ENERGY AND ENVIRONMENTAL PERFORMANCE OF EXISTING AND EMERGING PUBLIC TRANSPORTATION TECHNOLOGIES

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Introduction

Public transit managers and planners face a range of newly emerging demands and conflicts from the traveling and voting public, public policy decision makers and innovative transit technology manufactures. On one hand, many middle class urban travelers do not use public modes of transportation because of the lack of adequate access and flexibility of conventional transit modes. These travelers are demanding more specialized and flexible transit services. Meanwhile the general public and public policy decision-makers are requiring more accountable, cost-effective transit system investment decision making, and demanding higher energy efficiency and lower pollution levels from our nations transit systems operation. [1]

Energy conservation and air quality improvements have been critical factors motivating transit managers to consider alternative fueled transit investments. Historically transit ' has been viewed as an important means of improving air quality and energy conservation over the conventional auto dominated urban transportation systems. However, the changing technological capabilities of transit combined with the various new technologies and fuel sources for both transit and automobiles results in a great deal of uncertainty in assessing the true comparative impacts of the modes when one is evaluating long range plan alternatives.

Over the past several decades national and international transportation technology manufacturers have responded to these diverse demands with the development of a wide range of innovative high (and low) tech transit solutions - each with it's own set of performance characteristics and claims. Such technology innovations include, but are not limited to alternative transit vehicles energy propulsion sources (such "clean fuels" include propane, compressed natural gas, liquefied natural gas, ethanol, methanol, bio-diesel and electricity), light weight materials, automated controls, and so forth.[2]

In this environment of uncertainty, public transit managers and planners are attempting to match a variety of transit needs to the diversity of technologies, fuel sources and conflicting manufacturers claims to best serve their traveling public. Despite the conflicting performance assertions, very little systematic and objective evaluation of the efficiencies and effectiveness of the various transit technologies in varying transit applications have been completed in the public transit literature. Transit managers are often left to make multi-million dollar decisions on partial or incomplete episodic information and ultimately rely on manufacturer’s assertions alone. The problem is compounded by the tendency to use historical empirical data on energy consumption and apply that to evaluations of energy or air quality impact for a design year that may be 15 to 25 years in the future.

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[1] See for example the Clean Air Act Amendments of 1990 and the Environmental Protection Agency (EPA) established air pollution standards set forth in the National Ambient Air Quality Standards (NAAGS) and the Energy Policy Act (EPACT) OF 1992

[2] See for example Alternative Fuels Implementation Plan for Pinellas County: Transit Component Evaluation Report, Center for Urban Transportation Research, College of Engineering, University of South Florida, October, 1995

The research provided in this report is intended to help remedy this void of analytical information available in the public domain. The analysis reported on in this report brings to public transit planners systematic and objective analysis of the performance of these emerging technologies to help them in a practical way make more informed long range planning decisions for their traveling public.

Public Transit Policy Questions to Be Addressed

The primary focus for this project will to evaluate and answer the following key public policy question:

1. How effectively do a wide variety of conventional and newly emerging public transit technologies perform in a diverse range of actual settings across the country?

2. What actual energy, transportation, and environmental performance levels have these systems achieved in real world use?

This analysis is blended into a comprehensive public transportation technology assessment report and model that will allow transit planners and managers to evaluate the performance of one or several of these technologies in combination in proposed new mixed use transit settings.

Literature Review

Introduction

The first step in this analysis was to gather actual performance information on a wide range of transit technologies in use across a variety of settings from across the United States. Researchers completed a comprehensive literature review of the public transit research literature and contacted key public transit properties that operate innovative alternative fuels technology pilot or demonstration programs. Researchers then assembled the growing body of performance information into a single comprehensive annotated bibliographic reference section in this report. The data gathered from these combined literature and current transit demonstration experiences incorporates relevant site-specific ridership characteristics and regional demographics as appropriate.

The focus of this research was to systematically gather information. on:

- Alternative fuels technical factor performance (such as energy efficiencies, emission levels, reliability and so forth); and

- public transit financial performance (such as system operating costs of fuel and labor, materials costs, capital costs and so forth);

- The results of these technical and financial analyses are summarized in the Technical appendix and within the summary performance tables described throughout the report.

Alternative Fuels

The literature on alternative fuels has become substantial in recent years as the transportation industry seeks efficient, clean alternatives to petroleum based fuels. Incentives for using alternative fuels has been generated at the federal level through the Energy Policy and Conservation Act (42 U.S.C. 6201 et seq.), the Energy Policy Act of 1992 (Public Law 102-486), and Executive Order 13031 (December 1996), “Federal Alternative Fueled Vehicle Leadership.” As the technologies continues to improve, more vehicles will be powered by various alternative power sources in the search for more efficient power sources, cleaner air and reduced emission of nitrogen oxides (NOx), Carbon monoxide (CO), particulate matter (PM or TPM), carbon dioxide (CO_2) and other waste product of transportation.

Worldwide Web

Turning to the Worldwide Web (WWW) where we can find tens of thousands of citations on alternative fuels evidences an indicator of the rapidly growing interest in alternative fuels. Most, however, focus on the technology that has been developed and is being developed for the individual automobile and other small vehicles. Furthermore, the tendency is to concentrate on the technological aspects of the fuels and the engines being developed and used. When we look specifically to urban mass transit, the number of web sites drops dramatically, and is reduced even further when the search is constrained to "research" and "journals." For example, a search through Alta Vista using the qualifiers "alternative fuels, urban mass transit, research, and journals" yields two entries, one of which is a U.S.D.O.T. Federal Transit Administration (FTA) 1992 bibliography. Neither of the websites has much information regarding alternative fuels for urban transit systems.

Doing a search with the terms "mass transit, alternative fuels, and research" yields 383 documents, but few of real value with respect to this research project. Adding the term "journal" reduces the number of entries to 87. Among these are the "Clean Fuels Florida Newsletter" published by CUTR (http://www.cutr.eng.usf.edu/research/afitc/cffv2n1.htm) and the 1993 version of FTA's "Transit Planning and Research Reports: Annotated Bibliography" (http://www.fta.dot.gov/fta/library/reference/93ftabib.html). Within this document, however, only four entries relate to alternative fuels and these are on fuel properties and prices. Searching further on the web reveals that most of the entries listed deal with alternative fuels in a general way, or they focus on the individual vehicle. Interestingly, several web entries lead to the Center for Urban Transportation Research (CUTR) at the University of South Florida, which turned out to be one of the primary source for the published literature reviewed herein.

Perhaps the most important source of Internet information is the U.S. Department of Energy's Alternative Fuels Data Center (AFDC) which maintains an "Alternative Fuels Data Base" (http://afdc3.nrel.gov/amfa.html). This web site provides the nation's most comprehensive source of information on alternative fuels. The AFDC collects operating information from vehicles running on alternative fuels, analyzes those data, and makes them available to the public. Of particular interest to this review is the Alternative Fuels Transit Bus Program which is designed to provide a comprehensive study of alternative fuels currently used by the transit bus industry. The study looks at the reliability, fuel economy, capital and operating costs, and emissions of vehicles running on the various alternative fuels.

Among other significant sources of Internet information on alternative fuels and transportation technology is CALSTART (http://www.calstart.org) which provides extensive information and links to other sources of information for the transportation industry (Calstart, 1996). Calstart claims to be "your best information source for advanced transportation technologies." Much of Calstart's information is technology-based, and the only transit report noted is a four-year report on the Santa Barbara Metropolitan Transit District's use of battery-electric transit vehicles since 1991. The use of these vehicles has proven to be quite successful, with a ten-fold increase in ridership during its first year of operation. The fleet of battery-electric vehicles currently stands at twelve, with six more in fabrication.

Electric buses are also mentioned in a brief review of a test program by the Electric Power Research Institute and a consortium of its member energy companies (ASCE, 1997). The goal of the trial program is to demonstrate to American metropolitan transportation agencies the efficiency and cost-effectiveness of battery powered buses. Eight test programs are now running with 150 buses in service, the largest being in Chattanooga with 15 battery-electric buses. (Also see Passenger Transport, 1994). Dugan (1994) provides more information on the Chattanooga experience. His review of the Chattanooga program includes a history of the program and a discussion of the policy and operational issues that were addressed by the transit management and governing board. The paper provides information that may be useful for transit systems that seek to implement this new technology.

Review of Technical Sources and Publications

General Analysis

One of the early uses of alternative fuels in bus operations started in Seattle in 1987, New York in 1988, and in Denver and Los Angeles in 1989 with the use of methanol in a demonstration program under the U.S.D.O.T., Urban Mass Transit Administration (Krenelka and Murphy, 1990). In addition to these four participating cities, data were received from three other sites operating methanol buses: Riverside Transit Agency, Golden Gate Transit, and Jacksonville Transportation Authority. The database was obtained from almost two million miles of revenue operation of methanol demonstration buses. The study showed considerable improvements over the first troublesome prototype at Golden Gate. The primary focus of the study was to identify any technical, safety, health and environmental issues from using methanol in transit operations.

CUTR Alternate Transit Data

Further insight into Florida operations of alternative fuel buses is provided in the evaluation report of alternative fuels prepared by CUTR for the Pinellas County Metropolitan Planning Organization (CUTR, 1995). The report focused on developing an alternative fuels implementation plan for the Pinellas SunCoast Transit Authority (PSTA). The report analyzed Pinellas County air quality data and identified the most pressing air quality problems that could be addressed by an alternative fuels program. It also analyzed alternative fuel vehicles in transit and evaluated advantages and disadvantages of each of eight fuel types:

- reformulated gasoline and diesel fuel (RFG, RFD)
- propane - the main ingredient in liquefied petroleum gas (LPG)
- compressed natural gas (CNG)
- liquefied natural gas (LNG)
- ethanol
- methanol
- biodiesel
- electric vehicles (including EVs with solar recharging stations)

A general assessment and detailed analysis was performed for each of these fuels in all types of vehicles in the PSTA fleet, particularly full-size buses. Two of the liquid/gas fuels, CNG and LNG, showed the highest potential for successful conversion. “The recommended alternative fuels implementation plan utilizes CNG as the primary fuel, with electricity and diesel as the secondary fuel for routes that either have short range and low load factors or require a spare CNG bus from garage to resume operations during refueling” (CUTR, 1995). Table 1, which is extracted from the CUTR report, provides a fuel assessment matrix that lists several attributes of each alternative fuel. The report gives extensive tables and figures that provide substantial information on their alternative fuels study.

As part of the CUTR study, a literature review looks at air quality impacts of alternative fuels and provides a summary of alternative fuels bus pilot projects. Notable in CUTR’s literature review is the observation that in 1994, one of 25 transit vehicles in operation and one of every three transit vehicles on order nationally is powered by an alternative fuel. These results are shown in Table 2 and as cited in a survey by the American Public Transit Association (APTA, 1994). The report also noted that the most popular alternative fuel for transit is CNG, followed by LNG and propane. The CUTR literature review also looks at alternative fuels for transit according to the type of fuel being used. The review essentially dealt with technology, emissions, performance and costs.

Alternative Fuels Newsletters

In the broad range of literature on alternative fuels are a number of newsletters from various organizations providing current information on trends and activities relating to alternative fuels. Although the information is limited, the newsletters provide occasional clues on mass transit use of alternative fuels. The "AFDC Update"(1997), published by the Alternative Fuels Center, informs us that alternative fuel bus data is available from a study by the National Renewable Energy Lab and Battelle Columbus Lab for cities that provided information: Houston, Miami, Tacoma, Peoria, Portland, OR., Minneapolis, New York and St. Louis.

The newsletter also provides bits of information on new systems that are being tested or put into place, pertinent legislation, and news from manufacturers. The "Alternative Fuels Insider," a monthly newsletter, tends to concentrate on alternative fuels technology. From the "Alternative Fuels Transportation Briefs" newsletter, we learn that the nation's largest transit system uses 342 heavy-duty alternative fuel vehicles (AFV) to improve on air quality. Another issue of the newsletter tells us about Peoria's ethanol buses leads Illinois efforts to support ethanol AFVs.

Mass Transit Literature

If we restrict our literature search to mass transit or urban transportation systems, we find the literature is not abundant, but it does yield information on the major action with respect to alternative fuels used in urban transit. Conference proceedings appear to be the major repository on information on alternative fuels for mass transit. A notable example is from the proceedings for the "Third National Clean Cities Stakeholders Conference" (Daly and Cromwell, June 1997) which gave an overview of the SunLine Transit Agency in Thousand Palms, California (Riverside County) which includes 40 CNG (compressed natural gas) buses and 7 CNG street sweepers.

Daly and Cromwell gave CNG performance information as well as cost and benefit information. They also discussed how the alternative fuel decision was made, starting with a visit to the Toronto transit agency which had purchased 35 CNG buses, followed shortly after by the SunLine board's unanimous approval of 100 percent conversion to alternative fuels. SunLine's initial research showed CNG to be the most viable fuel because it is abundantly available, politically stable and CNG technology is available and working.

Among other issues presented in their report is a discussion of costs and financing, and identification of partnerships needed to make the transition. On May 5, 1994, the 40-bus CNG fleet rolled into service, making SunLine the first U.S. fleet to convert 100 percent to CNG overnight. Daly and Cromwell go on further to review the CNG fleet performance, including cost savings, environmental impact, safety record and economic impact.

An option usually included among alternative fuels technology is the use of battery-electric buses, such as reported in a study of the feasibility of electric bus operations in Austin, Texas (Fowler and Euritt, 1995). Their study attempted to determine the technical and economic feasibility of electric bus operations using Austin's Capital Metropolitan Transportation Authority as a case study. Their findings indicate that battery-electric buses are feasible in low-mileage circulator routes in the central business district, but they have a limited range and a substantially higher capital cost than other types of alternative fuel buses.

Society of Automotive Engineers (SAE)

The Society of Automotive Engineers (SAE) has a number of special publications on alternative fuels. The 1996 publication Alternative Fuel: Composition, Performance, Engines and Systems" has numerous papers on recent advances in utilization of alternative fuels. The papers were primary on technology, however, especially engines, catalysts and fuels. Only one article in the volume dealt with transit systems in providing preliminary program results of an alternative fuels bus evaluation study (Chandler et al., 1996). Earlier interim results of the same study were provided in a DOE report (Motta, et al., 1995).

The study, supported by a U.S. Department of Energy (DOE) program through the National Renewable Energy Laboratory (NREL), was to provide an unbiased and comprehensive comparison of transit buses operating on alternative fuels and diesel fuel. Based on the need for a multi-fuel, multi-site data collection program, information was collected at eight bus systems: Houston Metro; Tri-Met (Portland, OR); Metro-Dade Transit Authority (Miami); Pierce Transit (Tacoma, WA); GP Transit (Peoria, IL); Metropolitan Council of Transit Operations (Minneapolis/St. Paul); Triboro Coach Company (New York); and Bi-State Development Agency (St. Louis).

It is worth noting that these are the same eight systems mentioned above in the newsletter, "AFDC Update" (1997). Data were gathered on operations, maintenance, emissions, safety incidents, and bus duty cycle for the following fuels:

- liquefied natural gas (LNG)
- compressed natural gas (CNG)
- ethanol (E93: 93%ethanol, 5% methanol, 2% kerosene)
- propane
- biodiesel (20% blend)

Actual and representative capital costs were obtained for alternative fuels and used as estimates for conversion costs.

Another SAE publication, Clean Fuels: Progress and Experiences of Demonstration Programs, includes a paper on mobile source demonstration projects, including transit bus retrofits and ongoing demonstrations of alternative fuel buses (Sullivan and Leonard, 1993). The paper reports on the South Coast Air Quality Management District (California), focusing primarily on emissions and air quality. Also in 1993, SAE published a report on the Canadian-based "Ballard PEM Fuel Cell Powered ZEV Bus" (Howard and Greenhill, 1993).

The report provided technical information on a 32-foot transit bus which demonstrated that Proton Exchange Membrane (PEM) fuel cells can provide the same performance as a diesel engine but with no harmful emissions from the Zero Emissions Vehicle

(ZEV). In the same publication, another technical report was given on the use of fuel cells in heavy-duty transit buses (Cantoni, 1993). A discussion was given of the main differences between two types of fuel cells under consideration for heavy-duty vehicles: phosphoric acid (PAFC) and proton exchange membrane (PEM).

A third 1993 publication by SAE included two articles of interest on transit systems. One provided an "Analysis of Diesel-Electric Hybrid Urban Bus System" over an idealized bus-driving cycle in Chicago, but the emphasis was on the technological aspects of a diesel engine and a battery pack (Marr, W.W., R. Sekar and M. Alheim, 1993). Similarly, a report on urban electric public transportation vehicles focused on the technological aspects of a small electric powered bus design in Mexico City (Romero, 1993).

Two 1994 publications by SAE included additional information on alternative fuels for urban transit systems. One dealt with the emissions from urban transit buses powered by methanol, ethanol, and diesel fuel (Rideout, Kishenblatt, Prakash, 1994). The other devoted the entire publication to alternative fuel developments and foreign design influences on American bus operations (SAE 1994). As with the other SAE publications, the primary emphasis was on technology.

The proceedings of a 1995 alternative fuels conference by SAE included two articles dealing with buses (Clark, et al., 1995; Carlucci and Hill, 1995). The Clark article reported on comparative emissions from buses run by diesel fuel and natural gas to show that natural gas resulted in much cleaner operations. Carlucci and Hill reported on the transition to alternative fuels in a California school bus system. In both papers, the focus was on alternative fuels technology, but the latter paper emphasized the intent to provide fleet managers with information on the choices available in using alternative fuel buses.

More relevant to our study is the 1996 article published by SAE on transit fleet operating experience using alternative fuels (Marinetti, et al., 1996). This article provides a review of the operation of CNG transit buses divided among five transit properties in New York State. The 31 compressed natural gas (CNG) transit buses operating in five transit systems were monitored by the New York State Energy Research and Development Authority from 1992 to September 1995. Data were collected on fuel consumption, maintenance, driveability, and emissions. The paper summarizes the findings of the operation and compares the results with recent CNG transit bus engine and fuel system developments.

Also published by SAE in 1996 was a technical report on compressed natural gas buses (Wool, Jackson, and Bassett, 1996). The paper discussed the applicability of compressed natural gas (CNG) engines to transit bus operations. To study their performance, four CNG vehicles and for control diesel buses were studied over an 18-month period in West Sacramento, California.

The California Department of Transportation Alternative Fuels in Urban Transit

One of the more through reports on alternative fuels in urban transit was done by the firm Booz-Allen & Hamilton, Inc. for the California Department of Transportation, Division of Mass Transportation (Booz-Allen, 1992). The purpose of the study was to provide small, public transportation systems in California with information on alternative fuels and technologies for complying with current and future state and federal emission standards and regulations.

The alternative fuels covered in the study were methanol, natural gas (compressed and liquid), ethanol, liquefied petroleum gas (LPG) and “clean diesel” fuel. These fuels were studied with respect to a number of criteria, including fuel availability and costs, vehicle reliability, durability, safety, fuel economy and emission characteristics. The equipment and facilities needed for refueling were reviewed, as well as modifications to vehicle maintenance garages needed in order to ensure safe operations.

Capital and operating costs for implementing each of the above alternative fuels were studied in detail for different size transit properties. Although not covered in equal detail, advanced electric technologies were also examined, including batteries, hydrogen fuels cells, and electric trolley buses.

The Battelle Alternatives Fuel Analysis, Final Alternative Fuel Transit Bus Evaluation Results

In the private sector, it appears that Battelle - Columbus is the most active in producing research on alternative fuels for transit systems. As noted at the beginning of the review of published literature, Battelle produced a report in 1990 on a methanol bus demonstration project that had been going on for more than three years (Krenelka and Murphy, 1990). Several years later, Battelle reported on "Properties of Alternative Fuels" (Murphy, 1994).

The most significant Battelle publication appears to be the recent report, Final Alternative Fuel Transit Bus Evaluation Results (Chandler, et al., December 1996). This appears to be the final report of a study that produced some the publications identified earlier.

Under a program sponsored by the U.S. Department of Energy, Battelle served as the interface between West Virginia University, the University of Missouri - Columbia, the National Renewable Energy Laboratory (NREL), and the following eight participating transit agencies:

METRO SYSTEM	URBAN AREA	NUMBER OF BUSES
- Houston Metro	Houston	15*
- Tri-Met	Portland, OR	13
- Metro-Dade Transit Authority	Miami	30
- Pierce Transit	Tacoma, WA	10
- GP Transit	Peoria, IL	8
- Metropolitan Council Transit Operations	Minneapolis/St. Paul	15
- Triboro Coach Company	New York	10
- Bi-State Development Agency	St. Louis	10

*includes both alternative diesel buses

The individual reports as well as this final evaluation report can be found on the Internet at www.afdc.doe.gov.

The essence of the Battelle report is on results and recommendations drawn from the NREL study. Three major objectives of the NREL Alternative Fuels Transit Bus Evaluation Program were to:
Gather detailed information on transit bus operations for a few carefully chosen types of heavy transit buses.

Provide detailed data on transit bus operations to NREL for public access in their Alternative Fuels Data Center (AFDC), which NREL designed and operates.

Provide unbiased comparisons of heavy-duty alternative fuel and diesel transit buses currently in use. These fleets were intended to be alternative fuel and diesel buses currently in revenue service."

The alternative fuels studied included natural gas (LNG, CNG), methanol, ethanol, and biodiesel blend.. Engine models and year of manufacture were noted. Data collected in the study were grouped into three types: operating descriptions (vehicle system, vehicle-operating descriptions), bus operations (fuel usage and costs, maintenance costs), and capital costs (buses, facility modifications).

Program results were grouped into reliability, fuel economy, bus operating costs, capital costs, and emissions testing. A number of tables and charts were provided to show the results in these various categories. Among the more interesting conclusions and lessons reported:

Transit buses represent one of the best potential applications for alternative fuels because most transit buses are run from a central location (and fueling location) and the federal government contributes a significant portion of the cost of capital purchases (vehicles and facilities). The results of this program show that alternative fuels are competing well with diesels in many areas:

The Tacoma site has clearly shown that the reliability of alternative fuels was equal to diesel...

Operating costs of the buses consisted mostly of costs for fuel (not including costs for driver labor)....Operating costs were lowest for the CNG buses and highest for alcohol and bio-diesel blend buses.

Capital costs (including facility conversions) were inverse to operating costs. At the present time, no alternative fuel combines low operating cost with a low up-front capital cost.

Emission testing results of natural gas and alcohol buses show that alternative fuel technologies have the potential to significantly lower PM and NOx emissions as compared with diesel. With natural gas, PM emissions were virtually eliminated.

During the course of this study, several lessons were learned that do not appear in the numbers...

For alternative fuel buses to deliver the maximum benefit to the environment, proper maintenance is very important.

If using a bio-diesel blend, splash blending the fuel on the site may not work.
A Summary of Principal Technologies and Sites Reviewed by Battelle are provided in the Technical Appendix A.

A technical description and Summary of the key Battelle alternative fuels evaluation findings follows.

Technical Description of Battelle Alternative Transit Fuels and Systems Reviewed

Metro-Dade Transit Authority

CITY	MIAMI, FL
ALTERNATIVE FUEL(S)	CNG, M100, TRAP
BUSES	30

CNG

The data for the CNG test and control fleets represent 18 months of operation. The diesel control buses accumulated 3.5 times more mileage than the CNG buses. This is due to the CNG buses being used only to supplement peak service during the morning and evening rushes.

Road Calls
The CNG buses experienced 60% more road calls than diesel controls per 1,000 miles; 4 times as many fuel related systems road calls.
The fuel related systems road call rate for the diesel control buses had a constant level of .13, which is significantly lower than the CNG buses.
The peak in road calls for the CNG fleet early in the test period was a result of fuel system or engine problems; a combined 17 of the 20 calls.
Fuel Economy
Fuel economy by month isn't available for Miami since the authority didn't measure the volume of CNG regularly. Calculations were based on a 4-week period during which regular measurement was performed.
The diesel control (3.5 mpeg) had 3% higher fuel economy than the CNG fleet (3.4 mpeg).
The diesel control fleet consumed 2.7 quarts of oil per 1,000 miles of service, while the CNG fleet used 2.1 quarts, a more than 50% difference.
The diesel fleet is comparable to most diesel fleets; however, the CNG fleet is significantly lower.
Operating Cost
Fuel & Oil
The CNG buses had a 12% higher cost for fuel and oil. CNG cost per equivalent diesel #2 gallon was $.69 (not including compression costs), and $.64 for the diesel control.
Oil cost $1.30 per quart for the CNG and $.79 for the diesel.
Per 1,000 miles the CNG was 12% higher in fuel and oil cost, when lower fuel economy and higher cost are taken into consideration.
Maintenance
For the fuel-related costs, the CNG fleet was 96% more expensive to operate.
For the total costs, the CNG fleet was 24% more expensive to operate.
Fuel related systems repairs accounted for 40% of the CNG buses, and 26% for the diesel buses.
Overall, CNG buses were far more expensive for maintenance; although the low mileage causes few conclusions to be made.
Total Operating Costs
For the fuel-related costs, the CNG fleet was 34% more expensive to operate.
For the total costs, the CNG fleet was 19% more expensive to operate.
Capitol Cost
Incremental cost of CNG bus is $50K.
Facility incremental conversion cost(fueling, maintenance, and storage): $3.8M

Methanol

The methanol and diesel control buses have 18 months of operating data to analyze. The control fleet accumulated nearly 1.9 times more mileage than the M100 buses, on a monthly basis. Because of range and reliability issues, Miami decided to use the Methanol buses at a lesser degree than the control fleet.

Road Calls

The road call rate for the Methanol buses was consistently higher. The diesel control units maintained an average fuel related road call rate of .25.

The methanol buses experienced 20% more road calls than the diesel control buses on a per 1,000 miles basis for fuel related and total road calls.

The diesel control fleet (3.5 qt. per 1000 miles) used considerably more oil than the methanol test fleet (2.1 qt. per 1000 miles); and comparatively the same as other diesel fleets.

Fuel Economy

The methanol and diesel fleets had similar economies; with the diesel control (3.5 mpeg) being slightly better (3%) than the methanol fleet (3.4 mpeg).

The methanol fleet showed much lower oil consumption, 2.1 versus 3.5 quarts per 1000 miles for the control fleet.

Operating Cost

<u>Fuel & Oil</u>

The methanol buses had a 170% higher cost for fuel and oil.

Fuel cost for the methanol fleet was (per equivalent diesel #2 gallon) $1.72, and $.64 for the diesel fleet. On an energy equivalent basis, the methanol was 2.7 times more expensive.

Oil cost was 2 times higher for the methanol buses; however, consumption was 40% lower and thus the overall costs for the two fleets were essentially the same.

<u>Maintenance</u>

For the fuel-related costs, the methanol fleet was 267% more expensive to operate.

For the total costs, the methanol fleet was 66% more expensive to operate.

Fuel related systems repairs accounted for 48% of the methanol buses, and 22% for the diesel buses.

<u>Total Operating Costs</u>

For the fuel-related costs, the methanol fleet was 187% more expensive to operate.

For the total costs, the methanol fleet was 118% more expensive to operate.

In general, Miami's methanol fleet cost was similar to the other methanol sites (Peoria and Mpls). Parts costs were significantly higher, and the labor costs were higher as well.

Capitol Cost

Marginal cost of methanol bus: $20K.

Facility incremental conversion cost(fueling, maintenance, and storage): $.1M

Trap

The data for the trap fleets represents 14 months of operation. These traps were removed from the buses in August of 1994; causing the collection of data to end. The diesel control fleets accumulated 1.4 times more mileage than the trap fleet on a monthly basis. This was due to a significant amount of down time for the trap fleet from maintenance. Besides this, these fleets were randomly dispatched on any route.

Road Calls

The trap fleet experienced a 30% higher road call rate than the diesel control fleet, for both the fuel-related and the total amount of calls.

For the total road call rate it was .51 calls per 1,000 for the trap fleet miles versus .40 for the diesel control fleet.

For the fuel-related road call rate it was .14 calls per 1,000 for the trap fleet miles versus .11 for the diesel control fleet.

Fuel Economy

The fuel economy was slightly lower for the trap fleet (3.7 mpeg) than for the diesel fleet (3.0 mpeg).

The oil consumption for the trap buses (2.4 qts per 1,000) was nearly double that of the diesel control buses (1.3 qts per 1,000 miles).

Operating Cost

<u>Fuel & Oil</u>

The trap buses had a 7% higher cost for fuel and oil.

There is a negligible difference in fuel costs for the two fleets since they both relied on the same fuel. The trap buses were 7% higher in fuel cost (lower economy).

Oil costs were also equal; however the trap fleet used 2 times more oil

Maintenance

For the fuel-related costs, the trap fleet was 444% more expensive to operate.
For the total costs, the trap fleet was 146% more expensive to operate.
41% of maintenance costs were fuel related; 19% for the diesel control buses.

Total Operating Costs

For the fuel-related costs, the trap fleet was 65% more expensive to operate.
For the total costs, the trap fleet was 70% more expensive to operate.

Metropolitan Transit Authority of Harris County

CITY	HOUSTON, TX
ALTERNATIVE FUEL(S)	LNG
BUSES	15

LNG

The LNG fleet of buses began data collection in February of 1993, seven months after the diesel control buses began the same process. Each respective fleet has 16 months of service data to report. While both fleets were dispatched on random routes, the LNG buses were held back from the longer runs, and did not experience the same usage as the control fleet. This is reflected in the average monthly mileage of the LNG fleet being 50% less. The LNG buses are dual-fueled with LNG and diesel, and in times of problem with respect to the LNG fuel systems the buses were run only on diesel.

Road Calls

The LNG fleet had total road calls more than twice that of the control fleet; nearly 8 times that with respect to the fuel-related road calls.

The control fleet maintained a monthly fuel-related road call per 1000 miles rate just less than .1, while the LNG fleet started high and then settled around the .4.

Fuel Economy

Fuel economies by month for the LNG fleet were not available due to inaccuracy in the measurement of the LNG until July of 1993.

The LNG fleet experienced a fuel economy of 3.1 mpeg when using at least 30% LNG by volume. The diesel control buses had a fuel economy of 3.5 mpeg. This is a 13% advantage for the diesel fleet.

The oil consumption for the LNG fleet was 2.1 qts per 1,000 miles, while the diesel control buses used 2.2 qts per 1,00 miles.

Operating Cost

Fuel & Oil

The LNG buses had a 26% higher cost for fuel and oil. Although LNG use was low and it’s higher price had little influence on total fuel usage cost.

Fuel costs for LNG were $.80 per equivalent diesel #2 gallon, which does not take into consideration the margin of possible fuel loss during fueling and storage that could be as high as 25%. Diesel cost was $.61 per gallon.

Maintenance

For the fuel-related costs, the LNG fleet was 245% more expensive to operate.

For the total costs, the LNG fleet was 41% more expensive to operate.

Fuel related repair costs accounted for 36% of all maintenance casts for the LNG fleet and 14% for the diesel control fleet.

The total maintenance costs were much higher at this site due to high costs for contaminants in the fuel and gaseous fuel injector problems.

Total Operating Costs

For the fuel-related costs, the LNG fleet was 62% more expensive to operate.

For the total costs, the LNG fleet was 35% more expensive to operate.

This transit’s experience with LNG should not be used as a representative case of LNG performance; the out of date engine used is no longer in production and the majority of the problems are engine related.

Capitol Cost

Marginal cost of LNG bus: $55K.

Facility incremental conversion cost(fueling, maintenance, and storage): $3.5M

Pierce County Public Transportation Benefit Area Authority Corporation

CITY	TACOMA, WA
ALTERNATIVE FUEL(S)	CNG
BUSES	
CNG	

Both the CNG and diesel control fleets have 18 months of operational data. The diesel buses accumulated about 10% more mileage than the CNG buses. The CNG buses were not used on some of the longer routes, due to range issues for the CNG. Aside from this all buses were dispatched randomly on routes.

Road Calls

The CNG and diesel control buses had the same road call rates for both total road calls (.21 per 1,000 miles) and the fuel related road calls (.11 per 1,000 miles).

The CNG fleet was showing a gradual reduction in the fuel related road calls over the observation period.

A policy initiated by the transit authority that causes a bus to shut down if idle for 10 minutes caused both the CNG and control fleets to have inflated road call rates.

Fuel Economy

The CNG buses (4.5 mpeg) experienced a 20% lower fuel economy than the diesel control buses (5.8 mpeg). This difference was expected because of engineering differences in the engines.

Both the CNG and diesel buses operated at a fuel economy higher than all the other fleets (alternative fuel and diesel); of the three fleets that obtained an average fuel economy greater than 4 mpeg, the two Tacoma fleets were first and second (Portland's diesel fleet was third). These above average numbers are due to the buses not having air conditioning and operating on long, non-interrupted routes.

The CNG buses used 2 qts of oil per 1,000 miles while the diesel buses consumed 2.5 qts; a 25% difference.

Operating Cost

Fuel & Oil

The CNG buses had a 4% higher cost for fuel and oil.

Fuel cost for CNG was $.52 per equivalent diesel #2 gallon, and $.65 for diesel. Compression and storage costs for the CNG would be $.06 per gallon and this results in a total cost difference of 11% (down from 20% when compression costs are not included).

However, after the data collection at Tacoma was complete, they began buying their LNG on a commodity basis. This allows for considerable costs saving for total LNG costs per 1,000 miles; resulting in the LNG fuel costs being 30% lower than the diesel fleet – completely changing the conclusion drawn from the fuel economy perspective.

Oil costs was $1.30 for the CNG buses and $.70 for the diesel buses. However the oil consumption for the CNG buses was 20% lower.

Maintenance

For the fuel-related costs, the CNG fleet was 14% more expensive to operate.

For the total costs, the CNG fleet was 1% more expensive to operate.

Fuel related maintenance costs accounted for 40% of total maintenance costs for the CNG fleet and for 35% for the diesel fleet.

Total Operating Costs

For the fuel-related costs, the CNG fleet was 8% more expensive to operate.

For the total costs, the CNG fleet was 2% more expensive to operate.

Results from Tacoma are considered more reliable and conclusive than Miami because of the high mileage on the CNG buses in the data collection, Tacoma's dedication to CNG, and the percentage of the fleet that the CNG buses make up.

Capitol Cost

Marginal cost of CNG bus: $50K.

Facility incremental conversion cost (fueling, maintenance, and storage): $3.8M

Tri-County Metropolitan Transportation District of Oregon

CITY	PORTLAND, OR
ALTERNATIVE FUEL(S)	LNG
BUSES	

LNG

The data collection for the LNG and control fleets represents 18 months of service. In the early stages of the program, the LNG buses were only assigned to short routes. As time passes the LNG buses were randomly dispatched along with the diesel buses. Overall the diesel buses accumulated 90% more mileage then the LNG fleet.

Road Calls
The LNG buses had 2.5 times as many total road calls as the diesel control buses, but only 50% more for the fuel-related road calls.
The LNG fleet has an initial peak in the road call rate and then levels off at about .2 road calls per 1,000 miles of bus service.
The diesel control fleet's road call rate was never near or above .2, averaging about .15 road calls per 1,00 miles.
Fuel Economy
The LNG buses (3.0 mpeg) experienced a 30% lower fuel economy than the diesel control buses (4.2 mpeg). A 15 –25% difference is expected because of compression differences in the engines.
These buses sat idle on many weekends, possibly explaining the above average differences in fuels economy as compared to the diesel fleet.
The LNG fleet (6.7 qts per 1,000 miles) had twice the oil consumption of the diesel fleet(3.4 qts per 1,000 miles); exceeding the averages by the CNG fleets in other cities by far.
Operating Cost
<u>Fuel & Oil</u>
The LNG buses had a 144% higher cost for fuel and oil.
Fuel costs were: $.93 per equivalent D#2 gallon for LNG and $.55 per diesel gallon.
Portland's price per gallon for LNG was the highest reported in the US.
<u>Maintenance</u>
For the fuel-related costs, the LNG fleet was 52% more expensive to operate.
For the total costs, the LNG fleet was 48% more expensive to operate.
Fuel related maintenance costs represented 31% of total maintenance for both fleets.
<u>Total Operating Costs</u>
For the fuel-related costs, the LNG fleet was 107% more expensive to operate.
For the total costs, the LNG fleet was 78% more expensive to operate.
The LNG fleet was idled more than the diesel buses and the routes they were dispatched on were not identical to the diesel control routes.
Capitol Cost
Marginal cost of LNG bus: $55K.
Facility incremental conversion cost (fueling, maintenance, and storage): $3.5M

Greater Peoria Mass Transit District

CITY PEORIA, IL
ALTERNATIVE FUEL(S) ETHANOL
BUSES

E95/E93

The data collection for the Peoria site included 24 months operation. During this period the test buses were run on both E93 (8 months) and E95 (16 months) grade ethanol. Also during this time period all buses were randomly dispatched. All buses, both ethanol and diesel, experienced equal average monthly mileage.

Road Calls
The ethanol buses had 10% more total road calls; 70% more fuel related road calls.
The rate of road calls for the ethanol buses increased over the test period, while decreasing for the diesel control fleet.
Fuel Economy
All three bus fleets experienced very similar fuel economies throughout the study. The diesel control fleet (both grades of ethanol used the same diesel control group) recorded economies of 3.5 mpeg while the E95 fleet (3.6 mpeg) and then E93 fleet (3.3 mpeg) were very close by.
The ethanol fleets consumed on average 3.6 quarts of oil per 1,000 miles of service while the diesel control fleet used 2.5, a 44% difference.
Operating Cost
Fuel & Oil
The ethanol buses had a 191% higher cost for fuel and oil.
Fuel costs were as follows: $1.83 for E95 (per equivalent diesel #2 gallon), $1.21 for E93 (per equivalent diesel #2 gallon), and $.61 for diesel.
Based on energy equivalency the E95 was 3 times as expensive as diesel, E93 was twice as much.
Oil consumption cost for the ethanol buses was double that of the diesel buses (the actual level of consumption was very similar but the ethanol buses require a considerably more expensive grade of oil).
Maintenance
For the fuel-related costs, the ethanol fleet was 48% more expensive to operate.
For the total costs, the ethanol fleet was 25% more expensive to operate.
Fuel related maintenance repairs accounted for27% of the total maintenance costs for the ethanol fleet and 18% for the diesel fleet.
Total Operating Costs
For the fuel-related costs, the ethanol fleet was 173% more expensive to operate.
For the total costs, the ethanol fleet was 109% more expensive to operate.
The high cost of the ethanol fuel and the parts for the ethanol buses was the driving force behind the high operating cost for the buses.
Capitol Cost
Marginal cost of ethanol bus: $20K.
Facility incremental conversion cost (fueling, maintenance, and storage): $.1M

Metropolitan Council Transit Operations

CITY	MINNEAPOLIS / ST. PAUL, MN
ALTERNATIVE FUEL(S)	ETHANOL (E95), TRAP
BUSES	

E95

The diesel control buses had 2.8 times more mileage per month than the ethanol buses. Like the Miami routes, the test buses in Minneapolis / St. Paul were used on a "tripper" basis; meaning that they were used only randomly. The data for this site represents 8 months of operation. The control buses were the same units for both the ethanol study and the Trap study.

Road Calls
Both the trap and the ethanol fleets utilized the same diesel control fleet.
The total rate of road calls for the ethanol buses was 40% less than the control buses; and 10% more for the fuel related calls.
While the ethanol buses were not used to the same extent that the diesel control buses were, the ethanol road call rate declined from its initial level. The control fleet increased over the observation period. The increase of the control fleet and the decrease for the ethanol fleet averaged to just about the same level(10% lower for the ethanol).
Fuel Economy
The diesel control buses had an average fuel economy of 3.1 mpeg while the ethanol fleet was 2.9. This figure for the ethanol units would have been much higher, but in the cold months in Minneapolis the ethanol buses were run overnight to avoid engine problems.
The oil consumption rates for the ethanol and diesel control fleets were very similar at 2.5 and 2.7 quarts per 1,000 miles respectively.
Operating Cost
<u>Fuel & Oil</u>
The ethanol buses had a 197% higher cost for fuel and oil.
The cost of the ethanol fuel for Minneapolis was even higher than in Peoria.
Fuel cost for the ethanol (E95) in Minneapolis was $1.80 (per equivalent diesel #2 gallon), and $.65 for the diesel fuel. On an energy equivalent basis the ethanol was 2.8 times as expensive as the diesel.
While the oil consumption for the ethanol fleet was lower than the diesel fleet, the total oil cost was 4 times higher for the ethanol fleet due to the high price of the special grade oil needed for the ethanol buses.
<u>Maintenance</u>
For the fuel-related costs, the ethanol fleet was 272% more expensive to operate.
For the total costs, the ethanol fleet was 44% more expensive to operate.
Fuel related maintenance costs accounted for 42% of total maintenance costs for the ethanol buses, and 16% for the diesel control buses.
<u>Total Operating Costs</u>
For the fuel-related costs, the ethanol fleet was 205% more expensive to operate.
For the total costs, the ethanol fleet was 125% more expensive to operate.
Capitol Cost
Marginal cost of ethanol bus: $20K.
Facility incremental conversion cost (fueling, maintenance, and storage): $.1M

Trap

The data for this site represents 8 months of operation. The control buses were the same units for both the ethanol study and the Trap study. The diesel control buses accumulated 10% lower mileage than the trap buses. This was due to differences in route assignments; as both fleets were randomly dispatched.

Road Calls
Both the trap and the ethanol fleets utilized the same diesel control fleet.
The total road call rate for the trap buses was 30% less than the diesel buses; 60% less for the fuel related calls.

The control fleet averaged .14 road calls per 1,000 miles versus .06 calls for the trap fleet.

Fuel Economy

The diesel control buses had an average fuel economy of 3.1 mpeg while the trap fleet was 2.9, a 6% difference. The results from the trap fleet are comparable to the results for the same type of fleet in Miami.

The diesel trap engines (1.5 qts per 1,000 miles) consumed far less oil than that of the diesel control buses(2.7 qts per 1,000 miles).

Operating Cost

Fuel & Oil

The trap buses had 8% higher cost for fuel and oil.

Fuel costs were the same for the two fleets since they both relied on the same fuel: $.65 per gallon. The only differences in fuel usage costs were due to different fuel economies.

Oil costs were also the same at $.50 per quart; but since the trap fleet used 44% less oil, the usage cost was lower for this fleet.

Maintenance

For the fuel-related costs, the trap fleet was 52% less expensive to operate.

For the total costs, the trap fleet was 40% less expensive to operate.

Fuel related maintenance costs for the trap fleet accounted for 13% of the total maintenance costs; 16% for the diesel fleet.

Data collection was stopped on the trap fleet at the end of August, 1994 when the manufacturer no longer supported the product.

Total Operating Costs

For the fuel-related costs, the trap fleet was 1% more expensive to operate.

For the total costs, trap fleet was 15% less expensive to operate.

The trap buses at Minneapolis were almost new, and this resulted in better than average numbers for the majority of the categories of interest.

New York City Department of Transportation / Triboro Coach Company

CITY NEW YORK, NY
ALTERNATIVE FUEL(S) METHANOL
BUSES

M100

The methanol and diesel control buses have 19 and 21 months (respectively) of data from operation. The two fleets accumulated almost identical per month mileage, with the diesel fleet having 10% more. Although the two fleets show low amounts of usage, they were used in heavy traffic downtown areas quite extensively. Both fleets were randomly dispatched on routes.

Road Calls
The methanol fleet in New York experienced a 70% higher total road call rate than the control fleet; 140% for that of the fuel related calls.
Except for their respective initial spikes in fuel related road call rate, the methanol and control fleets averaged a steady difference of about .10 calls per 1,000 miles (.17 vs. .07).
Fuel Economy
The methanol fleet had a 13% lower fuel economy(2.6 mpeg for the methanol and 3.0 mpeg for the diesel control). Both fleets were exposed to the high demand downtown service routes. This difference in economy was expected due to different engine characteristics.
The methanol fleet (3.1 qts per 1,000 miles) used almost double the amount of engine oil as compared to the diesel control buses (1.6 qts per 1,000 miles).
Operating Cost
<u>Fuel & Oil</u>
The methanol buses had a 194% higher cost for fuel and oil.
51% of the total maintenance costs for the methanol fleet were fuel related; 18% for the diesel fleet.
Fuel costs in New York were as follows: $1.72 (per equivalent diesel #2 gallon) for the methanol fleet, and $.64 for the diesel fuel.
On an energy equivalent basis the methanol was 2.7 times more expensive than diesel.
Consumption costs for oil were nearly equal for both fleets.
<u>Maintenance</u>
For the fuel-related costs, the methanol fleet was 267% more expensive to operate.
For the total costs, the methanol fleet was 29% more expensive to operate.
<u>Total Operating Costs</u>
For the fuel-related costs, the methanol fleet was 210% more expensive to operate.
For the total costs, the methanol fleet was 95% more expensive to operate.
The total costs for the two fleets were consistent with the other alcohol sites.
Capitol Cost
Marginal cost of methanol bus: $20K.
Facility incremental conversion cost (fueling, maintenance, and storage): $.1M

Bi-State Development Agency

CITY ST. LOUIS, MO
ALTERNATIVE FUEL(S) BIODIESEL
BUSES

BD20

The data for the St. Louis site represent 9.5 months of operation. The diesel control buses accumulated essentially the same mileage as the biodiesel units. Both fleets were randomly dispatched on routes. However, the data that was collected during this time frame was incomplete due to issues concerning the blending of the fuel. The data used to evaluate the effectiveness of the fuel are for a period when the fuel was assured of being the correct concentration of 20%(BD20). The St. Louis fleets are composed of older vehicles and engines. The engines were rebuilt before the biodiesel study.

Road Calls

The biodiesel buses in St. Louis experienced a 50% less total and fuel related road call rate than the diesel control buses.
Total road calls per 1,000 miles of service: .08 (BD20) vs. .15 (control); Fuel-related: .06 (BD20) vs. .11 (control)

Fuel Economy

Both fleets of buses experienced the same fuel economies (3.9 mpeg). Data collection problems limited the time period to only 9 months, however.
The biodiesel fleet used considerably more oil per 1,000 miles of bus service;
Both of the above statements on fuel economy and oil usage are inconclusive since there isn't enough data and engines are old enough that it is not possible to speculate on the situation.

Operating Cost

<u>Fuel & Oil</u>

The biodiesel buses had a 123% higher cost for fuel and oil.
Fuel cost for the St. Louis biodiesel fleet was $1.32 (per equivalent diesel #2 gallon), and $.56 for the diesel fuel.
On an energy equivalent basis the biodiesel was 2.3 times more expensive than the diesel.

<u>Maintenance</u>

For the fuel-related costs, the biodiesel fleet was 65% more expensive to operate.
For the total costs, the biodiesel fleet was 44% more expensive to operate.
The total fleet maintenance costs for St. Louis didn't include maintenance on all systems of the buses, and were therefore much lower than the other similar fleets.

<u>Total Operating Costs</u>

For the fuel-related costs, the biodiesel fleet was 106% more expensive to operate.
For the total costs, the biodiesel fleet was 95% more expensive to operate.
Due to the short period of data collection conclusive results were not possible from St. Louis.

Introduction to the Alternative Fuels Transit Technology Simmulation Model (AFTTSM)

Summary of Battelle Technical Findings

A review of the principal findings and results are of the Battelle study presented in the following summaries - organized by the alternative fuel used and cross referenced by urban area transit system evaluated by alternative fuel used in each setting.

LNG	Reliability	Fuel Economy	Operation Cost	Capitol Cost
Houston	The LNG fleet had total road calls more than twice that of the control fleet; nearly 8 times that with respect to the fuel-related road calls. The control fleet maintained a monthly fuel-related road call per 1000 miles rate just less than .1, while the LNG fleet started high and then settled around the .4.	Fuel economies by month for the LNG fleet were not available due to inaccuracy in the measurement of the LNG until July of 1993. The LNG fleet experienced a fuel economy of 3.1 mpeg when using at least 30% LNG by volume. The diesel control buses had a fuel economy of 3.5 mpeg. This is a 13% advantage for the diesel fleet. The oil consumption for the LNG fleet was 2.1 qts per 1,000 miles, while the diesel control buses used 2.2 qts per 1,00 miles.	<u>Fuel & Oil</u> The LNG buses had a 26% higher cost for fuel and oil. Although LNG use was low and it's higher price had little influence on total fuel usage cost. Fuel costs for LNG were $.80 per equivalent diesel #2 gallon, which does not take into consideration the margin of possible fuel loss during fueling and storage that could be as high as 25%. Diesel cost was $.61 per gallon. <u>Maintenance</u> For the fuel-related costs, the LNG fleet was 245% more expensive to operate. For the total costs, the LNG fleet was 41% more expensive to operate. Fuel related repair costs accounted for 36% of all maintenance casts for the LNG fleet and 14% for the diesel control fleet. The total maintenance costs were much higher at this site due to high costs for contaminants in the fuel and gaseous fuel injector problems. <u>Total Operating Costs</u> For the fuel-related costs, the LNG fleet was 62% more expensive to operate. For the total costs, the LNG fleet was 35% more expensive to operate. This transit's experience with LNG should not be used as a representative case of LNG performance; the out of date engine used is no longer in production and the majority of the problems are engine related.	Marginal cost of LNG bus: $55K. Facility incremental conversion cost(fueling, maintenance, and storage): $3.5M
Portland	The LNG buses had 2.5 times as many total road calls as the diesel control buses, but only 50% more for the fuel-related road calls. The LNG fleet has an initial peak in the road call rate and then levels off at about .2 road calls per 1,000 miles of bus service. The diesel control fleet's road call rate was never near or above .2, averaging about .15 road calls per 1,00 miles.	The LNG buses (3.0 mpeg) experienced a 30% lower fuel economy than the diesel control buses (4.2 mpeg). A 15 –25% difference is expected because of compression differences in the engines. These buses sat idle on many weekends, possibly explaining the above average differences in fuels economy as compared to the diesel fleet. The LNG fleet (6.7 qts per 1,000 miles) had twice the oil consumption of the diesel fleet(3.4 qts per 1,000 miles); exceeding the averages by the CNG fleets in other cities by far.	<u>Fuel & Oil</u> The LNG buses had a 144% higher cost for fuel and oil. Fuel costs were: $.93 per equivalent D#2 gallon for LNG and $.55 per diesel gallon. Portland's price per gallon for LNG was the highest reported in the US. <u>Maintenance</u> For the fuel-related costs, the LNG fleet was 52% more expensive to operate. For the total costs, the LNG fleet was 48% more expensive to operate. Fuel related maintenance costs represented 31% of total maintenance for both fleets. <u>Total Operating Costs</u> For the fuel-related costs, the LNG fleet was 107% more expensive to operate. For the total costs, the LNG fleet was 78% more expensive to operate. The LNG fleet was idled more than the diesel buses and the routes they were dispatched on were not identical to the diesel control routes.	Marginal cost of LNG bus: $55K. Facility incremental conversion cost (fueling, maintenance, and storage): $3.5M

CNG	Reliability	Fuel Economy	Operation Cost	Capitol Cost
Miami	The CNG buses experienced 60% more road calls than diesel controls per 1,000 miles; 4 times as many fuel related systems road calls. The fuel related systems road call rate for the diesel control buses had a constant level of .13, which is significantly lower than the CNG buses. The peak in road calls for the CNG fleet early in the test period was a result of fuel system or engine problems; a combined 17 of the 20 calls.	Fuel economy by month isn't available for Miami since the authority didn't measure the volume of CNG regularly. Calculations were based on a 4-week period during which regular measurement was performed. The diesel control (3.5 mpeg) had 3% higher fuel economy than the CNG fleet (3.4 mpeg). The diesel control fleet consumed 2.7 quarts of oil per 1,000 miles of service, while the CNG fleet used 2.1 quarts, a more than 50% difference. The diesel fleet is comparable to most diesel fleets; however, the CNG fleet is significantly lower.	<u>Fuel & Oil</u> The CNG buses had a 12% higher cost for fuel and oil. CNG cost per equivalent diesel #2 gallon was $.69 (not including compression costs), and $.64 for the diesel control. Oil cost $1.30 per quart for the CNG and $.79 for the diesel. Per 1,000 miles the CNG was 12% higher in fuel and oil cost, when lower fuel economy and higher cost are taken into consideration. <u>Maintenance</u> For the fuel-related costs, the CNG fleet was 96% more expensive to operate. For the total costs, the CNG fleet was 24% more expensive to operate. Fuel related systems repairs accounted for 40% of the CNG buses, and 26% for the diesel buses. Overall, CNG buses were far more expensive for maintenance; although the low mileage causes few conclusions to be made. <u>Total Operating Costs</u> For the fuel-related costs, the CNG fleet was 34% more expensive to operate. For the total costs, the CNG fleet was 19% more expensive to operate.	Incremental cost of CNG bus is $50K. Facility incremental conversion cost(fueling, maintenance, and storage): $3.8M
Tacoma	The CNG and diesel control buses had the same road call rates for both total road calls (.21 per 1,000 miles) and the fuel related road calls (.11 per 1,000 miles). The CNG fleet was showing a gradual reduction in the fuel related road calls over the observation period. A policy initiated by the transit authority that causes a bus to shut down if idle for 10 minutes caused both the CNG and control fleets to have inflated road call rates.	The CNG buses (4.5 mpeg) experienced a 20% lower fuel economy than the diesel control buses (5.8 mpeg). This difference was expected because of engineering differences in the engines. Both the CNG and diesel buses operated at a fuel economy higher than all the other fleets (alternative fuel and diesel); of the three fleets that obtained an average fuel economy greater than 4 mpeg, the two Tacoma fleets were first and second (Portland's diesel fleet was third). These above average numbers are due to the buses not having air conditioning and operating on long, non-interrupted routes. The CNG buses used 2 qts of oil per 1,000 miles while the diesel buses consumed 2.5 qts; a 25% difference.	<u>Fuel & Oil</u> The CNG buses had a 4% higher cost for fuel and oil. Fuel cost for CNG was $.52 per equivalent diesel #2 gallon, and $.65 for diesel. Compression and storage costs for the CNG would be $.06 per gallon and this results in a total cost difference of 11% (down from 20% when compression costs are not included). However, after the data collection at Tacoma was complete, they began buying their LNG on a commodity basis. This allows for considerable costs saving for total LNG costs per 1,000 miles; resulting in the LNG fuel costs being 30% lower than the diesel fleet – completely changing the conclusion drawn from the fuel economy perspective. Oil costs was $1.30 for the CNG buses and $.70 for the diesel buses. However the oil consumption for the CNG buses was 20% lower. <u>Maintenance</u> For the fuel-related costs, the CNG fleet was 14% more expensive to operate. For the total costs, the CNG fleet was 1% more expensive to operate. Fuel related maintenance costs accounted for 40% of total maintenance costs for the CNG fleet and for 35% for the diesel fleet. <u>Total Operating Costs</u> For the fuel-related costs, the CNG fleet was 8% more expensive to operate. For the total costs, the CNG fleet was 2% more expensive to operate. Results from Tacoma are considered more reliable and conclusive than Miami because of the high mileage on the CNG buses in the data collection, Tacoma's dedication to CNG, and the percentage of the fleet that the CNG buses make up.	Marginal cost of CNG bus: $50K. Facility incremental conversion cost (fueling, maintenance, and storage): $3.8M

Ethanol	Reliability	Fuel Economy	Operation Cost	Capitol Cost
Peoria	The ethanol buses had 10% more total road calls; 70% more fuel related road calls. The rate of road calls for the ethanol buses increased over the test period, while decreasing for the diesel control fleet.	All three bus fleets experienced very similar fuel economies throughout the study. The diesel control fleet (both grades of ethanol used the same diesel control group) recorded economies of 3.5 mpeg while the E95 fleet (3.6 mpeg) and then E93 fleet (3.3 mpeg) were very close by. The ethanol fleets consumed on average 3.6 quarts of oil per 1,000 miles of service while the diesel control fleet used 2.5, a 44% difference.	Fuel & Oil The ethanol buses had a 191% higher cost for fuel and oil. Fuel costs were as follows: $1.83 for E95 (per equivalent diesel #2 gallon), $1.21 for E93 (per equivalent diesel #2 gallon), and $.61 for diesel. Based on energy equivalency the E95 was 3 times as expensive as diesel, E93 was twice as much. Oil consumption cost for the ethanol buses was double that of the diesel buses (the actual level of consumption was very similar but the ethanol buses require a considerably more expensive grade of oil). Maintenance For the fuel-related costs, the ethanol fleet was 48% more expensive to operate. For the total costs, the ethanol fleet was 25% more expensive to operate. Fuel related maintenance repairs accounted for27% of the total maintenance costs for the ethanol fleet and 18% for the diesel fleet. Total Operating Costs For the fuel-related costs, the ethanol fleet was 173% more expensive to operate. For the total costs, the ethanol fleet was 109% more expensive to operate. The high cost of the ethanol fuel and the parts for the ethanol buses was the driving force behind the high operating cost for the buses.	Marginal cost of ethanol bus: $20K. Facility incremental conversion cost (fueling, maintenance, and storage): $.1M
Mpls.	Both the trap and the ethanol fleets utilized the same diesel control fleet. The total rate of road calls for the ethanol buses was 40% less than the control buses; and 10% more for the fuel related calls. While the ethanol buses were not used to the same extent that the diesel control buses were, the ethanol road call rate declined from its initial level. The control fleet increased over the observation period. The increase of the control fleet and the decrease for the ethanol fleet averaged to just about the same level (10% lower for the ethanol).	The diesel control buses had an average fuel economy of 3.1 mpeg while the ethanol fleet was 2.9. This figure for the ethanol units would have been much higher, but in the cold months in Minneapolis the ethanol buses were run overnight to avoid engine problems. The oil consumption rates for the ethanol and diesel control fleets were very similar at 2.5 and 2.7 quarts per 1,000 miles respectively.	Fuel & Oil The ethanol buses had a 197% higher cost for fuel and oil. The cost of the ethanol fuel for Minneapolis was even higher than in Peoria. Fuel cost for the ethanol (E95) in Minneapolis was $1.80 (per equivalent diesel #2 gallon), and $.65 for the diesel fuel. On an energy equivalent basis the ethanol was 2.8 times as expensive as the diesel. While the oil consumption for the ethanol fleet was lower than the diesel fleet, the total oil cost was 4 times higher for the ethanol fleet due to the high price of the special grade oil needed for the ethanol buses. Maintenance For the fuel-related costs, the ethanol fleet was 272% more expensive to operate. For the total costs, the ethanol fleet was 44% more expensive to operate. Fuel related maintenance costs accounted for 42% of total maintenance costs for the ethanol buses, and 16% for the diesel control buses. Total Operating Costs For the fuel-related costs, the ethanol fleet was 205% more expensive to operate. For the total costs, the ethanol fleet was 125% more expensive to operate.	Marginal cost of ethanol bus: $20K. Facility incremental conversion cost (fueling, maintenance, and storage): $.1M

Methanol	Reliability	Fuel Economy	Operation Cost	Capitol Cost
Miami	The road call rate for the Methanol buses was consistently higher. The diesel control units maintained an average fuel related road call rate of .25. The methanol buses experienced 20% more road calls than the diesel control buses on a per 1,000 miles basis for fuel related and total road calls. The diesel control fleet (3.5 qt. per 1000 miles) used considerably more oil than the methanol test fleet (2.1 qt. per 1000 miles); and comparatively the same as other diesel fleets.	The methanol and diesel fleets had similar economies; with the diesel control (3.5 mpeg) being slightly better (3%) than the methanol fleet (3.4 mpeg). The methanol fleet showed much lower oil consumption, 2.1 versus 3.5 quarts per 1000 miles for the control fleet.	<u>Fuel & Oil</u> The methanol buses had a 170% higher cost for fuel and oil. Fuel cost for the methanol fleet was (per equivalent diesel #2 gallon) $1.72, and $.64 for the diesel fleet. On an energy equivalent basis, the methanol was 2.7 times more expensive. Oil cost was 2 times higher for the methanol buses; however, consumption was 40% lower and thus the overall costs for the two fleets were essentially the same. <u>Maintenance</u> For the fuel-related costs, the methanol fleet was 267% more expensive to operate. For the total costs, the methanol fleet was 66% more expensive to operate. Fuel related systems repairs accounted for 48% of the methanol buses, and 22% for the diesel buses. <u>Total Operating Costs</u> For the fuel-related costs, the methanol fleet was 187% more expensive to operate. For the total costs, the methanol fleet was 118% more expensive to operate. In general, Miami's methanol fleet cost was similar to the other methanol sites (Peoria and Mpls). Parts costs were significantly higher, and the labor costs were higher as well.	Marginal cost of methanol bus: $20K. Facility incremental conversion cost(fueling, maintenance, and storage): $.1M
New York	The methanol fleet in New York experienced a 70% higher total road call rate than the control fleet; 140% for that of the fuel related calls. Except for their respective initial spikes in fuel related road call rate, the methanol and control fleets averaged a steady difference of about .10 calls per 1,000 miles (.17 vs. .07).	The methanol fleet had a 13% lower fuel economy (2.6 mpeg for the methanol and 3.0 mpeg for the diesel control). Both fleets were exposed to the high demand downtown service routes. This difference in economy was expected due to different engine characteristics. The methanol fleet (3.1 qts per 1,000 miles) used almost double the amount of engine oil as compared to the diesel control buses (1.6 qts per 1,000 miles).	<u>Fuel & Oil</u> The methanol buses had a 194% higher cost for fuel and oil. 51% of the total maintenance costs for the methanol fleet were fuel related; 18% for the diesel fleet. Fuel costs in New York were as follows: $1.72 (per equivalent diesel #2 gallon) for the methanol fleet, and $.64 for the diesel fuel. On an energy equivalent basis the methanol was 2.7 times more expensive than diesel. Consumption costs for oil were nearly equal for both fleets. <u>Maintenance</u> For the fuel-related costs, the methanol fleet was 267% more expensive to operate. For the total costs, the methanol fleet was 29% more expensive to operate. <u>Total Operating Costs</u> For the fuel-related costs, the methanol fleet was 210% more expensive to operate. For the total costs, the methanol fleet was 95% more expensive to operate. The total costs for the two fleets were consistent with the other alcohol sites.	Marginal cost of methanol bus: $20K. Facility incremental conversion cost (fueling, maintenance, and storage): $.1M

Biodiesel & Trap	Reliability	Fuel Economy	Operation Cost
St. Louis (BD20)	The biodiesel buses in St. Louis experienced a 50% less total and fuel related road call rate than the diesel control buses. Total road calls per 1,000 miles of service: .08 (BD20) vs. .15 (control); Fuel-related: .06 (BD20) vs. .11 (control)	Both fleets of buses experienced the same fuel economies (3.9 mpeg). Data collection problems limited the time period to only 9 months, however. The biodiesel fleet used considerably more oil per 1,000 miles of bus service; Both of the above statements on fuel economy and oil usage are inconclusive since there isn't enough data and engines are old enough that it is not possible to speculate on the situation.	Fuel & Oil The biodiesel buses had a 123% higher cost for fuel and oil. Fuel cost for the St. Louis biodiesel fleet was $1.32 (per equivalent diesel #2 gallon), and $.56 for the diesel fuel. On an energy equivalent basis the biodiesel was 2.3 times more expensive than the diesel. Maintenance For the fuel-related costs, the biodiesel fleet was 65% more expensive to operate. For the total costs, the biodiesel fleet was 44% more expensive to operate. The total fleet maintenance costs for St. Louis didn't include maintenance on all systems of the buses, and were therefore much lower than the other similar fleets. Total Operating Costs For the fuel-related costs, the biodiesel fleet was 106% more expensive to operate. For the total costs, the biodiesel fleet was 95% more expensive to operate. Due to the short period of data collection conclusive results were not possible from St. Louis.
Miami (trap)	The trap fleet experienced a 30% higher road call rate than the diesel control fleet, for both the fuel-related and the total amount of calls. For the total road call rate it was .51 calls per 1,000 for the trap fleet miles versus .40 for the diesel control fleet. For the fuel-related road call rate it was .14 calls per 1,000 for the trap fleet miles versus .11 for the diesel control fleet.	The fuel economy was slightly lower for the trap fleet (3.7 mpeg) than for the diesel fleet (3.0 mpeg). The oil consumption for the trap buses (2.4 qts per 1,000) was nearly double that of the diesel control buses (1.3 qts per 1,000 miles).	Fuel & Oil The trap buses had a 7% higher cost for fuel and oil. There is a negligible difference in fuel costs for the two fleets since they both relied on the same fuel. The trap buses were 7% higher in fuel cost (lower economy). Oil costs were also equal; however the trap fleet used 2 times more oil Maintenance For the fuel-related costs, the trap fleet was 444% more expensive to operate. For the total costs, the trap fleet was 146% more expensive to operate. 41% of maintenance costs were fuel related; 19% for the diesel control buses.
Mpls. (rap)	Both the trap and the ethanol fleets utilized the same diesel control fleet. The total road call rate for the trap buses was 30% less than the diesel buses; 60% less for the fuel related calls. The control fleet averaged .14 road calls per 1,000 miles versus .06 calls for the trap fleet.	The diesel control buses had an average fuel economy of 3.1 mpeg while the trap fleet was 2.9, a 6% difference. The results from the trap fleet are comparable to the results for the same type of fleet in Miami. The diesel trap engines (1.5 qts per 1,000 miles) consumed far less oil than that of the diesel control buses(2.7 qts per 1,000 miles).	Fuel & Oil The trap buses had 8% higher cost for fuel and oil. Fuel costs were the same for the two fleets since they both relied on the same fuel: $.65 per gallon. The only differences in fuel usage costs were due to different fuel economies. Oil costs were also the same at $.50 per quart; but since the trap fleet used 44% less oil, the usage cost was lower for this fleet. Maintenance For the fuel-related costs, the trap fleet was 52% less expensive to operate. For the total costs, the trap fleet was 40% less expensive to operate. Fuel related maintenance costs for the trap fleet accounted for 13% of the total maintenance costs; 16% for the diesel fleet.

The literature review amply surveys the most relevant alternative transit fuels technology research available to date. Researchers next take the best of this existing literature and develop it into a comparative performance profile. This comparison evaluates the performance of the examined alternative technology to the “standard diesel” technology developed as an average from among all of the existing reported operating diesel systems examined in the Battelle study.

The intent of this comparative analysis summarizing the performance results from among the best available literature currently available and to provide a base of information that can assist transit planners doing long range planning and major investment studies. These comparisons should assist planners in effectively evaluating the air quality and energy impacts of various investment and service choices from among the various fuel alternatives. The data bases developed will provide information for various future scenarios of modal performance and fleet composition. Thus, planners can evaluate the comparative transit system air quality and energy consumption performance using various technology mixes (bus fleet fueled with alternative energy sources), occupancy rates and operating characteristics. This precision would allow planners to more accurately estimate future transit service investments and achieve attained targeted transit system energy efficiency and pollution characteristics compared to the design year of a given alternative auto fleet mix.

This analysis will systematically integrate and statistically simulate the performance of the various technologies under a variety of operational settings. This will enable planners to establish a range of performance characteristic curves for each technology and thereby generate unique projections of potential applications. The final results from this analysis will allow public transit managers in the U.S. to go to a single source to objectively assess the potential use of new and emerging transit technologies in a variety of transit demand settings independent of manufacturers claims.

Our urban traveling public is increasingly demanding increased convenience, comfort, safety and individualized mobility from our public transit systems while at the same time demanding greater environmental and energy efficiency. The results stemming from this analysis will help public transit managers:

Understand the respective tradeoffs between alternative technology investments.
Make local transportation long range community-based planning decisions.
Efficiently make sound cost-effective decisions in selecting the most appropriate kind or mix of high tech and
Implement innovative and conventional transit technologies to solve real (and changing) needs of our urban traveling public.

Hopefully, the ultimate goal of increasing the use of these diverse technologies will conclude with improving operating performance, reducing operating costs, energy consumption and pollution emissions. Ultimately a broader objective is to move more middle class urban travelers back to using public transit, stabilize existing users and ultimately raise transit ridership levels, revenues and efficiencies in the process.

Description of the Literature Selected for the Analysis

As indicated in the Literature Review, the researchers concluded that one of the most thoroughly documented and standardized evaluations of alternative fuels comparison available was completed in the Battelle-Columbus Alternative Fuel study [3]. This study therefore is one of the central documents for development of the alternative fuels transit performance and output profiles. A review of the principal findings and results are presented in the following summaries organized by urban public transit system evaluated and cross referenced by alternative fuel used in each setting.

The Battelle study did not, however, provide any information on the use and performance of electric powered public transit vehicles as one of the defined fuel alternatives. Researchers were able to secure additional information from two alternative sources: Chattanooga, Tennessee [4], and Santa Barbara, California [5]. These transit systems have the most extensive experience of any transit properties in use of electric busses in actual operation in the country.

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[3] Final Alternative Fuel Transit Bus Evaluation Results (Chandler, et al., December 1996)

[4] Source: Mr. Jose I. Herrera, Director of Technology, Electric Transit Vehicle Institute, Chattanooga Area Regional Transportation Authority (CARTA) and Advanced Vehicle Systems, Inc. (AVS),

[5] Source: "Six Years of Battery-Electric Bus Operations at the Santa Barbara Metropolitan Transit District", Paul Griffith, Director, Santa Barbara Transit Authority,(SEBTI), Santa Barbara, California, 805-568-0985 and Gary Gleason, General Manager, Santa Barbara, MTD, Presented at the 13th International Electric Vehicle Symposium 9EVS-13), Symposium Proceedings, Volume 1, Japan Electric Vehicle Association, 1996

Performance Alternativesl

This model will develop differences in average performance of diesel and each of the alternative fueled public transit busses in the five performance categories include:

Reliability
Energy consumption
Operating costs
Capital costs
Air pollution emissions

The basic comparisons developed in this model evaluate the differences between the performance for each of the alternative modes in each of the categories examined with the standard diesel powered bus in use in nine (TL Check final number) urban regions of the U.S.

Researchers relied upon the “average” performance from among all of the diesel bus fleets reported on in the Battelle study to establish a baseline of assessment against which each of the alternative technologies could be compared. A total of 44 diesel powered vehicles operating in six widely dispersed U.S. urban areas are reported on in the Battelle study. The sum of performance in each of the categories of evaluation were calculated (see Table x).

An “average” diesel bus performance profile emerged to serve as a baseline against which to compare each “alternative fuel” bus fleet. Some categories of diesel performance, such as energy consumption, are fairly uniform across a small range (for example fuel consumption averaged between 3.1 to 4.2 mpg for each of the fleets). By comparison a number of categories such as bus labor and parts operating costs varies fairly widely across a wide range. These variations can be explained in part based on fleet operating characteristics, weather conditions and a host of other operating realities. Researchers believe the most reasonable method to capture these variations is to use the average of all systems as a best proxy for the likely mix of vehicles a transit property manager will operate in any given U.S. urban area.

While the same can be true for alternatively fueled bus systems, discussions with the Battelle study’s principal investigator[6] also indicates that performance for these fleets is also tied much more directly with the maintenance attention and support these vehicles enjoy and each advance in level of technological

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[6] Private phone communications with principal authors June, 1998

innovation. Since these technologies are still relatively new innovations in design and performance can have significant impacts on bus performance. For example considerable advances in performance (i.e. significant reductions in the amount of emissions with greater operating experience and system redesign) is achieved as newer advances in the alternative technology operating cycle are learned and implemented.

While diesel systems can also improve performance with enhanced technological design, the diesel technology is very mature and far down the performance design stage and further improvements in performance will likely not match the advances (in emission reductions for example) possible for some of the other technologies in the future. For these reasons this study will choose the most advanced use of alternative fuels as the base line for comparison purposes to existing diesel technologies for the described comparisons. Table x provides a summary of the differences established between the diesel technology and the alternative technologies derived from the literature described above.

Summary of Net Performance Category Operational Differences Between Diesel and Alternative Technologies

Reliability

Within the Reliability performance category CNG, Ethanol, and methanol each out perform diesel on road call frequency by 46%, 46% and 61% respectively while LNG trailed in number of road calls by 46% per average 1,000 miles.

Energy Consumption

Within the Energy Consumption - Fuel Economy performance category LNG and CNG, used less engine oil on average (18%, 23% less respectively) while Ethanol, and Methanol each consumed 32% and 20% respectively more oil than diesel per average 1,000 miles of operation.

Within the Energy Consumption - Fuel Economy performance category LNG, Ethanol, and Methanol each out performed diesel bus performance and consumed 23%, 16% and 47% less fossil fuel respectively and CNG consumed 15% more energy than diesel per average 1,000 miles of operation.

Fuel and Total Bus System Operating Costs

Within the Bus Operating Cost - fuel operating cost performance category purchases of CNG cost 17% less while total operational costs were 31% less than diesel. The other alternative fuels all had higher average fuel and total operational cost than diesel. LNG experienced a 36% higher fuel and 32% total operating cost while Ethanol reported 50% and 38% higher costs and finally Methanol reported 69% and 57% higher average fuel cost for every 1,000 miles traveled.

Emissions

Within the Emissions category nearly every alternative fuel exhibited substantial improvements in emissions pollution. Both natural gas fuels (LNG & CNG) and both alcohols (ethanol & methanol) showed significant decreases in particulate matter exhaust: 98%, 98%, 56%, and 86% respectively less than the standardized diesel fleet. Three of these four fuels also had much lower levels of oxides of nitrogen emissions; CNG with 65% less, ethanol with 55% less, and methanol with 77% less. LNG had levels 82% higher than the diesel fleet. The Carbon Monoxide (CO) emissions test resulted in 93% and 26% lower discharges for CNG and Methanol respectively, and increases of 51% and 203% for LNG and Ethanol. Carbon Dioxide emissions were also lower with the two natural gas fuels with 18% and 3% less respectively for LNG and CNG. CO2 was higher by 17% and 10% respectively for the alcohol based fuels of Ethanol and Methanol respectively. Other emission results are indeterminate at this time.

Development of a Comprehensive Public Transit Alternative Technology Simulation Assessment Model

The preceding sections of this report complete several important tasks. First we completed a comprehensive literature review of the available technologies and secondly prepared a comprehensive overview of the best available technology performance assessment among the conventional diesel and advanced fuels. Lastly, we completed a comparative "static" evaluation of each performance between the various available fuels.

The final sections of this report will provide transit property managers with a flexible "dynamic" alternative fuels simulation tool that will enable analysts to examine a wide range of possible bus fuel fleet shifts. Specifically this simulation tool will allow transit property managers to change any of the critical parameters for a single bus or any number of busses in a fleet and calculate the change in fleet performance behavior across all output characteristics.

The standard comparison will be between the calculated performance of an "average diesel" vehicle(s) technology and the performance of one (or more) of the alternative fuels technologies reported on in the literature review and operational performance section of this report. The average performance categories that can be evaluated for either the diesel or the alternative fueled public transit busses include:

1. Reliability
2. Operating costs
3. Energy consumption
4. Air pollution emissions

The basic comparisons developed in this dynamic simulation model evaluate the differences between the average performance for the "standard deisel" base case and each of the alternative modes in each of the categories examined. Since all of these technologies (including deisel) are undergoing constant change each transit property fleet has different performance characteristics. This is why we decided to create the model with *complete performance flexibility.*

This model allows an analyst to change the performance of *any or all* of the characteristics for *a single or every* technology examined simultaniously. The default "base diesel" and each "base alternative fuels" case are drawn from the best current literature as reported on in the Battelle study (see Literature Review).

These dynamic comparisons should assist planners in effectively evaluating the air quality and energy impacts of various investment and service choices from among the various fuel alternatives. The databases developed will provide information for various future scenarios of modal performance and fleet composition. Thus, planners can evaluate the comparative transit system air quality and energy consumption performance using various technology mixes (bus fleet fueled with alternative energy sources), occupancy rates and operating characteristics.

This precision would allow planners to more accurately estimate future transit service investments and achieve targeted transit system energy efficiency and pollution characteristics compared to the design year of a given alternative diesel fleet mix. The final results from this analysis will allow public transit managers in the U.S. to go to a single source to objectively assess the potential use of new and emerging transit technologies in a variety of transit demand settings, independent of manufacturers claims.

The results stemming from this analysis will help public transit managers:

- Understand the respective tradeoffs between alternative technology investments.
- Make local transportation long range community-based planning decisions.
- Efficiently make sound cost-effective decisions in selecting the most appropriate kind and mix of advanced fuel types and
- Implement innovative and conventional transit technologies to solve real (and changing) needs of our urban traveling public.

Hopefully, the ultimate goal of increasing the use of these diverse technologies will conclude with improving operating performance, reducing operating costs, energy consumption and pollution emissions. Ultimately a broader objective is to move more middle class urban travelers back to using public transit, stabilize existing users and ultimately raise transit ridership levels, revenues and efficiencies in the process.

Use of Simulation Models with Hypothetical Examples

The following sections of this report provide reviewers with a working insight into the basic operations of the simulation model with applied base case and hypothetical examples.

Base Case Simulation

The base case provided examines the differences in performance between the base case (average diesel performance) and for each of the alternative fuel technologies examined (LNG, CNG, ethanol, methanol, for each the five criteria examined (reliability, energy consumption, operating costs, and air pollution emissions). The best performance values used in each of these five criteria are the most reliable performance data that the transit literature currently reports.

Alternative Case Simulations

The Alternative Case Simulation provided in these examples are strictly hypothetical performance that represent arbitrary values of exactly half of the Base Case Simulation Scenarios provided earlier. These are provided for the reviewer’s edification and *do not represent any currently reported or proposed level of performance*. These examples are only instructive and provide a foundation on which the users of these materials can be guided to better understand how to appropriately use these simulation capabilities.

Discussion of the Variables

Included in the Analysis Tool are twenty variables intended to aid in the estimation of potential effects of switching from one fuel to another. These variables are divided into five sections:

1. Reliability
2. Fuel and oil consumption
3. Maintenance costs
4. Energy consumption
5. Emissions

Reliability

Reliability is measured by the number of Road Calls required per fuel type. More specifically, the variable Road Calls is broken down into two sub-groups. In order to avoid attributing all reliability issues to the fuel type, Road Calls is separated into fuel-related and total Road Calls. If a bus requires road service as a result of a flat tire or air-conditioning trouble, it is hardly fair to penalize the alternative or standard fuel for this event. Therefore, from the category of Reliability, there are three variables to be analyzed: **Total Road Calls**, **Fuel-Related Road Calls**, and **Other Road Calls**.

Fuel and Oil Consumption

Fuel consumption is measured by the common unit of miles per gallon. However, in order to accurately compare and contrast different fuel types all fuels are converted into equivalent diesel #2 gallons. Oil consumption is measured in quarts. Therefore, from the category of Fuel and oil consumption, there are two variables to be analyzed: **Miles Per Gallon of Fuel** and **Quarts of Oil**.

Maintenance Costs

Maintenance costs are measured by dollars spent on bus repair and maintenance. As in the reliability measurement, maintenance costs are separated into fuel-related expenses, other expenses, and total expenses. Furthermore, each of these expenditure categories is divided into part costs and labor costs. In all this represents nine variables of measurement: **Fuel-Related** (parts and labor), **Other** (parts and labor), and **Total** (parts and labor).

Energy Consumption

Energy consumption is measured by the number of biothermal units (BTUs) per gallon of equivalent diesel #2 fuel consumed during bus service. This category has only the one variable: **BTUs**.

Emissions

Emission levels are measured by five pollutants: particulate matter (**PM**), nitrous oxide (**N_oX**), hydrocarbons (**HC**), carbon monoxide (**CO**), and carbon dioxide (**CO_2**). The unit of measurement for each of these is grams per unit.

The Simulated Model for Alternative Transit Fuels

Quick Compare

The *Quick Compare* mode allows the user to compare any alternative fuel (CNG, LNG, ethanol or methanol) to the diesel base case. Any combination of user-defined values and/or default values can be utilized throughout the analysis. That is to say, any alternative fuel (LNG, CNG, ethanol, and methanol) can be compared using the default values provided with the analysis tool or any other user-defined values. The same is true for the diesel values with which the alternative fuel will be compared.

The output of the *Quick Compare* mode is in per mileage units while the output of the *Fleet Analysis* mode is in annualized figures. Therefore, the unit of analysis that is desired will in part determine which mode is selected.

Quick Compare Using Default Values

To compare any alternative fuel to the diesel base case by using the default values supplied by the Alternative Fuels Analysis Tool:

1. click on the *Quick Compare* button located on the *Main Menu*. The user is presented with a table made up of the five fuels (diesel, LNG, CNG, ethanol, and methanol) and the twenty variables included in the analysis. Each of the five fuels is divided into two separate columns.
    - The first column is the list of default values supplied by the program.
    - The second column is the area that allows the user to define their own values for the comparison. This column is empty, and will remain so until the user chooses to supply values for an analysis.

2. Next, click on the name of the alternative fuel to calculate the comparison. The output screen is displayed with the associated values of the requested comparison.
    - It is important to remember that the results given in the *Quick Compare* mode are ***always*** with respect to the diesel base case. All positive values represent increases with respect to the diesel values. For example, if LNG is selected the value corresponding to road calls per 1,ooo miles of bus service is .325. Thus, the

LNG fuel can be expected to produce on average an increase in road calls per 1,00 miles of .325, holding all else constant.

Quick Compare Using User-Defined Values

To compare any alternative fuel to the diesel base case by using any combination of user-defined values:

1. Click on the *Quick Compare* button located on the Main Menu. The user is presented with a table made up of the five fuels (diesel, LNG, CNG, ethanol, and methanol) and the twenty variables included in the analysis. Each of the five fuels is divided into two separate columns.
   - The first column is the list of default values supplied by the program.
   - The second column is the area that allows the user to define his/her own values for the comparison. This column is empty, and will remain so until the user chooses to supply values for an analysis.

2. Next, click the cell in the user-defined column corresponding with the variable for which user-specific data is known. After all values are entered click on the name of the fuel. The output screen is displayed with the associated values of the requested comparison.
   - It is important to remember that the results given in the *Quick Compare* mode are *always* with respect to the diesel base case. All positive values represent increases with respect to the diesel values. For example, if LNG is selected the value corresponding to road calls per 1,ooo miles of bus service is .325 (assuming the default value for LNG road calls is used). Thus, the LNG fuel can be expected to produce on average an increase in road calls per 1,00 miles of .325, holding all else constant.

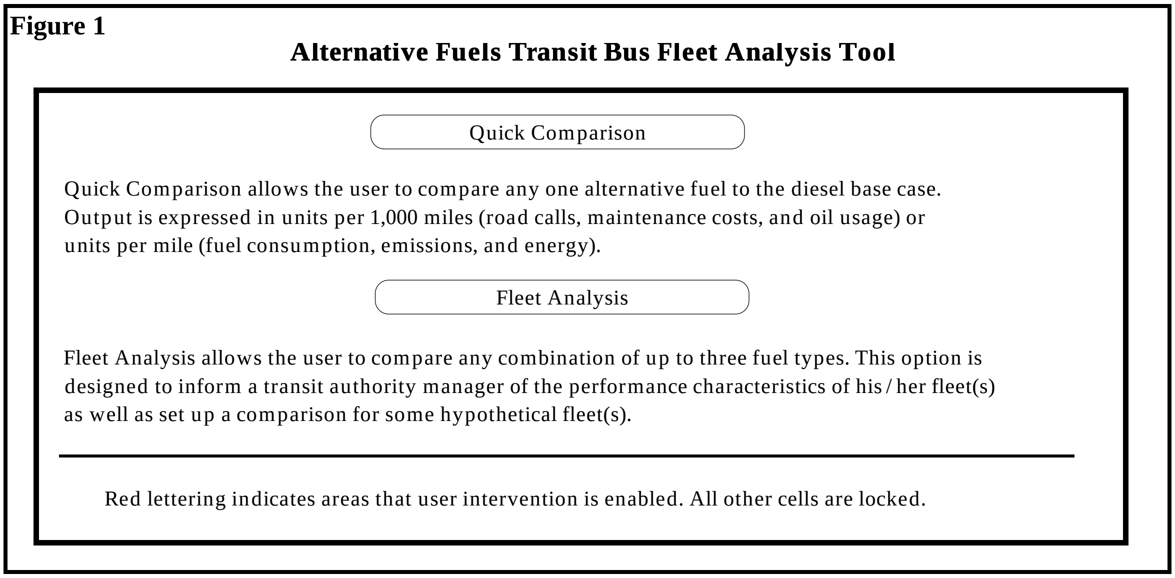
Example: Using Quick Compare

Suppose that Joe Smith is the transit manager for his bus authority, and he would like to gather an approximation of the performance characteristics of liquefied natural gas (LNG) versus diesel fuel. As a result of his own data gathering Mr. Smith knows;

a) the average total amount spent on maintenance for his diesel fleet is $325 per thousand miles of bus service,
b) the average rate of fuel consumption is 7 miles per gallon, and
c) the average rate of oil consumption is 3.4 quarts per thousand miles.

Mr. Smith has decided to use the remaining default values since he his unable to accurately collect the data.

Figure 1



Alternative Fuels Transit Bus Fleet Analysis Tool

Quick Comparison allows the user to compare any one alternative fuel to the diesel base case. Output is expressed in units per 1,000 miles (road calls, maintenance costs, and oil usage) or units per mile (fuel consumption, emissions, and energy).

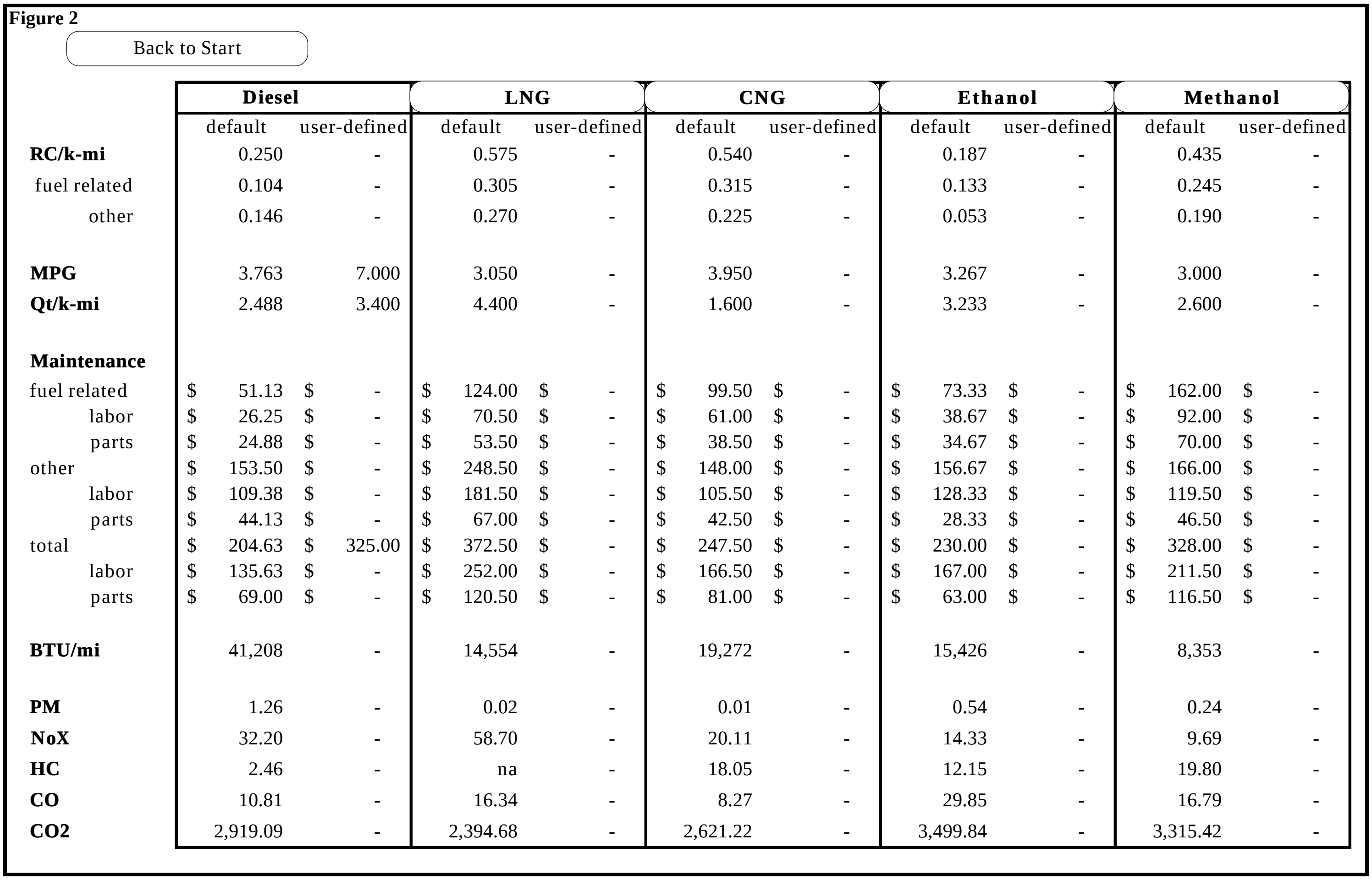
Fleet Analysis allows the user to compare any combination of up to three fuel types. This option is designed to inform a transit authority manager of the performance characteristics of his / her fleet(s) as well as set up a comparison for some hypothetical fleet(s).

Red lettering indicates areas that user intervention is enabled. All other cells are locked.

To begin this analysis, Mr. Smith would press the Quick Compare button located on the opening page of the analysis tool (Figure 1). Under the user-specified diesel column (Figure 2) Mr. Smith enters his own data by clicking on the appropriate cell for each of the three variables (total maintenance, MPG, and Qt/k-mi) and entering the values he gathered from his own fleet (325, 7, and 3.4 respectively). To compare LNG and diesel, he would now click on the LNG button. Figure 3 depicts the output, which is a per bus comparison of LNG and diesel.

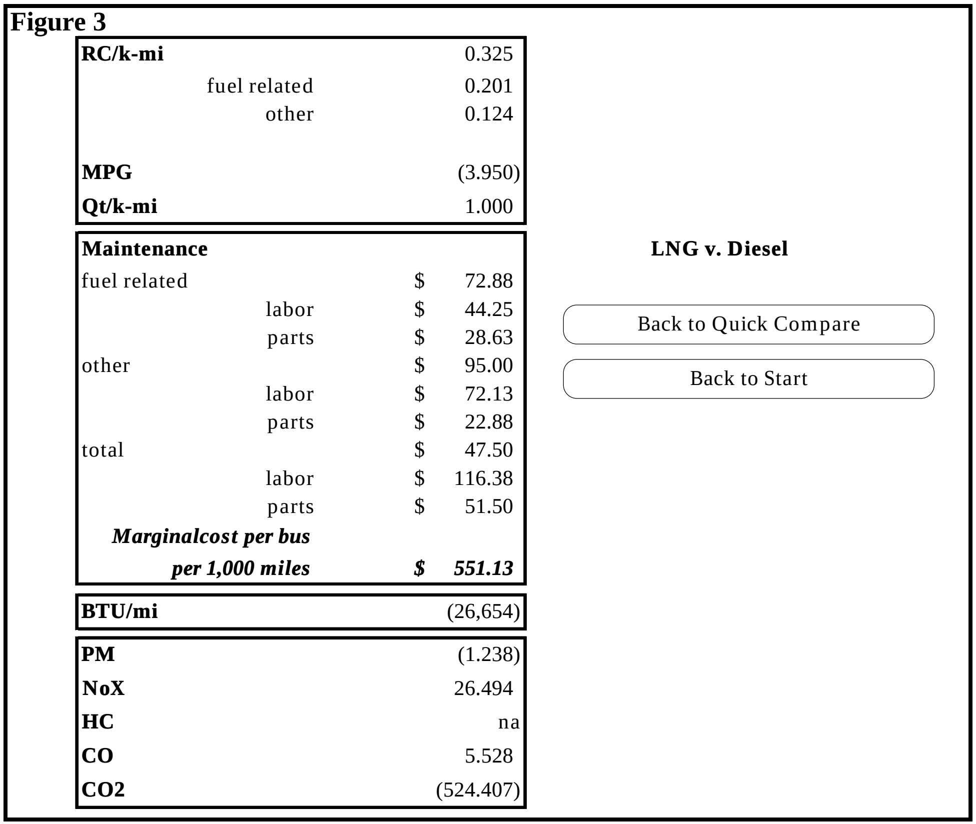
Note that the if Mr. Smith wanted to compare his fleet data against any of the other fuels instead of LNG he would simply click on another alternative fuel after entering the three points of data he knew to be true for his own fleet (Figure 2). This is the case whenever a user alters *only* the diesel default data and not any of the alternative fuel data (CNG, LNG, ethanol, or methanol). If a user wanted to enter user-specific values for any one of the five alternative fuels he/she would first alter the data in the user-specified column under the desired fuel, (in addition to entering the data in the diesel user-specified column) and then click on the button for whichever fuel the analysis was covering.

Figure 2



	Diesel		LNG		CNG		Ethanol		Methanol	
	default	user-defined	default	user-defined	default	user-defined	default	user-defined	default	user-defined
RC/k-mi	0.250	-	0.575	-	0.540	-	0.187	-	0.435	-
fuel related	0.104	-	0.305	-	0.315	-	0.133	-	0.245	-
other	0.146	-	0.270	-	0.225	-	0.053	-	0.190	-
MPG	3.763	7.000	3.050	-	3.950	-	3.267	-	3.000	-
Qt/k-mi	2.488	3.400	4.400	-	1.600	-	3.233	-	2.600	-
Maintenance										
fuel related	$ 51.13	$ -	$ 124.00	$ -	$ 99.50	$ -	$ 73.33	$ -	$ 162.00	$ -
labor	$ 26.25	$ -	$ 70.50	$ -	$ 61.00	$ -	$ 38.67	$ -	$ 92.00	$ -
parts	$ 24.88	$ -	$ 53.50	$ -	$ 38.50	$ -	$ 34.67	$ -	$ 70.00	$ -
other	$ 153.50	$ -	$ 248.50	$ -	$ 148.00	$ -	$ 156.67	$ -	$ 166.00	$ -
labor	$ 109.38	$ -	$ 181.50	$ -	$ 105.50	$ -	$ 128.33	$ -	$ 119.50	$ -
parts	$ 44.13	$ -	$ 67.00	$ -	$ 42.50	$ -	$ 28.33	$ -	$ 46.50	$ -
total	$ 204.63	$ 325.00	$ 372.50	$ -	$ 247.50	$ -	$ 230.00	$ -	$ 328.00	$ -
labor	$ 135.63	$ -	$ 252.00	$ -	$ 166.50	$ -	$ 167.00	$ -	$ 211.50	$ -
parts	$ 69.00	$ -	$ 120.50	$ -	$ 81.00	$ -	$ 63.00	$ -	$ 116.50	$ -
BTU/mi	41,208	-	14,554	-	19,272	-	15,426	-	8,353	-
PM	1.26	-	0.02	-	0.01	-	0.54	-	0.24	-
NoX	32.20	-	58.70	-	20.11	-	14.33	-	9.69	-
HC	2.46	-	na	-	18.05	-	12.15	-	19.80	-
CO	10.81	-	16.34	-	8.27	-	29.85	-	16.79	-
CO2	2,919.09	-	2,394.68	-	2,621.22	-	3,499.84	-	3,315.42	-

Figure 3



LNG v. Diesel

RC/k-mi		0.325
	fuel related	0.201
	other	0.124
MPG		(3.950)
Qt/k-mi		1.000
Maintenance		
fuel related		$ 72.88
	labor	$ 44.25
	parts	$ 28.63
other		$ 95.00
	labor	$ 72.13
	parts	$ 22.88
total		$ 47.50
	labor	$ 116.38
	parts	$ 51.50
	Marginalcost per bus per 1,000 miles	***$ 551.13***
BTU/mi		(26,654)
PM		(1.238)
NoX		26.494
HC		na
CO		5.528
CO2		(524.407)

Fleet Analysis

While the *Quick Compare* mode only allows the user to analyze one fuel at a time and only with respect to a diesel base case, the *Fleet Analysis* mode allows the user to design an analysis that is customized to their requests. Up to three fuels can be compared in this mode, and any combination of the five fuels is possible. The user can customize the analysis by having the output reflect annualized values with respect to their estimated fleet performance. This does require, however, that the user be knowledgeable of a few performance characteristics of their present fleet. Aside from any values for the twenty performance variables that may or may not be known by the user (default values are provided), the tool customizes the analysis by including:

- number of buses in fleet
- average number of miles per day of bus use
- average number of days per year of bus use

This allows the user to produce an estimate of the potential results of altering the fuel-type distribution for their fleet. The output is in annualized units, and is representative of the three specifications listed above.

Using the Fleet Analysis Mode

To use the *Fleet Analysis* mode of the Alternative Fuels Analysis Tool:

1. click on the appropriate button on the *Main Menu*. Now the user should be looking at the Fleet Analysis Input area. It is here that the user will enter the number of buses and mileage for each of up to three fuel types. Recall that the only cells that are open for user input are marked with red lettering.

Entering Fleet Characteristics

For each of the three fuels the user is asked for:

2. the number of buses, average number of miles traveled per bus per day, and average number of days per year of bus service per bus. These criteria are necessary for the calculations that the tool will compute. No default values are provided, and each of

these three criteria must be entered for each fuel that is analyzed. To enter values for these parameters click on the appropriate cell and enter a value.

It is not necessary that all three fuels are utilized, if a fuel type or either the average miles per day or average days per year are left blank no output will be computed. Recall that the output will be in annualized units based on the number and mileage of buses entered.

Present Fleet

The left side of the screen contains the three fuels for the Present Fleet. This fleet will be compared *against* the Test fleet. Each of the three fuels has four input areas:

- number of buses,
- fuel type,
- average miles per day per bus of service, and
- average number of days per year per bus of service.

3. The fuel type can be selected by clicking on the drop-down menu and selecting from the list of fuels.
4. The other three are manually entered by clicking on the appropriate cell and typing a value.

Test Fleet

The left side of the screen contains the three fuels for the Test Fleet. This fleet will be compared *against* the Present Fleet. Each of the three fuels has four input areas:

- number of buses,
- fuel type,
- average miles per day per bus of service, and
- average number of days per year per bus of service.

5. The fuel type can be selected by clicking on the drop-down menu and selecting from the list of fuels.
6. The other three are manually entered by clicking on the appropriate cell and typing a value.

Modifying Default Data

Unless user-defined data is provided to the program all calculations are based on default values. If the user wishes to use values other than these default settings they may do so by:

1. in the *Fleet Analysis* mode clicking on the *Modify Default Data* button. Each of the three fuels for each fleet has this feature available.
2. The user will be presented with a table of values as shown in Figure 4.

Regardless of the fuel type entered on the previous screen all fuel default values are displayed. Each of the five fuels is divided into two columns. The first of each of these columns is complete with values representing the default settings of the program. These values are annualized on a per bus basis. Therefore the value found in the default data column is independent of the number of buses entered on the Fleet Analysis screen. To use values in the comparison other than these default values:

3. click on the cell in the user-defined column corresponding with the variable that is to be altered. It is important to insure that any user-defined values are entered in the correct cell. If values are either entered under the incorrect fuel or variable the result will not be valid.

The Modify Default Data option should be completed *after* the other three variables (number of buses, miles per day, and days per year) have been entered. While these values are not dependent on the number of buses in the fleet (recall the values listed in the default column are annualized per bus) they are dependent on the number of miles per day and days per year given on the previous screen. If the user attempts to modify the default data before entering these two variables the default values will be zero.

4. To complete the Modify Default Data process and return to the Fleet Analysis page click the *Return to Fleet Analysis* button.

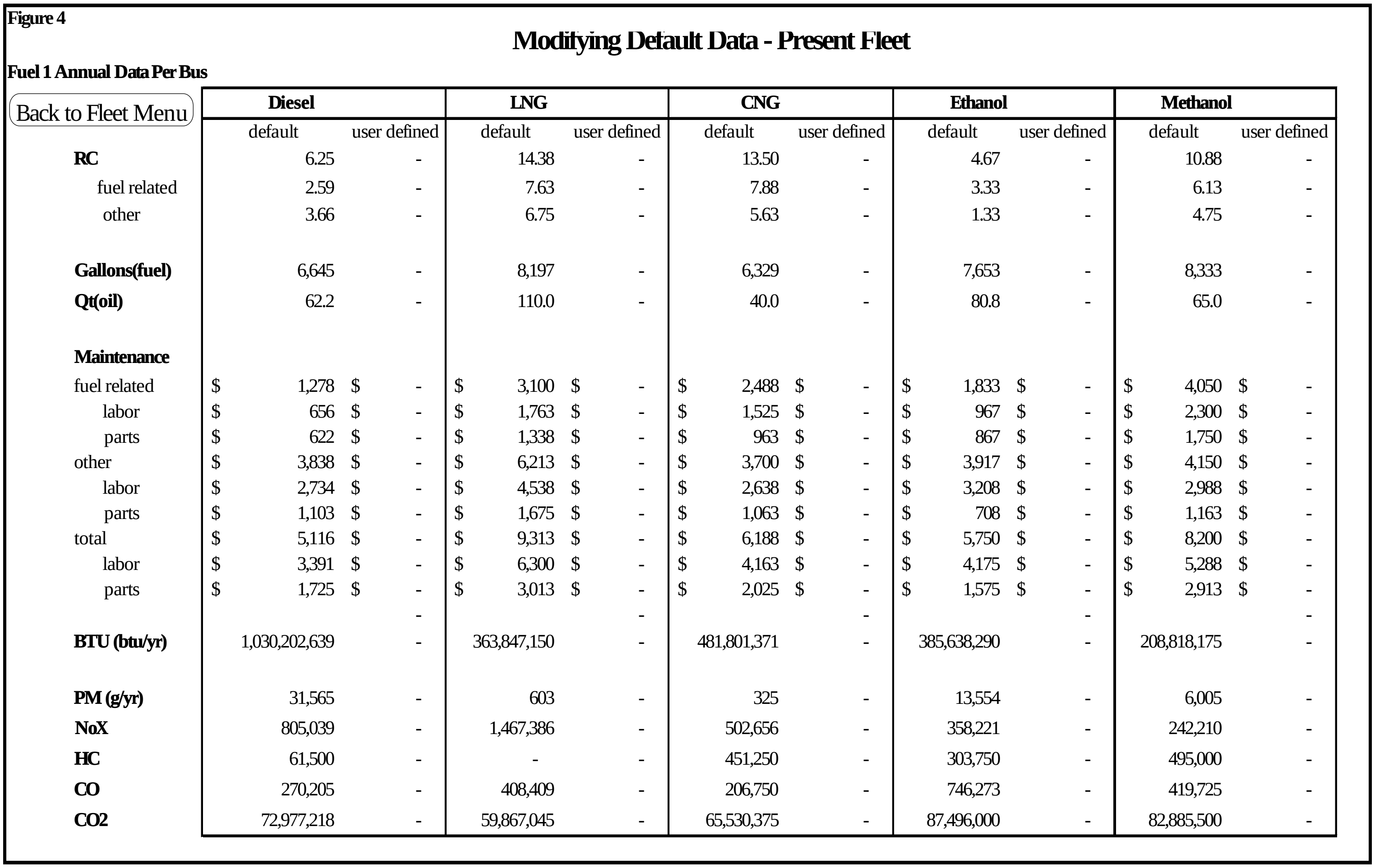


Figure 4

Modifying Default Data - Present Fleet

Fuel 1 Annual Data Per Bus

	Diesel		LNG		CNG		Ethanol		Methanol	
	default	user defined	default	user defined	default	user defined	default	user defined	default	user defined
RC	6.25	-	14.38	-	13.50	-	4.67	-	10.88	-
fuel related	2.59	-	7.63	-	7.88	-	3.33	-	6.13	-
other	3.66	-	6.75	-	5.63	-	1.33	-	4.75	-
Gallons(fuel)	6,645	-	8,197	-	6,329	-	7,653	-	8,333	-
Qt(oil)	62.2	-	110.0	-	40.0	-	80.8	-	65.0	-
Maintenance										
fuel related	$ 1,278	$ -	$ 3,100	$ -	$ 2,488	$ -	$ 1,833	$ -	$ 4,050	$ -
labor	$ 656	$ -	$ 1,763	$ -	$ 1,525	$ -	$ 967	$ -	$ 2,300	$ -
parts	$ 622	$ -	$ 1,338	$ -	$ 963	$ -	$ 867	$ -	$ 1,750	$ -
other	$ 3,838	$ -	$ 6,213	$ -	$ 3,700	$ -	$ 3,917	$ -	$ 4,150	$ -
labor	$ 2,734	$ -	$ 4,538	$ -	$ 2,638	$ -	$ 3,208	$ -	$ 2,988	$ -
parts	$ 1,103	$ -	$ 1,675	$ -	$ 1,063	$ -	$ 708	$ -	$ 1,163	$ -
total	$ 5,116	$ -	$ 9,313	$ -	$ 6,188	$ -	$ 5,750	$ -	$ 8,200	$ -
labor	$ 3,391	$ -	$ 6,300	$ -	$ 4,163	$ -	$ 4,175	$ -	$ 5,288	$ -
parts	$ 1,725	$ -	$ 3,013	$ -	$ 2,025	$ -	$ 1,575	$ -	$ 2,913	$ -
		-		-		-		-		-
BTU (btu/yr)	1,030,202,639	-	363,847,150	-	481,801,371	-	385,638,290	-	208,818,175	-
PM (g/yr)	31,565	-	603	-	325	-	13,554	-	6,005	-
NoX	805,039	-	1,467,386	-	502,656	-	358,221	-	242,210	-
HC	61,500	-	-	-	451,250	-	303,750	-	495,000	-
CO	270,205	-	408,409	-	206,750	-	746,273	-	419,725	-
CO2	72,977,218	-	59,867,045	-	65,530,375	-	87,496,000	-	82,885,500	-

Fleet Analysis Output

The output of the *Fleet Analysis* mode displays the estimated performance values for each of the six fleets (three Present and three Test). If less than three fuels is selected for a particular fleet the output will contain a column of zeros. Furthermore, each of the two fleets has a single column representing the summation of each of its three fuels. Lastly, the right most column on the *Fleet Analysis Output* page is the expected change in performance values as a result of moving from the Present Fleet to the Test Fleet. All positive values suggest an increase while negative values suggest a decrease. For example, if the value for Total Maintenance Costs in this 'difference' column were $100 the interpretation would be as follows. Holding all other things constant, it is estimated that Total Maintenance Costs will increase annually by $100 should the Test Fleet replace the existing Present Fleet. Figure 6 below illustrates the Fleet Analysis Output page.

Important Notes

Number of Buses

In order for an accurate comparison of any combination of fuels there are a few important points to remember. The premise here is that it is crucial that the user be comparing apples to apples, per se, throughout the analysis. For example, if the present fleet is composed of 10 buses and the test fleet is composed of 12 buses then obviously the output is going account for the disproportionate amount of buses in the two fleets. At the bottom of the Fleet Analysis screen, below each of the fleets, is a sum of the number of buses in each respective fleet. A quick check to verify that these two values are equal will maintain a fair comparison as so far as the number of buses is concerned.

Mileage Values

Another important point to keep in mind is that the output of the Fleet Analysis is based on the values of miles per day and days per year for the present and test fleet. If fuel #1 of the present fleet and fuel #1 of the test fleet do not have equal values for each of these three parameters the output will not represent a fair comparison of the two fuels. The same is true for fuel #2 and #3.

Modifying Default Data

One note on modifying default data; always remember to modify data under both Present and Test Fleets. This is to ensure that the comparison is that of apples to apples. If the basis of the comparison is not the same for each of the fleets, it is to be expected that the output will not be equal.

Example: Using Fleet Analysis

Suppose that Joe Smith is the transit manager for his bus authority, and he would like to estimate the results of changing from his current fleet to a new (partially alternative-fuel) fleet. The present fleet is composed of 25 diesel units and he is considering replacing 10 of those buses with 5 CNG and 5 ethanol units. Furthermore, from his own records he has determined that in the past year his 25 buses averaged 100 miles per day and 250 days per year of service.

To begin, click on the Fleet Analysis button as shown in Figure 1 above. Next, enter 25, 100, and 250 into the cells for number of buses, miles per day, and days per year, respectively under

Present Fleet fuel #1 on the Fleet Analysis Input sheet (Figure 5). Diesel would be selected on the pull down menu for fuel type. For the Test Fleet, fuel #1, 15 would be entered for number of buses (since Mr. Smith is changing ten of his buses to a new fuel type, his Test Fleet has 15 diesel buses) and the remaining two variables would be the same as the Present Fleet (100 and 250 for miles per day and days per year). Diesel would be selected on the pull down menu for fuel type. This last process would be repeated for *Test Fuels #2 and #3*. The only differences being the number of buses (5 for fuel #2 and 5 for fuel#3) and fuel type (CNG for fuel #2 and ethanol for fuel #3) selected.

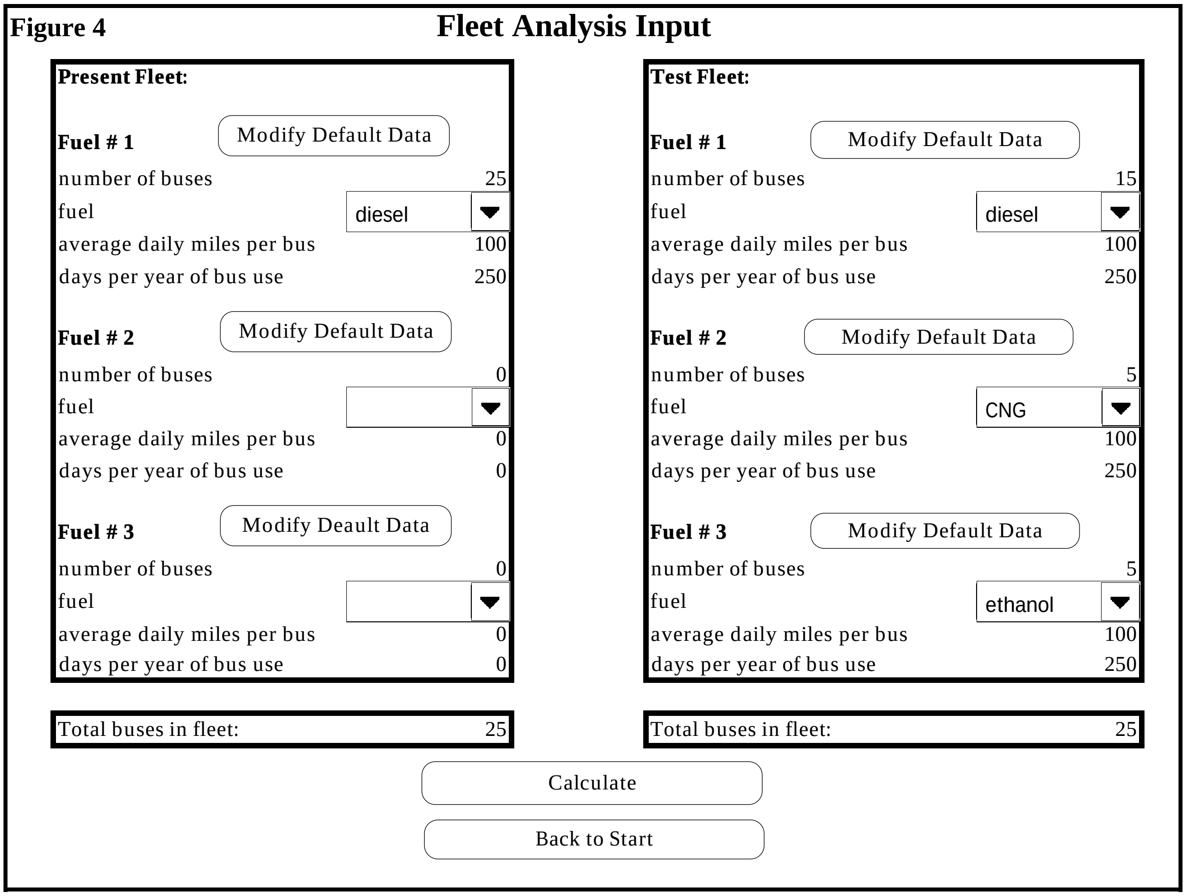


Figure 4

Fleet Analysis Input

Present Fleet:

Fuel # 1
number of buses 25
fuel diesel
average daily miles per bus 100
days per year of bus use 250

Fuel # 2
number of buses 0
fuel
average daily miles per bus 0
days per year of bus use 0

Fuel # 3
number of buses 0
fuel
average daily miles per bus 0
days per year of bus use 0

Total buses in fleet: 25

Test Fleet:

Fuel # 1
number of buses 15
fuel diesel
average daily miles per bus 100
days per year of bus use 250

Fuel # 2
number of buses 5
fuel CNG
average daily miles per bus 100
days per year of bus use 250

Fuel # 3
number of buses 5
fuel ethanol
average daily miles per bus 100
days per year of bus use 250

Total buses in fleet: 25

At this point Mr. Smith has a choice to use either the default values for the twenty variables or enter his own values. Each of the six fuels (three for Present Fleet and three for Test Fleet) has the option to change these default values, and this is done by clicking on the *Modify Default Data* button associated with each of the fuels (Figure 5). Further explanation of using this feature is above in the Modifying Default Data section. For this example, however, Mr. Smith is choosing to use the entire set of default values.

To complete the fleet analysis Mr. Smith would click the Calculate button, which would then present him with the *Fleet Analysis Output* screen, as shown in Figure 6. An explanation of the Fleet Analysis Output page is found above.

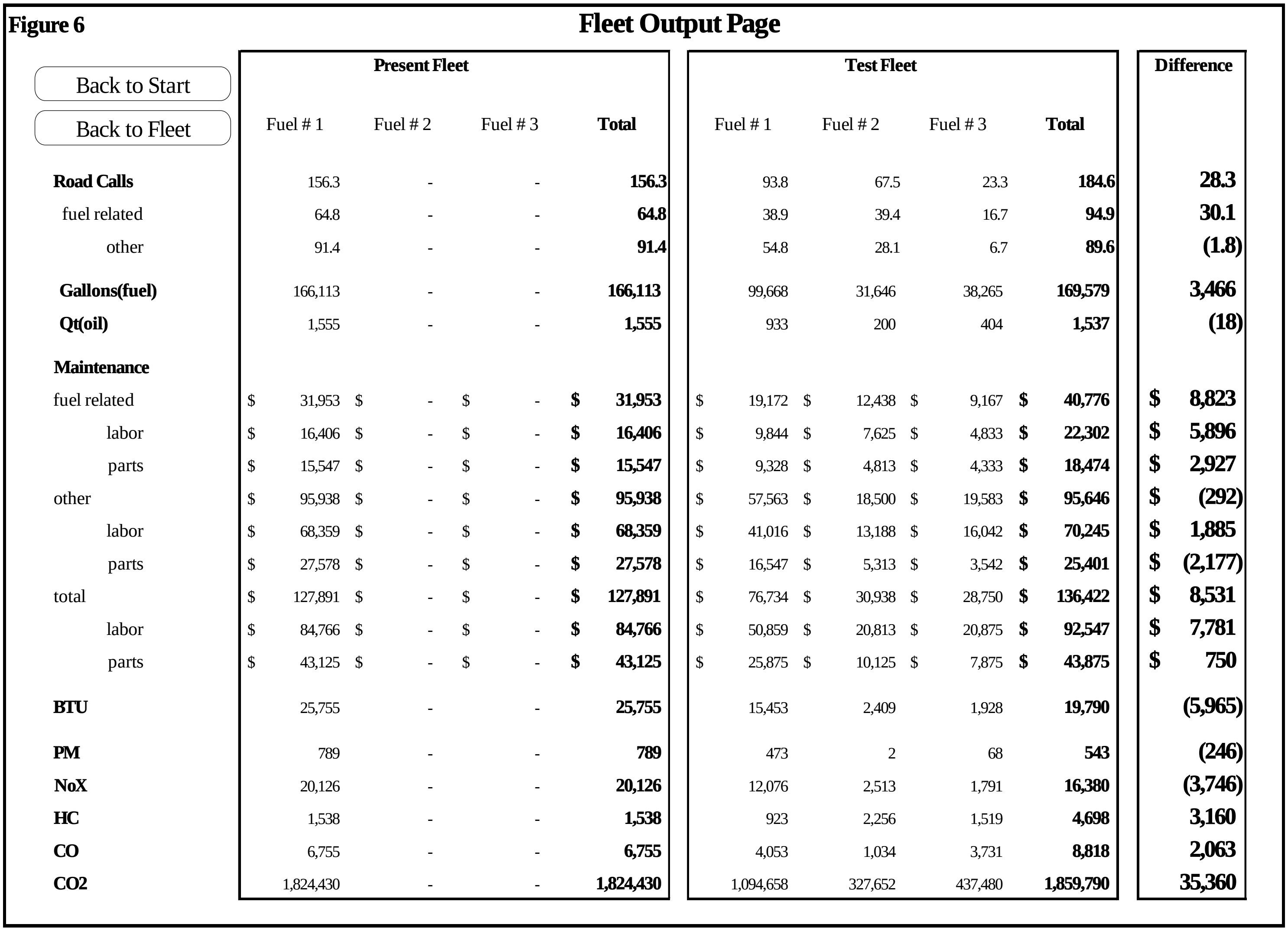


Figure 6

Fleet Output Page

	Present Fleet				Test Fleet				Difference
	Fuel # 1	Fuel # 2	Fuel # 3	**Total**	Fuel # 1	Fuel # 2	Fuel # 3	**Total**	
Road Calls	156.3	-	-	**156.3**	93.8	67.5	23.3	**184.6**	**28.3**
fuel related	64.8	-	-	**64.8**	38.9	39.4	16.7	**94.9**	**30.1**
other	91.4	-	-	**91.4**	54.8	28.1	6.7	**89.6**	**(1.8)**
Gallons(fuel)	166,113	-	-	**166,113**	99,668	31,646	38,265	**169,579**	**3,466**
Qt(oil)	1,555	-	-	**1,555**	933	200	404	**1,537**	**(18)**
Maintenance									
fuel related	$ 31,953	$ -	$ -	**$ 31,953**	$ 19,172	$ 12,438	$ 9,167	**$ 40,776**	**$ 8,823**
labor	$ 16,406	$ -	$ -	**$ 16,406**	$ 9,844	$ 7,625	$ 4,833	**$ 22,302**	**$ 5,896**
parts	$ 15,547	$ -	$ -	**$ 15,547**	$ 9,328	$ 4,813	$ 4,333	**$ 18,474**	**$ 2,927**
other	$ 95,938	$ -	$ -	**$ 95,938**	$ 57,563	$ 18,500	$ 19,583	**$ 95,646**	**$ (292)**
labor	$ 68,359	$ -	$ -	**$ 68,359**	$ 41,016	$ 13,188	$ 16,042	**$ 70,245**	**$ 1,885**
parts	$ 27,578	$ -	$ -	**$ 27,578**	$ 16,547	$ 5,313	$ 3,542	**$ 25,401**	**$ (2,177)**
total	$ 127,891	$ -	$ -	**$ 127,891**	$ 76,734	$ 30,938	$ 28,750	**$ 136,422**	**$ 8,531**
labor	$ 84,766	$ -	$ -	**$ 84,766**	$ 50,859	$ 20,813	$ 20,875	**$ 92,547**	**$ 7,781**
parts	$ 43,125	$ -	$ -	**$ 43,125**	$ 25,875	$ 10,125	$ 7,875	**$ 43,875**	**$ 750**
BTU	25,755	-	-	**25,755**	15,453	2,409	1,928	**19,790**	**(5,965)**
PM	789	-	-	**789**	473	2	68	**543**	**(246)**
NoX	20,126	-	-	**20,126**	12,076	2,513	1,791	**16,380**	**(3,746)**
HC	1,538	-	-	**1,538**	923	2,256	1,519	**4,698**	**3,160**
CO	6,755	-	-	**6,755**	4,053	1,034	3,731	**8,818**	**2,063**
CO2	1,824,430	-	-	**1,824,430**	1,094,658	327,652	437,480	**1,859,790**	**35,360**

Summary and Conclusions

The conclusions one can draw from the analysis and the final simulation tool reported on in this study suggest:

- the sophistication and performance reliability of these fuels is increasingly competitive with (or sometimes superior to) conventional diesel fuels.

- transit related air pollution emissions from alternative fuels increasingly are developing the capability of reducing net emissions over conventional diesel fuels.

- emission testing results of natural gas and alcohol busses particularly indicate that alternative fuel technologies have the potential to significantly lower PM and NOx emissions and the prospect of virtually eliminating PM with natural gas fuels.

- operation costs for either conventional or alternative fueled busses are mostly driven by fuel and alternative fuels are increasingly competitive or lower than conventional fueled busses.

- while alternative fueled bus systems are still typically higher than conventional diesel fuels, they are becoming increasingly competitive (and with research advances promised for the future may become very competitive or less expensive than conventional diesel fuels.

- growth in the capabilities and reliability of alternative fueled transit vehicles in the U.S. portend an increasingly expanded role for the use of alternative fueled transit vehicles across the both the U.S. and international transit property markets.

- the use of this simulation and other economic, technical and environmental impact assessment tools will help expand the understanding of the role alternative fueled transit bus systems can play in transit properties across the U.S.

- as advances in alternative fuels capabilities emerge, simulation tools of the sort presented in this report will be modified to help facilitate the examination of the favorable impact these new systems will have on fleet operational and performance characteristics.

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