7,200	$1,088	$0	0.68	($3,091)
14	$1,573	$0	$1,088	$0	0.66	$1,760
15	$1,573	$0	$1,088	$10,000	0.64	$8,127
16	$0	$0	$0	$0	0.62	$0
17	$0	$0	$0	$0	0.61	$0
18	$0	$0	$0	$0	0.59	$0
19	$0	$0	$0	$0	0.57	$0
20	$0	$0	$0	$0	0.55	$0
21	$0	$0	$0	$0	0.54	$0
22	$0	$0	$0	$0	0.52	$0
23	$0	$0	$0	$0	0.51	$0
24	$0	$0	$0	$0	0.49	$0
25	$0	$0	$0	$0	0.48	$0

Incremental Initial Investment	$21,400
Lifecycle Savings	$33,288
Savings to Investment Ratio	1.56

Note: Initial investment is only investment for this analysis.

Discounted Payback Period

Year	Cumulative Present Value Savings	=1 if > Incremental Investment
0	$0	0
1	$2,584	0
2	$5,093	0
3	$7,528	0
4	$9,893	0
5	$12,189	0
6	$14,418	0
7	$16,582	0
8	$18,683	0
9	$20,723	0
10	$22,703	1
11	$24,626	1
12	$26,492	1
13	$23,402	1
14	$25,161	1
15	$33,288	1
16	$33,288	1
17	$33,288	1
18	$33,288	1
19	$33,288	1
20	$33,288	1
21	$33,288	1
22	$33,288	1
23	$33,288	1
24	$33,288	1
25	$33,288	1

Hybrid Electric School Bus Project
Business Feasibility Study

This Excel workbook estimates the lifecycle cost of a conventional, diesel powered, 65-passenger, type C school bus and compares that to the lifecycle costs for two types of hybrid electric school buses: non plug-in and plug-in versions. Costs that are the same for all options are ignored. The values reported are therefore not the complete lifecycle costs but are representative values for comparison. The report that accompanies this tool contains additional details.

This worksheet shows cost estimates for the initial capital cost of any required infrastructure. Inputs for the conventional option are assumed to be zero because maintenance facilities and refueling infrastructure already exist. Therefore, only costs associated with the hybrid options are calculated.

The hybrid options may require new diagnostic equipment. However, initial estimates show that the diagnostic interface will be exactly the same as that required for a conventional bus. The input cells are included in the calculations if uses desire to input these costs. The plug-in option will require recharging infrastructure.

These costs are assumed to occur in year zero of the lifecycle analysis. Therefore, the costs as shown are present value costs.

	Conventional	**Hybrid**	**Plug-in Hybrid**
New Diagnostic Equipment	$0	$0	$0
Charger	$0	$0	$1,000
Wiring	$0	$0	$200
Electric Metering	$0	$0	$200
Infrastructure Subtotal	**$0**	**$0**	**$1,400**

Hybrid Electric School Bus Project
Business Feasibility Study

This Excel workbook estimates the lifecycle cost of a conventional, diesel powered, 65-passenger, type C school bus and compares that to the lifecycle costs for two types of hybrid electric school buses: non plug-in and plug-in versions. Costs that are the same for all options are ignored. The values reported are therefore not the complete lifecycle costs but are representative values for comparison. The report that accompanies this tool contains additional details.

This worksheet estimates lifecycle fuel costs. This includes diesel and electricity. Initial diesel price per gallon is copied from the 'Summary' worksheet. Users input electricity costs and energy cost escalation rates.

The Energy Information Administration provides energy price projections by region of the country and energy type. Rather than incorporate these values into the spreadsheet, this LCC analysis uses an annual escalation rate in real energy costs for diesel and electricity. This rate should include the transition to Ultra Low Sulfur Diesel.

Electricity rate schedules vary across the country. These calculations assume that some sort of time-of-use rate is available and that plug-in buses would preferentially charge during off-peak hours. Note that electricity consumption is a function of battery pack size and trips per year. This analysis assumes that the bus takes 220 trips per year and each trip drains the battery pack to 20% state of charge. Electricity consumption is therefore independent of annual mileage.

Common Variables

Annual Mileage	12,000	Miles
Bus Lifetime	15	Years
Lifecycle Mileage	180,000	Miles
Today's Diesel Price	$1.70	Dollars
Real Discount Rate	3.00%	
Real Diesel Escalation Rate	0.50%	
Real Electric Escalation Rate	0.50%	

	Conventional	**Hybrid**	**Plug-in**	
Diesel Efficiency	7.4	8.4	18	mpg
Electric Efficiency	-	-	1.25	miles per kWh
Peak Electric Demand	-	-	7	kW
Off-peak Electric Energy Cost	-	-	$0.0300	$/kWh
Demand Charge	-	-	$1.00	$/kW
Operating Months per Year	-	-	10	
Battery Pack Size	-	24.0	24.0	kWh
Trips per Year	220.00	220.0	220.0	
Minimum State of Charge		80%	20%	
First Year Diesel Cost	$2,756.76	$2,428.57	$1,133.33	
First Year Electric Cost	$0.00	$0.00	$196.72	
First Year Energy Cost	$2,756.76	$2,428.57	$1,330.05	Diesel + Electric
Lifecycle Diesel Cost	$34,163.70	$30,096.59	$14,045.08	
Lifecycle Electric Cost	$0.00	$0.00	$2,437.89	
Lifecycle Energy Cost	$34,163.70	$30,096.59	$16,482.97	

First Year Diesel Cost			
Annual Mileage	12000	12000	12,000
Diesel Efficiency	7.4	8.4	18
Total Gallons	1621.62	1428.57	666.67
Cost Per Gallon	$1.70	$1.70	$1.70
First Year Diesel Cost	$2,756.76	$2,428.57	$1,133.33

First Year Electric Cost				
Battery Pack Size	-	-	24	kWh
Depth of Discharge	-	-	0.80	= 1 - Min SOC
Discharges per Year	-	-	220.0	
Annual kWh	-	-	4224.00	= Pack Size * Discharge * Discharges per year
Off-peak Electric Energy Cost	-	-	$0.0300	$/kWh
Annual Energy Cost	-	-	$126.72	kWh * $/kWh
Monthly Peak Demand	-	-	7	kW
Annual Demand Cost	-	-	$70.00	
First Year Electric Cost	-	-	$196.72	Sum of Energy and Demand

Lifecycle Diesel Cost				
First Year Diesel Cost	$2,756.76	$2,428.57	$1,133.33	
Real Diesel Escalation Rate	0.50%			
Modified Uniform Present Value Factor	12.39			= ((1+esc)/(disc-esc))*(1-((1+esc)/(1+disc))^N)
Lifecycle Diesel Cost	$34,163.70	$30,096.59	$14,045.08	= First Year x Modified Uniform Present Value Factor

Lifecycle Electric Cost				
First Year Electric Cost	$0.00	$0.00	$196.72	
Real Electric Escalation Rate	0.50%			
Modified Uniform Present Value Factor	12.39			= ((1+esc)/(disc-esc))*(1-((1+esc)/(1+disc))^N)
Lifecycle Electric Cost	$0.00	$0.00	$2,437.89	= First Year x Modified Uniform Present Value Factor

Hybrid Electric School Bus Project
Business Feasibility Study

This Excel workbook estimates the lifecycle cost of a conventional, diesel powered, 65-passenger, type C school bus and compares that to the lifecycle costs for two types of hybrid electric school buses: non plug-in and plug-in versions. Costs that are the same for all options are ignored. The values reported are therefore not the complete lifecycle costs but are representative values for comparison. The report that accompanies this tool contains additional details.

This worksheet estimates the lifecycle costs for certain maintenance items for both types of buses. The HESB should have fewer brake changes, fewer oil changes, and reduced wear on the transmission when compared to a conventional bus. These calculations do not account for other maintenance costs such as tires, painting, or passenger compartment repairs since those costs would be identical for both options.

Users should input a real escalation rate for maintenance costs as well as per event costs and frequencies for the other service events. This model assumes, possibly incorrectly, that the frequency of maintenance does not increase as the bus ages.

Common Variables

Annual Mileage	12,000	Miles
Bus Lifetime	15	Years
Lifecycle Mileage	180,000	Miles
Real Discount Rate	0.030	
Technician Labor Rate	$15.00	$/hr
Material Cost per Oil Change	$40.00	
Labor Hours per Oil Change	1.0	
Material Cost per Brake Replacement	$150.00	
Labor Hours per Brake Replacement	4.0	
Material Cost per Transmission Repair	$300.00	
Labor Hours per Transmission Repair	16.0	
Real Material Escalation Rate	0.005	
Real Labor Escalation Rate	0.006	
Material Modified Uniform Present Value Factor	12.39	= ((1+esc)/(disc-esc))*(1-((1+esc)/(1+disc))^N)
Labor Modified Uniform Present Value Factor	12.49	= ((1+esc)/(disc-esc))*(1-((1+esc)/(1+disc))^N)

	Conventional	**Hybrid**	**Plug-in**	
Oil Change Schedule	4,500	6,750	6,750	Assume HESB has 50% longer life.
Brake Replacement Schedule	24,000	48,000	48,000	Assume HESB has 100% longer life.
Transmission Repair Schedule	48,000	72,000	72,000	Assume HESB has 50% longer life.
HESB Battery Replacement Mileage	-	150,000	150,000	
HESB Battery Cost	-	$7,200.00	$7,200.00	= 24 kWh pack * $300/kWh
First Year Maintenance Cost	$386.67	$240.28	$240.28	
Lifecycle Maintenance Cost	$8,008.77	$9,868.61	$9,868.61	
Lifecycle Oil Change Costs				
Single Event Material Cost	$40.00	$40.00	$40.00	
Single Event Labor Cost	$15.00	$15.00	$15.00	
Events per Year	2.67	1.78	1.78	
First Year Material Cost	$106.67	$71.11	$71.11	
First Year Labor Cost	$40.00	$26.67	$26.67	
First Year Cost	$146.67	$97.78	$97.78	
Lifecycle Material Cost	$1,321.89	$881.26	$881.26	
Lifecycle Labor Cost	$1,831.30	$1,220.87	$1,220.87	
Total Lifecycle Cost	$3,153.19	$2,102.13	$2,102.13	

Lifecycle Brake Replacement Costs

Single Event Material Cost	$150.00	$150.00	$150.00
Single Event Labor Cost	$60.00	$60.00	$60.00
Events per Year	0.50	0.25	0.25
First Year Material Cost	$75.00	$37.50	$37.50
First Year Labor Cost	$30.00	$15.00	$15.00
First Year Cost	$105.00	$52.50	$52.50
Lifecycle Material Cost	$929.45	$464.73	$464.73
Lifecycle Labor Cost	$1,311.04	$655.52	$655.52
Total Lifecycle Cost	$2,240.50	$1,120.25	$1,120.25

Lifecycle Transmission Repair Costs

Single Event Material Cost	$300.00	$300.00	$300.00
Single Event Labor Cost	$240.00	$240.00	$240.00
Events per Year	0.25	0.17	0.17
First Year Material Cost	$75.00	$50.00	$50.00
First Year Labor Cost	$60.00	$40.00	$40.00
First Year Cost	$135.00	$90.00	$90.00
Lifecycle Material Cost	$929.45	$619.64	$619.64
Lifecycle Labor Cost	$1,685.63	$1,123.75	$1,123.75
Total Lifecycle Cost	$2,615.08	$1,743.39	$1,743.39

Lifecycle Battery Replacement Costs

Year	SPV Factor	Battery No.	Battery No.	**Hybrid PV**	**Plug-in PV**
0	1.00	-	-	-	-
1	0.97	1	1	$0	$0
2	0.94	1	1	$0	$0
3	0.92	1	1	$0	$0
4	0.89	1	1	$0	$0
5	0.86	1	1	$0	$0
6	0.84	1	1	$0	$0
7	0.81	1	1	$0	$0
8	0.79	1	1	$0	$0
9	0.77	1	1	$0	$0
10	0.74	1	1	$0	$0
11	0.72	1	1	$0	$0
12	0.70	1	1	$0	$0
13	0.68	2	2	$4,903	$4,903
14	0.66	2	2	$0	$0
15	0.64	2	2	$0	$0
16	0.62	0	0	$0	$0
17	0.61	0	0	$0	$0
18	0.59	0	0	$0	$0
19	0.57	0	0	$0	$0
20	0.55	0	0	$0	$0
21	0.54	0	0	$0	$0
22	0.52	0	0	$0	$0
23	0.51	0	0	$0	$0
24	0.49	0	0	$0	$0
25	0.48	0	0	$0	$0
			TOTAL	$4,903	$4,903

Hybrid Electric School Bus Project
Business Feasibility Study

This Excel workbook estimates the lifecycle cost of a conventional, diesel powered, 65-passenger, type C school bus and compares that to the lifecycle costs for two types of hybrid electric school buses: non plug-in and plug-in versions. Costs that are the same for all options are ignored. The values reported are therefore not the complete lifecycle costs but are representative values for comparison. The report that accompanies this tool contains additional details.

This worksheet estimates the lifecycle, tailpipe emissions for each option for the following pollutants: PM, NOx, and CO2. It also calculates the benefits associated with reduced emissions using values input by the user. Note that MUPV is the Modified Uniform Present Value factor that discounts annual lifecycle cash flows to Present Values and includes escalation rates.

The Federal Aviation Administration and the US EPA have estimated the cost effectiveness of emission reductions from mobile sources and developed the following figures per ton: PM10 = $25,000 to $50,000; NOx = $5,000 to $10,000. CO2 is currently trading on global Greenhouse Gas markets at around $5 per ton. As time passes and emission trading markets reflect legislated caps on emissions, the value of these emission reductions may increase. Therefore, users may also input an associated real escalation rate for each pollutant. The value assigned for each removed ton should also reflect the expected funding level from grant agencies.

The model assumes, possibly incorrectly, that the emission factors do not change as the bus ages. The model does also not address other pollutants. See the Technical Feasibility Study for a discussion of this issue.

The pollutant emission factors are derived from studies referenced in the Technical Feasibility Study. Emissions for the electric utlities are derived from EPA documents. The diesel emissions of CO2 are tied to fuel efficiency through the emission factor. Emissions of PM and NOx are independent of fuel efficiency in this model.

Common Variables

Annual Mileage	12,000	Miles
Bus Lifetime	15	Years
Lifecycle Mileage	180,000	Miles
Real Discount Rate	0.030	
CO2 Emission Factor	9479.0	g/gallon

	Value ($/ton)	**Escalation Rate** (Increase/year)	**MUPV**
PM	$50,000	0.0001	11.95
NOx	$10,000	0.0001	11.95
CO2	$5	0.0050	12.39

	Conventional	**HESB**	**PHESB**	
Diesel Emissions				
Diesel Efficiency	7.4	8.4	18	mpg
PM	0.184	0.067	0.029	g/mile
NOx	11.58	9.83	3.97	g/mile
CO2	1280.95	1128.45	526.61	g/mile

Electric Emissions for PHESB		
Annual Electric Consumption	4224.00	kWh/year
PM	0	g/kWh
NOx	1.21	g/kWh
CO2	573	g/kWh

	Conventional	HESB	PHESB	
First Year Emissions				
PM	0.0024	0.0009	0.0004	Tons/Year
NOx	0.1530	0.1299	0.0581	Tons/Year
CO2	16.9288	14.9135	9.6252	Tons/Year
Lifecycle Emissions				
PM	0.04	0.01	0.01	Tons
NOx	2.30	1.95	0.87	Tons
CO2	253.93	223.70	144.38	Tons
Value of First Year Avoided Emissions				
PM	-	$77.31	$102.42	
NOx	-	$231.28	$949.44	
CO2	-	$10.08	$36.52	
Total	-	$318.67	$1,088.38	
Lifecycle Value of Avoided Emissions				
PM	-	$923.64	$1,223.63	
NOx	-	$2,763.03	$11,342.78	
CO2	-	$124.88	$452.56	
Total	-	$3,811.55	$13,018.96	