TRANSIT RESOURCE CENTER

Final Report

Wichita Falls Transit Alternative Fuels Study

To:

City of Wichita Falls
1300 Seventh Street
Wichita Falls, Texas 76301

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TABLE OF CONTENTS

1. BACKGROUND

STUDY PURPOSE

The purpose of this study is to provide Wichita Falls the information necessary to make informed decisions on the propulsion systems and fuel types for the future procurement of Wichita Falls Transit buses.

The City of Wichita Falls is the sponsor of the study. Transit Resource Center is the consultant for the project.

BACKGROUND OVERVIEW

The purpose of this section is to provide the background context for the analysis of alternative fuels for the transit fleet in Wichita Falls. The section discusses several distinct elements that are important to the review of alternative fuels:

Operational characteristics, including the route design, number of trips made, service frequency, the span of service and operating speeds; these are all important in considering different fuel options. For example, long service days may require buses to be refueled or swapped out if fuel capacity does not match the mileage demands..

Fleet characteristics include the size of the buses and how the fleet is utilized. Heavy passenger demand may require larger buses that need more power and more fuel capacity. Bus mileage on an average day is important because fuel capacity and range of natural gas systems are typically less than diesel fuel.

Infrastructure for fueling is also an important consideration, and existing conditions are reviewed.

EXISTING WICHITA FALLS TRANSIT OPERATIONS

As described below in Exhibit 1-1, the Wichita Falls Transit System operates six routes. The first five routes operate Monday through Friday from 5:30 am to 7:30 pm and on Saturdays from 10:30 am to 5:30 pm. Route 6, the Sheppard Express, operates 7 days a weeks and has various hours.

Exhibit 1-1
Wichita Falls Transit Operations Profile

Route	Description	Weekday Hours	Saturday Hours	Annual Passenger	Annual Miles
Blue Route 1	Eastside/Midwestern	5:30 am- 7:30 pm	10:30 am- 5:30 pm	39,753	75,671
Red Route 2	Kemp/Seymour	5:30 am- 7:30 pm	10:30 am- 5:30 pm	26,664	60,422
Green Route 3	Taft/Holiday	5:30 am- 7:30 pm	10:30 am- 5:30 pm	22,671	61,874
Yellow Route 4	Maurine/Sheppard	5:30 am- 7:30 pm	10:30 am- 5:30 pm	43,389	80,301
Brown Route 5	Southwest/Fairway	5:30 am- 7:30 pm	10:30 am- 5:30 pm	14,691	66,396
Orange Route 6*	Sheppard Express	3:00 pm- 9:30 pm	3:00 pm- 9:30 pm	83,456	76,507

* Service operates from 3:00 pm to 11:30 pm on Fridays and from 12:15 to 9:15 pm on Sundays

Route 4 has an average of 260 miles per day, the highest average daily total per route. From the data provided by Wichita Falls Transit system, it does not appear that any bus travels more than 310 miles in a day. Exhibit 1-2 shows the maximum miles traveled per vehicle for four sample days. Fuel storage capacity for all alternative fuels except electric vehicles does not appear to be a potential issue. The average daily miles traveled exceed the maximum range of 100% electric vehicles.

Exhibit 1-2
Maximum Daily Miles per Route

Route	Description	Maximum Daily Miles
Blue Route 1	Eastside/Midwestern	264
Red Route 2	Kemp/Seymour	250
Green Route 3	Taft/Holiday	232
Yellow Route 4	Maurine/Sheppard	309
Brown Route 5	Southwest/Fairway	232
Orange Route 6*	Sheppard Express	303

The average fuel consumption of diesel fuel per bus is 40 gallons per day. The fuel tank capacity is 100 gallons.

Buses travel at different speeds, depending on the road conditions. Most of the one-way loop routes travel on local streets at 25-35 mph. Route 6 utilizes Central Expressway, Spur 325 and State Route 240 to access Sheppard Air Force Base and can reach speeds of 55 miles per hour or higher.

The terrain that Wichita Falls Transit System utilizes is very flat.

Overall, the operating conditions for Wichita Falls Transit are conducive to a wide range of alternative fuels.

FLEET CHARACTERISTICS

Exhibit 1-3 provides a profile of the 12-bus fleet of Wichita Falls Transit. The majority of buses are Transmark RE-32 buses. Only 3 buses are scheduled for replacement before 2007.

Exhibit 1-3
Fleet Characteristics

Bus Number	Model Year	Vehicle Model	Engine	Vehicle Rating	Normal Vehicle Replacement
491	1996	Escort RE	5.9 Cummins	7- year	2002
493	1996	Escort RE	5.9 Cummins	7- year	2002
494	1996	Escort RE	5.9 Cummins	7- year	2002
496	1998	Transmark RE_32	8.3 Cummins	10-year	2007
497	1998	Transmark RE_32	8.3 Cummins	10-year	2007
488	2000	Transmark RE_32	8.3 Cummins	10-year	2009
489	2000	Transmark RE_32	8.3 Cummins	10-year	2009
498	2000	Transmark RE_32	8.3 Cummins	10-year	2009
499	2000	Transmark RE_32	8.3 Cummins	10-year	2009
475	2002	Transmark RE_32	8.3 Cummins	10-year	2011
476	2002	Transmark RE_32	8.3 Cummins	10-year	2011
479	2002	Escort RE	5.9 Cummins	7-year	2008

EXISTING ALTERNATIVE FUEL INFRASTRUCTURE

Texas is a major producer of propane and natural gas, both classified as alternative fuels under the Energy Policy Act of 1992. There are no existing compressed natural gas or liquid natural gas fueling facilities in Wichita Falls. According to TxDOT, the only existing fueling stations available for CNG are in Houston and Dallas.

TxDOT has developed a network of 200 propane fueling stations statewide, including one in Wichita Falls.

REGULATORY HISTORY

In late summer, 2001, the Texas Transportation Commission notified the Texas Department of Transportation Public Transportation Division that Commission approval of funding for all public transportation purchases, including vehicle capital replacement (VCR) program purchases, would be contingent upon the vehicles being alternatively fueled. [1]

[1] Letter from Margot Massey to Steve Seese, February 4, 2003.

The list of types of acceptable alternatively fueled vehicles included propane, compressed and liquefied natural gas, electrical, as well as duel-fueled and hybrid vehicles such as diesel/electrics. Clean diesel, sometimes referred to as green diesel, was not a viable alternative fuel option under TxDOT regulations for bus purchases during this time frame.

According to TxDOT, the Texas Transportation Commission has allowed a “waiver” process for transit agencies lacking access to alternative fuel and/or adequate maintenance facilities in their service area. [2]

In May 2001, the 77th Legislature established the Texas Emission Reduction Plan (TERP), the latest effort to help reduce air pollution in Texas. TERP administers a program of grants and incentives for improving air quality throughout the state. The program may pay incremental costs on the purchase or lease of "clean" heavy-duty vehicles as well as light duty vehicles that meet established emissions levels.

In March 2003, the Public Transportation Division of TxDOT issued a “Dear Colleague” letter that provided transit operators such as Wichita Falls with as much flexibility as possible with respect to alternative fuel requirements. At this time, TxDOT recognized “all commercially available technology and fuels that meet air quality goals. For example, ultra low sulfur diesel (ULSD) is now an option for you to consider.”[3]

TECHNICAL REVIEW COMMITTEE

A Technical Review Committee was formed by the City of Wichita Falls to review working papers and provide guidance to the study. The Technical Review Committee consisted of:

- Darron Leiker, Asst. City Mgr./Dir. of Traffic, Transportation and Aviation
- Steve Seese, MPO Director
- Larry Blowers, Transit Supervisor
- Lin Barnett, Planner II
- Karen Montgomery, Planner III

[2] ibid
[3] Letter from Margot Massey, Director, Public Transportation Division to all transit operators, March 28, 2003.

2. OVERVIEW OF ALTERNATIVE FUELS

This chapter first provides an overview of the range of propulsion and fuel alternatives for buses. These include:

- Internal combustion engine: diesel, compressed natural gas (CNG), and liquefied petroleum gas (LPG) fuel.
- Battery Propulsion
- Hybrid-Electric Propulsion
- Fuel Cells

Based on input from the Technical Review Committee on a working paper for this study, clean diesel and liquefied petroleum gas (commonly referred to as propane or LPG) were selected for further detailed study. Those options receive significant detailed cost analysis in Chapters 3 and 4. Appendix A provides additional information on fuels and propulsion systems not selected for detailed review. This chapter provides a general overview of the wider range of alternative fuel options and the current status of the technology.

INTERNAL COMBUSTION PROPULSION

Buses that operate solely on diesel, gasoline, or gaseous-based fuels such as CNG and propane, use that fuel to power an internal combustion (IC) engine. Although IC engine characteristics vary between engine designs, the basic principles remain the same. Air is mixed with fuel; the air/fuel mixture is compressed, and is then ignited. Diesel engines use the internal heat of the engine to ignite the air/fuel mixture, while gasoline and gaseous fuels require an electronic spark. In all cases, energy produced from the ignited air/fuel mixture is used to propel the vehicle and power auxiliary equipment such as air conditioning, power steering, alternators, etc. The spent fuel exits the engine through the exhaust system, emitting varying amounts of emissions for each fuel type.

When considering the prospects for future vehicle propulsion in Wichita Falls, one must keep in mind that the basic operating characteristics of the internal combustion engine -- regardless of whether it operates on diesel, gasoline, CNG, or LNG fuel -- have not changed since the engine was first developed over 100 years ago. Despite the fact that great advances have been made to significantly improve driveability, reliability, efficiency, and emissions, the reciprocating characteristics of the IC engine (pistons moving up and down in cylinders to compress and expel air/fuel mixture) remain the same.

Exhaust from diesel-fueled engines has been reduced significantly during the last 10 years.[1] Lower emissions levels can be attributed to three major factors:

- increasingly stringent emission regulations for buses
- major advances in diesel engine technology

[1] American Public Transportation Association

- reduced sulfur level content in diesel fuel

The first major improvement in diesel exhaust emissions was introduced in 1993, when a change was made from a two-stroke engine design to a four-stroke design to meet more stringent national emission regulations. Electronic fuel delivery, turbocharging and after-cooling of intake air, high-pressure fuel injection, exhaust gas re-circulation (EGR), exhaust after-treatment devices, and other advances all contributed to lower emissions.

For the 1988-89 model year, diesel transit bus emissions levels were regulated at 10.7 grams per brake horsepower-hour (g/bhp-hr) of oxides of nitrogen (NOx), and 0.60 g/bhp-hr for particulate matter (PM). Nationwide on average, diesel transit buses emit 4.0 g/bhp-hr of NOx and 0.05 g/bhp-hr of PM – a 92 percent reduction in PM emissions and a 63 percent reduction for NOx since 1989.

In order to reduce emissions of diesel even further to provide the cleanest possible diesel, three strategies are being utilized to meet the 2007 standards:

- Additional diesel aftertreatment technology
- Ultra low sulfur fuel
- Exhaust gas recirculation

Diesel aftertreatment technology is readily available. Ultra low sulfur fuel is only available in select geographic regions. Exhaust gas recirculation is in a developmental phase. For purposes of this report, the term "clean" diesel includes the use of additional diesel aftertreatment technology and the utilization of ultra low sulfur fuel. Clean diesel is one of two options selected for detailed cost analysis, and the results and further discussions about the attributes of clean diesel are reported in Chapter 3.

Natural Gas

Exhibit 2-1 is an overview of the primary components, main fuel source, energy content, and energy ratio of five different types of natural gas fuels.

CNG is the most popular alternative fuel for transit bus use. LNG is also being used successfully, primarily in the Phoenix (AZ) area, Dallas (TX), and Orange County (CA). Houston abandoned its LNG use, but the reasons to discontinue the fuel cannot be attributed to a failure of the technology (buses used older LNG technology; and the agency changed its focus). A review of the pros and cons of natural gas follows.

Exhibit 2-1
Overview of natural gas and alcohol based fuels

	Compressed Natural Gas (CNG)	Ethanol (E85)	Liquefied Natural Gas (LNG)	Liquefied Petroleum Gas (LPG)	Methanol (M85)
Chemical Structure	CH_4	CH_3CH_2OH	CH_4	C_3H_8	CH_3OH
Primary Components	Methane	Denatured ethanol and gasoline	Methane that is cooled cryogenically	Propane	Methanol and gasoline
Main Fuel Source	Under-ground reserves	Corn, grains or agricultural waste	Underground reserves	A by-product of petroleum refining or natural gas processing	Natural gas, coal, or woody biomass
Energy Content per Gallon	29,000 Btu	80,460 Btu	73,500 Btu	84,000 Btu	65,350 Btu
Energy Ratio Compared to Gasoline	3.94 to 1 or 25% at 3000 psi	1.42 to 1 or 70%	1.55 to 1 or 66%	1.36 to 1 or 74%	1.75 to 1 or 57%
Liquid or Gas	Gas	Liquid	Liquid	Liquid	Liquid

Liquid Petroleum Gas (LPG), commonly referred to as Propane, is the other propulsion system selected for detailed cost analysis by the technical review committee. Detailed attributes and a cost analysis are provided in Chapter 4. Appendix A provides the pros and cons and detailed attributes of alternative fuels not selected for detailed cost analysis.

BATTERY ELECTRIC PROPULSION

Several manufacturers of buses in the 22-30 foot range offer battery-electric buses, where propulsion is provided solely by battery power. Advantages include lower noise levels, zero exhaust emissions from the vehicle, and no problems associated with cold-starts. Additionally, infrastructure requirements for re-charging the batteries are minimal compared to CNG and LNG.

Principal disadvantages include reduced range and performance, and higher purchase price compared to IC-powered buses. Batteries require special maintenance, and need to be replaced about every two years. Although improvements in battery technology have been made, on-board systems such as heating, air conditioning, and air brakes that require battery power to operate, severely affects vehicle range. Agencies with short routes (i.e., downtown shuttle operation) may benefit from battery-electric propulsion, while agencies with longer routes will find battery technology more difficult, in that vehicles would need to return during the day for re-charging or swapping battery packs.

Because of Wichita Falls Transit's vehicle mileage requirements, 100% electric vehicles are not a realistic option for Wichita Falls.

HYBRID-ELECTRIC TRANSIT BUSES

Hybrid-electric propulsion, where an auxiliary power unit (APU) such as a conventional internal combustion (IC) engine is used together with an electric motor to turn, or help turn, the vehicle's wheels, is gaining popularity in US transit bus applications. Although alternatively-fueled engines and other APUs are also being used in conjunction with hybrid-electric propulsion, the most popular application nationwide is the diesel hybrid-electric application.

Proponents of diesel hybrid-electric propulsion feel that alternative fuels such as compressed natural gas (CNG) and liquefied natural gas (LNG) are interim solutions that will be abandoned once dedicated electric propulsion, such as fuel cells and improved batteries, are perfected. As a result, they seek <u>not</u> to make the substantial infrastructure investments needed for fueling stations and fuel storage, safety, and other considerations needed to support these fuels. If fuel cells are ultimately the solution to bus propulsion, then hybrids also become an interim solution. Since hybrid propulsion involves an electric drive element, proponents view hybrids as a bridge technology that prepares them for electric drive technology while eliminating the infrastructure expenses and safety concerns associated with alternative gaseous fuels.

While agencies such as New York City Transit Authority (NYCTA) claim many benefits from hybrid buses and show that emissions from its diesel hybrids are virtually identical to CNG buses, they admit that there is a reduction in bus availability due to technical problems. Although agencies such as NYCTA have the engineering resources, have a large spare ratio to replace hybrid buses when repairs/modifications are needed, and have the clout to have hybrid equipment/bus manufacturers respond quickly to technical problems, smaller agencies might not have these advantages.

At present there is only one manufacturer of hybrid electric vehicles in the 30-foot bus category, and these are considered experimental. It will probably be another three years before a 30-foot hybrid bus will be economical to purchase. Large agencies are providing the research and development to move this promising technology forward. While this is a very promising technology, it is not recommended for immediate implementation in Wichita Falls.

FUEL CELLS

All of the propulsion alternatives being used and considered today (CNG, LNG and hybrids) by transit agencies can be viewed as interim solutions until fuel cells become available. The question becomes which alternative (if any) best suits the agency's financial and operational needs until fuel cells are actually developed and perfected.

The recent announcement by the Bush Administration on January 9, 2002 to subsidize fuel cell development is seen by many as the beginning of the end for IC engines. The announcement changes the question from "if" the IC will be replaced, to "when" the replacement will occur. According to the CEO of General Motors, "no car company will be able to thrive in the 21st century if it relies solely on internal combustion engines." Every major automaker worldwide is in the process of developing fuel cell vehicles, including the so-called Big 3 of America (GM, Ford, Daimler-Chrysler) and those of Japan (Honda, Nissan, Toyota).

Fuel cells operate by harnessing the energy from a chemical reaction that combines hydrogen and oxygen to form water. The energy released by the oxidation of hydrogen to water is directly converted to an electric current. Fuel cells may be fueled by hydrogen directly, or may use reformers to generate hydrogen from methanol, natural gas, or other hydrocarbons (HCs) with water.

An extremely complex technology, fuels cells can provide propulsion in a variety of ways. As a hybrid, the fuel cell acts like the "engine" in a conventional hybrid vehicle where electrical energy produced by the fuel cell is delivered to an energy storage/load leveling device (i.e., battery). As a pure fuel cell vehicle, electrical energy is delivered directly to the drive wheels.

SunLine Transit in California has received funding for a fuel cell bus demonstration project. This will provide the industry with research and development information on the potential use of fuel cells for bus propulsion. While this is a very promising technology, it is currently not commercially available.

The following two chapters provide details on clean diesel and propane, the two fuels selected by the Technical Review Committee for detailed study. Appendix A provides additional information on the fuel and propulsion systems not selected.

3. CLEAN DIESEL

Clean diesel is being recommended by the Technical Review Committee as the future alternative fuel for future bus procurements by the City of Wichita Falls. This chapter defines clean diesel, provides background on its regulatory history, and discusses its key components: 1) aftertreatment devices, 2) ultra low sulfur diesel fuel, and 3) the prospect of exhaust gas recirculation. A cost comparison with existing diesel is provided. Finally, key implementation considerations are highlighted.

Diesel engines offer high efficiency, low maintenance and long life, but concerns over harmful exhaust emissions have resulted in significant research and development to make these engines operate more cleanly. While diesel engines produce little carbon monoxide (CO) or volatile hydrocarbon (HC) in the exhaust, their emissions of oxides of nitrogen (NOx) and particulate matter (PM) exceed those of gasoline engines and have become the target of increasingly stringent emissions regulations.

DIESEL FUEL REGULATORY HISTORY

Exhaust emissions from diesel-fueled engines have been reduced significantly during the last 10 years.[1] Lower emissions levels can be attributed to three major factors:

- increasingly stringent emission regulations for buses
- major advances in diesel engine technology
- reduced sulfur level content in diesel fuel

For the 1988-89 model year, when the Environmental Protection Agency (EPA) first regulated bus emissions, diesel transit bus emissions levels were regulated at 10.7 grams per brake horsepower-hour (g/bhp-hr) of oxides of nitrogen (NOx), and 0.60 g/bhp-hr for particulate matter (PM). Since that time, diesel engine manufacturers have responded to increasingly stringent EPA regulations and, as a result, diesel engines are much cleaner from an emissions standpoint. Nationwide, on average, diesel transit buses now produce 92 percent less in PM emissions and a 63 percent reduction in NOx emissions compared to the 1988-89 levels.

CLEAN DIESEL COMPONENT OVERVIEW

In order to reduce emissions of diesel engines beyond current EPA levels, some agencies have decided to pursue another technology. This so-called “clean diesel” strategy consists of using:

- Diesel aftertreatment technology in the form of a PM filter, and
- Ultra low sulfur diesel fuel

For the purposes of this report, the term “clean diesel” implies the use of a PM filter in combination with ultra low sulfur diesel fuel.

[1] American Public Transportation Association

Exhaust Gas Recirculation (EGR) is yet another technology used to further reduce emissions. All technologies are discussed below.

As stated earlier, CO and HC emissions are not an issue with diesel engines. However, diesel engine manufacturers face a difficulty in reducing both PM and NOx levels simultaneously because of the inverse relationship that exists between them. That is, efforts to reduce one of the emissions result in an increase in the other (i.e., when NOx levels are reduced, PM levels increase and visa versa). As a result of this inverse relationship, engine manufacturers typically concentrate their efforts on reducing NOx emissions through in-engine modifications and the application of EGR technology. PM emission reductions have been achieved through the use of so-called “aftertreatment” devices (i.e., add-on equipment that treats the exhaust gas after it leaves the engine). These aftertreatment devices typically take the place of the muffler as a direct replacement.

An oxidation catalyst is one aftertreatment device currently used in diesel engines to reduce PM levels to comply with existing EPA emissions regulations. Reducing PM levels even further requires the use of a passive regenerative catalyzed diesel particulate filter (referred to in this report as a PM filter).

PM FILTERS

Similar to the oxidation catalyst, the PM filter replaces the standard muffler. PM filters “trap” the solid particulate matter contained in the exhaust stream and include a precious metal catalyst that oxidizes the collected particulate matter. Use of PM filters, however, requires the use of diesel fuel with “ultra low” sulfur levels, which is not commercially available in all areas. (Use of standard diesel fuel destroys the emission-reduction capabilities of the PM filter.)

The explanation that follows is a simplified version of how a PM filter works. When exhaust gas temperatures exceed about 250 degrees C, the accumulated PM is burned off. The ash that builds up over time, however, increases backpressure to a point where the filters require periodic maintenance about once per year. The maintenance involves blowing out the ash with compressed air and disposing of it properly based on local regulation.

PM Filters are available for both Cummins 5.9 and 8.3 liter engines. They are available through Fleetguard Emissions Solutions, a division of Cummins Engine Company, and sold and serviced through Cummins dealers. PM filters are expected to be offered as standard equipment on all diesel transit bus engines when the use of ultra-low sulfur diesel fuel is mandated by the EPA in 2006 (see the section on Ultra-Low Sulfur Fuel below). Until then, PM filters are available as a retrofit. Some agencies are specifying the use of PM filters on new engines with the understanding that these engines will always be fueled with ultra-low sulfur diesel fuel.

The purchase cost for each PM filter depends on the make and model of bus. In general, the per-unit cost for PM filters is about $6,500 and includes the filter, all mounting hardware, and onboard data-logging equipment. The onboard data-logging equipment monitors exhaust backpressure and other conditions for determining maintenance frequency and equipment failure, and is highly recommended as part of the overall installation.

New heavy-duty transit bus diesel engines are typically equipped with a diesel oxidation catalyst, which reduce PM emissions by 35-45% compared to engines with no aftertreatment devices.[2] However, a PM filter when used in conjunction with ultra-low sulfur diesel fuel reduces PM emissions by more than 90%.[3]

The current recommendation for PM filter maintenance is annually. Data obtained from the on-board monitoring system may alter this schedule. In any case, periodic maintenance consists of removing the internal filter cartridge and blowing out the accumulated ash. Concerns over the toxic nature of the ash have caused many agencies to contract the cleaning to outside vendors. Typical per-unit cleaning costs are about $350. The time to remove and replace (R&R) the cleaned insert is about four (4) hours. To facilitate the cleaning of PM filters and to account for PM filter failures, agencies should keep a 20% spare of filters (e.g., two spares for every 10 buses). The spare ratio allows the agency to install a cleaned replacement filter, as opposed to keeping buses out of service, while the filter is being cleaned.

The spares also allow an agency to replace any defective filters that fail in service. The leading cause of filter failure appears to be engine failure that sends excessive oil into the filter and contaminates it. Outright filter failures have been a very rare transit industry occurrence to date.

ULTRA-LOW SULFUR FUEL

The PM filters are passive in that they do not require engine modifications or control systems. However, the catalyzed nature of the filter is such that it requires the use of ultra low sulfur diesel fuel with a maximum sulfur content of 50 parts-per-million (ppm) to oxidize the particulate matter without creating excessive sulfate. Tests have shown that the conversion efficiency of PM filters improves when diesel fuels with lower sulfur levels (e.g., ultra-low sulfur diesel fuel) are used.

Tests have shown that PM filters, used in conjunction with ECD (and ECD-1 for ultra-low sulfur diesel fuel), reduce PM emissions by more than 90% compared to vehicles with no aftertreatment.[4]

ECD and ECD-1 diesel fuels are produced by ARCO, a BP company, and have a sulfur content of less than 15 ppm. The ultra-low sulfur fuel and PM filter combination did not result in any significant change in fuel economy. The study concluded that emissions from transit buses retrofitted with PM filters were equivalent or lower than PM emissions from comparable natural gas vehicles previously tested at the same emissions laboratory.

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[2] Diesel Emissions Control Sulfur Effects (DECSE) Program – Final Report: Diesel Oxidation Catalyst and Lean NOx Catalysts, U.S. Department of Energy, Engine Manufacturers Association, Manufacturers of Emissions Controls Association, http://www.ott.doe.gov/decse/, June 2001.
[3] LeTavec, C., Uihlein, J., Vertin, K., Chatterjee, S., Hallstrom, K., Wayne, S., Clark, N., Gautam, M., Thompson, G., Lyons, D., Chandler, K., and Coburn, T., "Year-Long Evaluation of Trucks and Buses Equipped with Passive Diesel Particulate Filters," SAE Paper 2002-02-0433, 2002.
[4] ibid.

The EPA will mandate ultra-low sulfur fuel in 2006, similar to the way unleaded fuel was mandated for automobiles.

Federal Regulations for Ultra Low Sulfur Diesel[5]

Beginning June 1, 2006, refineries must begin producing diesel fuel that meets a maximum sulfur content of 15 parts per million (ppm). By way of comparison, traditional diesel fuel has a sulfur content of 500 ppm.

All 2007 model year diesel-fueled vehicles must use the 15-ppm sulfur fuel, which is commonly referred to as ultra-low sulfur diesel (ULSD) fuel. The characteristics of ULSD fuel allow diesel engine manufacturers to use PM filters and other emission-reducing equipment in model year 2007 and newer diesel engines to meet more stringent EPA regulations. ULSD fuel must be used in these specially equipped vehicles because use of diesel fuel with a sulfur content higher than 15 ppm will damage the PM filters. Likewise, ULSD fuel must be used in any vehicle that has been equipped with PM filters prior to the 2007 model year when PM filters are expected to become standard equipment.

The EPA is allowing the production of traditional diesel fuel with a sulfur content of 500 ppm in limited quantities during a transition period up to 2009. This is being done primarily to help alleviate potential hardships that may be caused to some of the smaller refineries. The 500 ppm fuel must be labeled as such so it will not be accidentally used in 2007 and later diesel vehicles (or in other pre-2007 vehicles equipped with PM filters). After 2009, standard diesel fuel (with 500 ppm sulfur content) will not be sold. Refiners that produce ULSD fuel before the June 1, 2006 date will receive incentives in the form of credits, which can be sold.

The EPA is expecting that centrally fueled fleets (i.e., transit agencies, public utilities, etc.) will only use the ULSD fuel once it becomes available in June 2006 or earlier (and therefore will not need to invest in dual storage tanks). The EPA is expecting that the sale of traditional 500 ppm diesel fuel (which will only be available in limited amounts and require dual sets of fuel storage tanks) will be confined primarily to public truck stops and fueling stations after June 2006.

Implications of Clean Diesel Federal Regulations on Wichita Falls

The EPA is not expecting much of a cost difference between the two diesel fuels once production of the ULSD fuel is required in 2006. The EPA is estimating that the cost of both fuels should be approximately the same due to the limited availability of the standard fuel during and after 2006, and the credits that refiners will have to purchase to continue producing the standard diesel fuel. The EPA estimates the net cost for ULSD fuel will be 0.4 cents per gallon. Likewise, the EPA is estimating that 500 ppm diesel fuel will increase by a similar amount in 2006. If the EPA projections hold true, the City of Wichita Falls will not see a distinguishable difference in fuel costs for 500 ppm diesel fuel and clean diesel after 2006.

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[5] Source: 40 CFR Parts 69, 80 and 86
"Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements – Final Rule" Federal Register, Vol. 66, No. 12, Thursday, January 18, 2001

The availability of ULSD before 2006 allows transit agencies and others to equip their vehicles with PM filters before 2007. Some agencies are making this move to help reduce emissions before more stringent regulations go into effect. While ULSD fuel must be used in vehicles equipped with PM filters, it can also be used in existing diesel vehicles (i.e., those not equipped with PM filters) without harming the engines. In fact, the EPA estimates that operators will realize several benefits from using ULSD fuel. EPA claims that a new heavy-duty vehicle introduced into the fleet in 2006 using ULSD fuel will realize a saving of $610 over its life. The fuel savings have also been expressed in terms of fuel cost savings as approximately one cent per gallon. The cost benefits come from reduced corrosion wear to piston rings, cylinder liners, exhaust system, and EGR components. However, it may be too early to start calculating cost savings resulting from the use of ULSD fuel due to the uncertainty related to fuel lubricity (see below) and the additional maintenance required (i.e., more frequent oil changes) as a result of using ULSD fuel.

There has been some concern about the potential lack of fuel lubricity associated with the use of ULSD. Diesel engines require lubricating characteristics of the fuel itself to lubricate moving parts within the fuel pumps and fuel injection system. The EPA recognizes that fuel lubricity standards do not exist and that additional research is needed. However, EPA believes that refiners will add sufficient quantities of lubricity agents to ULSD fuel and has included a 0.2 cents per gallon cost in its cost calculations for ULSD fuel to account for the additives.

At present, TxDOT has contracts with Valero Energy Corporation to supply ultra low sulfur fuel in the major Texas metropolitan areas, but not Wichita Falls.[6] According to Dallas Area Rapid Transit (DART) staff, they are currently paying 13 cents more per gallon for ultra low sulfur diesel fuel than the standard 500 ppm diesel fuel. As mentioned previously, the difference in fuel costs is expected to diminish in 2006. The City of Wichita Falls can utilize the Texas Building and Procurement Commission's cooperative purchasing program to procure ultra low sulfur diesel fuel through the TxDOT program. According to the City of Wichita Falls, the City will bid out its fuel procurement for clean diesel. As of August 2003, the cost for ultra low sulfur diesel was $1.11 per gallon. In April 2003, the cost of diesel fuel that Wichita Falls Transit was utilizing was $.99 per gallon.

EXHAUST GAS RECIRCULATION (EGR)

While PM filters, in combination with ultra-low sulfur diesel fuel, are highly effective in reducing PM emissions, they have no effect on lowering NOx. The ideal system for diesel engines is one that also reduces NOx in addition to PM. Studies are underway to evaluate several potential NOx-reduction technologies, but, except for EGR, most of these technologies are not yet ready for commercial use. Popular in gasoline engines for many years, some diesel engine manufacturers are now using EGR technology on new engines to reduce NOx and meet emissions regulations.

On the retrofit side, where equipment is added to engines already placed in service, EGR is still in the developmental stage. The first demonstrations of EGR retrofits for transit buses are now

[6] Email from Mr. Paul Moon, TxDOT, May 30, 2003

being planned for Washington, DC, and New York City. The benefit of an EGR retrofit is that the system incorporates the use of a PM filter, which has already been proven in a transit bus environment. As a result, agencies could monitor the progress of retrofit EGR technology. If an agency decides to go with clean diesel technology that involves the use of a PM filter and ultra-low sulfur fuel, an EGR could then be installed if the technology proves itself as a viable retrofit technology for reducing NOx.

FUTURE EMISSIONS STANDARDS

Regarding the future of transit bus exhaust emissions, it should be noted that the 2007 EPA transit bus standards place Particulate Matter (PM) emissions at .01 grams per brake horsepower hour and NOx at 1.2. While diesel and the gaseous fuel engines comply with current EPA requirements, emissions from gaseous engines such as CNG and LPG have typically been cleaner than traditional diesel engines. The gap between diesel and gaseous emissions has been reduced substantially with the introduction of clean diesel engines equipped with PM filters using ultra-low sulfur fuel.

Because ultra low sulfur diesel fuel is not available in all areas, and PM filters need this fuel to operate effectively, the clean diesel approach is currently a voluntary one. However, as stated above, the EPA will mandate ultra-low sulfur fuel in 2006 and the 2007 EPA regulations will cause manufacturers to equip their engines with the PM filters to achieve the lower emissions levels.

Since the 2007 EPA emission standards are below those that either current gaseous or diesel engines are capable of achieving, both engine types will require additional technology to meet these extremely low emission levels. As a result of the technology applied to both engine types by 2007, diesel engines operating on commercially available ultra-low sulfur fuel and gaseous engines equipped with aftertreatment devices will virtually have the same emissions levels. In fact, it will be nearly impossible to detect any differences in emissions levels because the measuring equipment will not be capable of detecting the miniscule differences.

DIESEL/CNG EMISSIONS COMPARISON

Note: CNG is used in the example below because it is more popular than LPG (propane). As a result, CNG has been tested more extensively and emissions data is available. Like CNG, LPG is gaseous at room temperature and atmospheric pressure, engine fuel delivery systems are similar, and exhaust emissions are also comparable to those of a CNG engine. The example below is also based on larger diesel engines – again, data is available on these engines because of their popularity with larger agencies that have the research and development (R&D) budgets needed to conduct the testing. Although the data below are based on CNG and the use of larger engines, the results can be used to illustrate how the emissions of clean diesel are now on par with gaseous fuels.

Exhibit 3-1 below compares the emissions from 1989 model year diesel buses to newer 1998-01 buses with standard diesel engines, clean diesel engines (those with PM filter and ultra-low sulfur diesel fuel), and CNG engines. Model year 1998 to 2000 engines are used in the comparison because they were all certified to the same emissions standards. (EPA regulations changed for 2002 buses, but there are no known emissions data available for these newer buses.) Emissions from two buses are used to illustrate how different the actual in-service emission characteristics can be from two engines certified under the same emissions standard. The emissions are expressed in grams per mile, and all tests were conducted using the central business district (CBD) duty cycle for comparison purposes.

Exhibit 3-1
Diesel/CNG Emissions Comparison

Emissions	Existing Engine 1989 DDC 6v92-TA	1998-2001 MY Standard Diesel	1998-2001 MY Clean Diesel (PM filter aftertreatment operating on ultra-low sulfur diesel fuel)	1998-2001 MY CNG Engine
PM	0.6-1.9+	Bus #1 - 0.22* Bus #2 - 0.21*	Bus #1 - 0.04* Bus #2 - 0.01*	Bus #1 - 0.09* Bus #2 - 0.01**
NOx	40-45 +	Bus #1 - 25.6* Bus #2 - 23.3*	Bus #1 - 26.4* Bus #2 - 23.8*	Bus #1 - 44.0* Bus #2 - 16.5**
CO	N/A	Bus #1 - 1.8* Bus #2 - 2.1*	Bus #1 - 0.2* Bus #2 - 0.1*	Bus #1 - 20.0* Bus #2 - 11.3**

Notes: MY=Model year
All emissions expressed in grams per mile (gm/mi) using a central business district (CBD) route profile. Emissions results from two buses were used to show the variation in emissions results from one bus to another.

* Testing done under New York City Transit's Clean Diesel Vehicle Air Quality Project by Environment Canada Environmental Technology center, Ottawa, Ontario. Results reported in SAE-2002-01-0430

** Testing under California EC-Diesel Technology Validation Program by West Virginia University. Results reported in SAE-2002-01-0433

+ TCRP Report 38 (test cycle unknown)

As Exhibit 3-1 illustrates, clean diesel buses using a PM filter and ultra-low sulfur fuel are comparable to CNG with respect to PM emissions (0.01 gm/mi).

Concerning NOx emissions, the chart reflects the wide variation that CNG buses typically exhibit in actual service. Gaseous-fueled engines normally exhibit lower NOx emission levels compared to diesel when they are tested as new engines operating in peak mechanical condition. However, when engines accumulate mileage in revenue service, and fuel and ignition adjustments begin to deteriorate, NOx emissions tend to be higher in gaseous-fueled buses. Research shows that the emissions performance of CNG buses is quite sensitive to fuel system calibration.[7] A call to West Virginia University confirmed the higher average NOx levels for CNG buses. Its database of 1998 and newer CNG buses averaged NOx emission levels of 54.0 gm/mi.[8] Diesel engines do not suffer from the same type of in-service emissions degradation
because of the nature of diesel fuel delivery and its auto-ignition system (i.e., no ignition wires or other components to break down or fail). The New York City buses shown in Exhibit 3-1 had NOx levels in the 23-26-gm/mile ranges, compared to a low of 16.5 and a high of 44.0 for comparable CNG buses tested.

Concerning CO emissions, diesel shows a clear advantage over CNG (0.1-2.1 gm/mi for diesel compared to 11.3-20.0 for CNG)

COST DIFFERENCE BETWEEN DIESEL AND CLEAN DIESEL

Exhibit 3-2 provides a summary of the cost difference between diesel and clean diesel for the replacement of the Transmark RE-32 buses for the Wichita Falls Transit System. The cost difference for capital costs would be $69,800 and the annual operating and maintenance cost difference would be $2,800 annually in 2003 dollars. The $69,800 for PM filters includes 10 PM filters, including two spares, and expected installation costs. As explained earlier, the Environmental Protection Agency is not expecting much of a cost difference between diesel and clean fuels once production of the ULSD fuel is required in 2006. Therefore, in 2006 the cost diesel and clean diesel fuel are both projected to be $92,752.

[7] Arcardis, Geraghty & Miller, Inc Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operators, Transit Cooperative Research Program (TCRP Report 38) Washington D.C., 1998
[8] Telephone conversation with Ralph Nine, Program Coordinator, West Virginia University, April 2003.

Exhibit 3-2
Diesel versus Clean Diesel Costs
Replacement of Transmark RE 32 buses

Capital Costs

Year	2003			2006*		
Fuel Type	Diesel	Clean Diesel	Cost	Diesel	Clean Diesel	Cost
Number buses: 10-year	8	8	Difference	8	8	Difference
Vehicle type	30 foot low	30 foot low		30 ft. low	30 ft. low	
Add PM Filters only	None	$ 52,000	$ 52,000	None	$ 56,680	$ 56,680
Spares	None	$ 13,000	$ 13,000	None	$ 14,170	$ 14,170
Installation	None	$ 4,800	$ 4,800	None	$ 5,232	$ 5,232
Total capital costs	None	$ 69,800	$ 69,800	None	$ 76,082	$ 76,082
Operating and Maint., Annual						
Fuel costs	$ 85,093	$ 95,408	$ 10,314	$ 92,752	$ 92,752	$ -
Regular maintenance	$ 237,290	$ 237,290	$ -	$ 258,646	$ 258,646	$ -
Maintenance PM Filter	None	$ 2,800	$ 2,800	None	$ 3,052	$ 3,052
Total Operating and Maintenance	$ 322,383	$ 335,498	$ 13,114	$ 351,398	$ 354,450	$ 3,052

* Assumes 9% inflation between 2003 and 2006

IMPLEMENTATION CONSIDERATIONS

The City of Wichita Falls has one diesel bus on order as of 2003, and does not have a bus procurement scheduled in 2004. The fleet will continue to be predominantly diesel fuel until 2006.

When ultra low sulfur diesel becomes readily available in 2006, and the cost difference between diesel and ultra low sulfur diesel diminishes, then the City of Wichita Falls will transition to ultra low sulfur diesel fuel. The existing fleet can continue to operate on ultra-low sulfur fuel. The existing fueling tank for diesel fuel can be utilized for ultra low sulfur diesel fuel.

After 2006, when ultra low sulfur diesel fuel is available for the Wichita Falls fleet, then new bus procurements will include a PM filter to fully take advantage of the emission benefits of ultra low sulfur diesel fuel.

4. LIQUEFIED PETROLEUM GAS

OVERVIEW

Liquefied petroleum gas (LPG) is a by-product of both petroleum refining and natural gas processing, is gaseous at room temperature and atmospheric pressure, but it liquefies at greater than 120 psi. This property makes it convenient to store and transport LPG as a pressurized liquid. The stored liquid fuel is easily vaporized into a gas with clean- burning combustion properties similar to those of CNG. Approximately 60 percent of the LPG produced in North America comes from natural gas processing.

Processing removes most of the ethane and heavier HCs as well as carbon dioxide, which may exist in the wellhead, to produce a pipeline gas with a relatively consistent heating value. In North America, LPG is formulated to consist mainly of propane with minor amounts of propylene, butane, and other light HCs.

CAPITAL COSTS

It is commonly recognized that propane-powered buses cost more then diesel-powered buses. Information on new, used, and remanufactured buses is provided below.

New Buses

The price for a 30-foot low-floor LPG bus is $230,000 per bus in 2003 dollars. The cost for a 30-foot low-floor diesel bus is $200,000 per bus. Vehicle specifications, and smaller order size can increase or decrease the price by 10% or more. According to one manufacturer, the delivery date is approximately one year from order date.

Used Buses

The used market for LPG buses is not good. This is based on the review of the availability of used vehicles currently on the used bus market. In general, used vendors do not have 30ft-LPG buses available. Some agencies have converted public transportation fleets to alternative fuels, and therefore the availability of used high-floor diesel vehicles is excellent.

LPG Conversion from Diesel Vehicles

Complete Coach Works in Riverside California recently completed a conversion of diesel buses to natural buses for Fairfield Transit. The work entailed a complete remanufacturing of the bus, including:

- Rewiring the bus

- Installing new floors
- Reupholstering all seats and repairing all seat frames
- Installing all new lower inside panels and repainting
- Installing new engines and Transmissions
- Installing new LPG fuel tanks
- Repairing and repainting exterior and interior
- Reworking radiator to operate in temperatures up to 130 degrees

The total cost to convert Wichita Falls diesel powered 30ft. buses to LPG will be about $160,000, about $70,000 less than a new LPG bus in 2003 dollars. This price will fluctuate depending on the City of Wichita Falls detailed specifications, but the price is a good planning number. The conversion company claims that the remanufactured bus will be good for another 7 years. However, there is not enough industry experience with conversions to validate this claim.

VEHICLE FUEL ECONOMY

According to the primary LPG engine manufacturer, the Cummins B5.9 LPG engine is rated at 2.5 to 2.9 mpg. The flat topography of Wichita Falls and the operating characteristics will generally favor lower fuel consumption. However, to be conservative, we have used 2.7 miles per gallon for LPG.

IMPROVEMENTS TO MAINTENANCE FACILITY

There are no codes specifically governing the design of LPG maintenance facilities. Generally, LPG facilities are designed to meet the codes for maintenance garages for gasoline vehicles, per National Fire Protection Association NFPA 88B, the standard for Repair Garages, and NFPA 70, the National Electric Code. As with the other widely used alternative fuels, the Federal Transit Administration (FTA) has published a comprehensive reference on transit facility design requirements for LPG vehicles. Transit agencies interested in converting to LPG should utilize this document to guide their planning process and/or their operating procedures. Wichita Falls Transit shares a building with the City of Wichita Falls Public Service Department. The following are guidelines for the type of improvements that would be necessary to comply with NFPA88B, NFPA70 and OSHA.

Many agencies, particularly those with light-duty vehicles, operate in facilities designed for gasoline or diesel vehicles with little or no LPG modification, while other agencies make major modifications to enhance the safety of the facility. It should be noted that no amount of facility upgrades would displace the requirement for safe operating procedures. Several specific guidelines have been provided in the above sections. The preliminary cost estimate for providing garage facility modifications to accommodate LPG, based on experience elsewhere, is estimated at $15,000 in 2003 dollars.

Ventilation

Liquefied Petroleum Gas is heavier than air and therefore will descend from the leak source. As a result, LPG leaks typically accumulate at the floor level and in pits/trenches. Because LPG is heavier than air, ceiling-mounted ventilation systems are not needed. However, agencies must ensure that there is adequate floor-level ventilation, as would be required for a facility designed for gasoline vehicles. Additionally, agencies with pits or trenches should take precautions in those areas because LPG leaks will collect in these low-lying areas (see heating, electrical and gas detection sections below).

Fire extinguishers located throughout the maintenance facility are essential for starving a small LPG fire of oxygen. Equipping LPG buses with automatic fire suppression systems is recommended.

Heating and electrical units

- All maintenance shop heaters should be replaced with non-flammable infra-red heaters, especially those located near or below floor level.
- All light fixtures and electrical outlets should be explosion-proof, especially those located near or below floor level.

Gas Detection

- Handheld gas detectors could be used prior to work (especially in pits), and periodically to determine if a gas leak exists. Although gas is odorized to a level detectable by an average person, frequent or prolonged exposure can reduce a person's ability to detect the gas leak.

OPERATIONS AND MAINTENANCE COSTS

Fuel Costs

Fuel costs are typically higher for LPG vehicles than diesel vehicles. Operating costs for LPG buses relative to diesel buses depend primarily on fuel and maintenance costs. The cost of both LPG and diesel fuel has seen wide fluctuations in recent months, and this is likely to continue into the future. Exhibit 4-1 provides a comparison of LPG and diesel fuel costs for the eight Transmark RE-32 buses.

Exhibit 4-1
LPG and Diesel Fuel Cost Comparison

Transmark RE-32 Buses

Fuel Cost Input	Diesel	Clean Diesel	Propane
Number Vehicles	8	8	8
Annual Bus Miles	421,171	421,171	421,171
MPG	4.9	4.9	2.7
Gallons Per Year	85,953	85,953	155,989
Cost of fuel per gallon (2003)	$ 0.99	$ 1.11	$ 1.33
Annual Estimated Cost (2003)	$ 85,093	$ 95,408	$ 207,465
Cost of fuel per gallon (2006)*	$ 1.079	$ 1.079	$ 1.450
Annual Estimated Cost (2006)*	$ 92,752	$ 92,752	$ 226,137

* Assume 9% inflation rate between 2003 and 2006.
Clean diesel and diesel prices are assumed to be equivalent in 2006

The cost of fuel per gallon is based on the price paid in April 2003 by Wichita Falls Transit for diesel and by the Sherman-Denison transit agency for propane. Please note that TxDOT is paying only 68 cents per gallon equivalent in Wichita Falls as part of the statewide program, almost one-half the price paid in the Sherman-Denison area.

The Transit Cooperative Research Program, funded by the Federal Transit Administration, and administered by National Academy of Science's Transportation Research Board, developed a Guidebook for Evaluating, Selecting and Implementing Fuel Choices for Transit Bus Operations, commonly referred to as TCRP Report 38. The difficulty of assigning a price to propane fuel costs is summed up well in the TCRP Report 38:

"It is difficult to be precise about the cost of LPG because its available purchase prices depends on so many factors, such as whether the purchase is at the wholesale or retail level, the quantity being purchased, the timing relative to yearly and seasonal propane market fluctuations, the location within the United States, and state tax treatment.

Historically, the pretax wholesale price of propane has been somewhat less than (e.g. typically 75 percent of) the price of gasoline on an energy-equivalent basis (i.e. per

BTU). Also, because a portion of propane production is associated with petroleum refining, propane's price fluctuations usually correlate with those of gasoline and diesel fuel. On the average, since the early 1990s, the energy-equivalent price of propane has been increasing relative to the price of gasoline and diesel fuel, so LPG is now nearly as expensive as gasoline and is more expensive than diesel fuel."

The reason that the Sherman-Denison area transit system is paying almost twice as much as TxDOT can be largely explained by the wholesale price and contract rate that TxDOT has been able to negotiate because of high volumes purchased statewide.

According the TxDOT fleet manager in Wichita Falls, there is sufficient capacity to handle the Wichita Falls Transit fleet for fueling purposes. If Wichita Falls decides to go with propane, this fueling option should be explored. There would be the daily logistical cost of fueling at TxDOT and these costs would need to be accurately measured.

Therefore, since propane has been historically higher than diesel fuel, the Sherman-Denison fuel costs were utilized for propane fuel cost estimation in this analysis.

As explained earlier, the Environmental Protection Agency is not expecting much of a cost difference between diesel and clean diesel fuel once production of the ULSD fuel is required in 2006. Therefore, in 2006 the cost diesel and clean diesel fuel are both projected to be $92,752.

Maintenance Costs

TCRP Report 38 also recognized a common problem that still exists today: "Reliable data on maintenance costs impacts are limited." Overall, this national report concludes that the engine durability of LPG and diesel buses is about the same. According to the TCRP Report 38, maintenance costs for LPG buses are not well documented. LPG burns with less deposit formation than either gasoline or diesel fuel, which could result in less scheduled maintenance. LPG leaves no varnish or carbon deposit that can cause premature wear of pistons, rings and valves. LPG's cold-starting characteristics prevent much of the wear and crankcase oil dilution associated with liquid motor fuel starting and warm-up periods.

The Los Angeles Department of Transportation (LADOT) recently placed an order for sixty (60) low-floor 30ft LPG buses with El Dorado National bus manufacturer, which will give them about 160 LPG buses in service after this order is completed.

The reasons cited by LADOT for moving to LPG include a lower vehicle purchase price and greater compatibility with their contract operations. LADOT awards bus-operating contracts for periods of 3 to 5 years. They stated that if there is a change in contractors with a new contract award, LADOT is faced with the problem of finding, relocating, or constructing new CNG fueling facilities near the new contractor's operating base. LADOT has found it much easier and less costly to install or relocate LPG than CNG fueling facilities. LADOT estimated that maintenance costs are 15-20% higher for LPG than diesel buses.

Overall, the reasons for the increased costs are because the LPG engines are inherently more complex than diesel, fuel costs are higher, and engines require:

- Spark plugs, ignition wire sets, coils, etc.
- Carburetor-type fuel mixing systems
- Additional fuel system components
- Gas detection

While recognizing that the published data is not conclusive, a synthesis of the literature and discussions with maintenance practitioners point to approximately 15% higher maintenance cost for LPG over diesel buses. Maintenance costs for LPG vehicles would be approximately $273,000 per year in 2003 dollars, about $35,500 more than the existing diesel fleet.

TRAINING COSTS

The transition to LPG would initially require 16-24 more hours for each mechanic, assuming they already have basic gasoline engine training. This training should be free from Cummins engine manufacturing for Wichita Falls Transit with the purchase of new buses. Wichita Falls should budget about $ 5,000 for on-going training on LPG.

Training course objectives are:

- Identify and locate LPG components utilized on the bus.
- Identify and locate LPG components utilized on the engine.
- Define operation of LPG components utilized on the bus.
- Define operation of the LPG engine.
- Demonstrate skills required to troubleshoot and diagnose engine, mechanical, and electrical faults on LPG engine.

While this report has pointed out some differences in opinion on some of the cost items between LPG and diesel buses, sufficient training of mechanics is an area where there is unanimous consensus.

SUMMARY OF COST DIFFERENCE BETWEEN DIESEL AND LPG

The cost difference between LPG and diesel buses is $30,000 in 2003 dollars. The eight LPG 30-foot vehicles would cost $240,000 more to replace than diesel vehicles. Facility improvements, including maintenance facility safety improvements and a basic propane fueling station, would cost approximately $31,000.

On an annual basis, propane buses would cost $162,966 more per year (2003 dollars) than diesel buses to operate and maintain, assuming Wichita Falls transit develops its own fueling station, as shown in Exhibit 4-2.

Exhibit 4-2
Comparison of Diesel and Propane Costs
Replacement of Transmark RE-32 Buses

	2003			2006*		
	Diesel	LPG	Cost Difference	Diesel	LPG	Cost Difference
Capital Costs						
Number buses: 10 year	8	8		8	8	
Vehicle type	30 foot low	30 foot low		30 foot low	30 foot low	
Vehicle Replacement						
New bus	$1,600,000	$1,840,000	$ 240,000	$1,744,000	$2,005,600	$ 261,600
Remanufactured bus	$1,040,000	$1,280,000	$ 240,000	$1,133,600	$1,395,200	$ 261,600
LPG fueling station		$ 16,000	$ 16,000		$ 17,440	$ 17,440
Facility improvement		$ 15,000	$ 15,000		$ 16,350	$ 16,350
Operating and Maint. Costs (Annual)						
Fuel costs	$ 85,093	$ 207,465	$ 122,372	$ 92,752	$ 226,137	$ 133,385
Maintenance costs	$ 237,290	$ 272,884	$ 35,594	$ 258,646	$ 297,444	$ 38,797
Additional training costs		$ 5,000	$ 5,000	$ -	$ 5,450	$ 5,450
Total annual operating/maint. costs	$ 322,383	$ 485,349	$ 162,966	$ 351,398	$ 529,031	$ 177,633

* Assume 9% inflation between 2003 and 2006

APPENDIX A
FUELS NOT SELECTED FOR DETAILED STUDY

COMPRESSED NATURAL GAS

To obtain the volume needed to achieve vehicle range similar to diesel, CNG is compressed from the supply pipeline to a high pressure of about 3,000 to 4,000 pounds per square inch (psi) and stored on-board in tanks mounted on the roof or under the vehicle.

Pros:

- Best-established alternative fuel for transit
- Lower NOx and PM emissions than diesel (similar to LNG)
- Vehicle performance can be made similar to diesel (similar to LNG)

Cons:

- Engine- tuning sensitive to emissions performance (similar to LNG new engine technology is more reliable)
- On-board fuel storage requires 3,600 psi capability, which adds up to 3,000 lbs. per vehicle (LNG tanks are only about 800 lbs. heavier than diesel)
- Fast-fill, off-board fuel dispensing (which is needed to match fuel rates of diesel) requires compression
- Fuel dryers are needed to remove water from CNG fuel; filters needed to remove contaminates (both are not needed with LNG)
- CNG fueling station maintenance higher than any other fuel
- Facility safety requirements for dispensing and indoor maintenance (similar to LNG)
- The extensive infrastructure modifications and investments needed for CNG may be short-lived if fuel cells become a viable alternative
- Fueling facility capital costs for a 10 bus fleet are estimated to be about $345,000 for CNG
- Maintenance facility capital costs for both CNG and LNG modifications are estimated to be about $155,000 for a 10 bus fleet
- Incremental costs over diesel: $30,000 to $35,000 per vehicle (slightly higher than LNG)
- Bus maintenance costs about 15% higher than diesel (similar to LNG)
- 30% less fuel efficient compared to diesel[1]

Exhibit A-1 summarizes the properties of CNG and their implications for bus use.

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[1] Use of Alternative Fuels in Transit Buses, GAO, December 1999. The report by the General Accounting Office states that CNG is 20-40 percent less fuel efficient than diesel; for purposes here, we are using the mid-point or 30%.

Exhbit A-1
CNG Properties

Property	Implications for Bus Use
Relative Storage Volume	CNG requires substantially more volume to achieve a similar diesel range
Engine Ignition	CNG is difficult to compression ignite and requires spark plugs or other ignition devices. Diesel engines are self-igniting and require no such equipment.
Flammability	CNG is lighter than air and leaks will pool near ceilings of enclosed structures. Leaks can form flammable vapors, which can potentially ignite. Adequate ventilation is required to disperse the vapors quickly to prevent a possible explosion. Facilities require explosion-proof electrical outlets and other precautions. Diesel leaks do not form flammable vapors, and does not require similar precautions.

LIQUIFIED NATURAL GAS

LNG fuel is produced by cooling natural gas to about –259 degrees Fahrenheit and purifying it to the desired methane content. Before being fed into the bus engine, the LNG fuel is heated and vaporized. All commercially available LNG buses use an engine that was originally designed for CNG because the fuel enters the engine in a gaseous state. The higher storage density of LNG gives it an advantage over CNG in that it requires less on-board fuel storage capacity.

The extremely low temperature of the fuel, however, introduces some disadvantages. As the stored on-board LNG fuel begins to warm and vaporize, the resulting gas pressure will have to be bleed out of the tanks and into the atmosphere. This need to bleed off gas as the fuel warms also occurs with the off-board fuel storage tanks and, as a result, LNG must be used in a timely manner. In addition, the fuel nozzles have a tendency to ice up, and fuel handlers are required to wear protective clothing. The following are other pros and con of LNG fuels.

Pros:

- Fuel is widely available in certain regions
- Uses same engines as CNG-powered buses
- Lower NOx and PM emissions compared to diesel (similar to CNG)
- Almost pure methane eliminates problems associated with CNG contaminates
- Vehicle performance can be made similar to diesel buses (similar to CNG)
- Don’t have the fuel compression energy costs associated with CNG
- On-board fuel storage less weight than CNG and does not have the extremely high pressure characteristics associated with the storage of CNG

Cons:

- On-board tank weight about 800 lbs., heavier than equivalent diesel (but much less than CNG)
- 30% less fuel efficient compared to diesel (similar to CNG)
- Emission reduction sensitive to engine tuning (similar to CNG) (newer engines more reliable)
- As fuel warms up on-board the bus it vents as gas from tanks and escapes into atmosphere, which can be hazardous with indoor storage (not an issue if buses are used regularly)
- Cryogenic nature of fuel requires special fuel handling safety considerations (i.e., frostbite protection)
- Off-board storage also causes warming fuel to vent gas to atmosphere, wasting fuel. This is not an issue if fuel is delivered and consumed on a regular basis. Escaping gas can be captured and compressed as CNG if needed to fuel CNG vehicles (i.e., service vehicles)
- Pressure relief valves are essential; when warmed to room temperature confined LNG will vaporize and can develop pressures as high as 5,000 psi, which is higher than CNG (otherwise, typical LNG storage pressures much lower than CNG – up to 250 psi for LNG compared to up to 3,600 psi for CNG)
- Requires additional maintenance facility safety modifications (similar to CNG, i.e., explosion proof wiring/lighting, methane detector, etc.); Maintenance facility capital costs for both CNG and LNG modifications are estimated to be about $155,000 for a 10 bus fleet
- Fueling facility capital costs for a 10 bus fleet are estimated to be about $300,000 for LNG
- Conventional odorants, which allows humans to smell fuel leaks, developed for CNG are not effective at LNG’s low temperatures
- Incremental costs over diesel: $30,000to $35,000 per vehicle
- A national research project found that bus maintenance costs are about 8-15% higher than diesel.[2] In Texas, the agency with the most experience with LNG is Dallas Area

[2] TCRP Report 38, Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations, Transportation Research Board, 1998

Rapid Transit (DART). DART reports LNG bus maintenance costs are 8-10% higher than diesel buses,[3] which is consistent with the national research results.

Exhibit A-2 provides a summary of LNG properties and their implications for bus use.

Exhibit A-2
LNG Properties

Property	Implications for Bus Use
Relative Storage Volume	LNG requires about twice as much volume to achieve a similar diesel range
Engine Ignition	LNG is difficult to compression ignite and requires spark plugs or other ignition devices. Diesel engines are self-igniting and require no such equipment.
Flammability	Although LNG is stored as a liquid, it is converted to a gas before introduced to the engine. Gaseous characteristics are similar to CNG. Natural gas vapors are lighter than air and leaks will pool near ceilings of enclosed structures. Leaks can form flammable vapors, which can potentially ignite. Adequate ventilation is required to disperse the vapors quickly to prevent a possible explosion. Facilities require explosion-proof electrical outlets and other precautions. Diesel leaks do not form flammable vapors, and does not require similar precautions.

Hythane

Sunline Transit Agency is currently operating two hythane bus prototypes. These buses take commercial natural gas technologies and modify them for optimal performance with a mixture of hydrogen and natural gas. The addition of hydrogen to natural gas allows stable combustion at leaner air fuel mixtures. Leaner mixtures burn at lower temperatures. Since NOx formation is a function of combustion temperatures, lower NOx emissions are expected. The fueling infrastructure for hythane requires natural gas, hydrogen, compressors (3600 psi) and a blend/dispenser.

[3] Fuel for Thought, Bus Ride Magazine, March 2002

ALCOHOL BASED FUELS

Ethanol and methanol are both alcohol-based fuels.

Methanol

Methanol, referred to as methyl alcohol, is a clear and colorless liquid that can be made from a variety of sources including coal, natural gas, and various grains. The primary source is natural gas because it is the most economical means to produce the fuel. Methanol is typically sold as M100 (unblended) or M80 (blended with 15% gasoline).

Exhibit A-3 below summarizes the basic properties of Methanol and the implications for use as a bus fuel.

Exhibit A-3
Methanol Properties

Property	Implications for Bus Use
Relative Storage Volume	Methanol requires about twice the storage volume of diesel to achieve similar range
Engine Ignition	Methanol is difficult to compression ignite and requires spark plugs or other ignition devices. Diesel engines are self-igniting and require no such equipment.
Flammability	Higher flammability of Methanol requires adequate ventilation in facilities to prevent flammable concentrations of vapors. Spark arrestors required in fuel tanks to prevent possible vapor ignition. Ignition sources must be avoided at dispensing, storage and maintenance areas. The fuel burns with nearly invisible flames. Diesel does not require such precautions.

Pros:

- Vehicle performance similar to diesel buses
- Fuel is stored and shipped much like gasoline and diesel fuels
- Low combustion temperature results in low NOx emissions; also has low PM emission characteristics

<u>Cons:</u>

- Early demonstrations did not prove successful
- No known methanol-fueled buses are currently being used in US transit operations
- Agencies experienced very high maintenance costs and poor engine reliability with overhauls required at 45,000 miles
- More fuel required to achieve comparable diesel range; larger fuel tanks increase bus weight
- Corrosive nature of fuel requires special lines/hoses to carry fuel
- Steel storage tanks require cathodic protection
- Some fiberglass tanks may not be methanol compatible
- Typically requires vapor recovery system with flame arrestors to comply with environmental regulations
- Flame arrestors needed in bus fuel tanks to prevent possible in-tank ignition of fuel vapors
- Higher fuel volatility and flammability requires facility modifications similar to those required for gasoline; fuel vapors are heavier than air and require ventilation to prevent concentration and possible ignition
- Energy content of Methanol is 57,000 Btu/gal, compared to 128,7000 Btu/gal for diesel Special fuel handling (safety) training is required; toxic nature of fuel can cause serious health problems, even in small quantities if ingested; gloves and safety glasses required for dispensing
- Methanol runoff into sewers and drains must be disposed of separately (methanol can not be separated from water with conventional oil/water separators)
- Limited fuel supply infrastructure
- Vehicle capital acquisition costs higher than diesel due to extra fuel capacity and higher engine cost
- Extra fueling facility costs (about $460,000) due to need for corrosion resistance fuel supply components, extra fuel capacity, and vapor recovery system
- Extra maintenance facility costs (about $360,000 unless facility is already designed for gasoline vehicle maintenance); increased ventilation, classified electrical service (explosion proof) in low-lying areas (less than 18”), fire protection upgrades, flow to drains must be managed separately
- Methanol is not considered by many as a viable fuel for transit bus applications

ETHANOL

Ethanol (ethyl alcohol), also known as "grain alcohol," is a liquid that is typically produced by fermenting grains such as corn. Unlike hydrocarbon-based fossil fuels, Ethanol is a renewable fuel resource because it is made from agricultural feedstocks that can be grown. It is produced primarily in the corn-growing states of the Mid-West, and is sold for the most part as an additive to gasoline (gasohol). When used as fuel, ethanol is typically mixed with gasoline (15% =E85 or 5% = E95) to provide an adverse taste to prevent it from being consumed as an intoxicating drink. The gasoline mixture also makes the flames easier to see in a fire.

Exhibit A-4 summarizes the basic properties of Ethanol and the implications for use as a bus fuel.

Exhibit A-4
Ethanol Properties

Property	Implications for Bus Use
Relative Storage Volume	Ethanol requires more volume to achieve a similar diesel range
Engine Ignition	Ethanol is difficult to compression ignite and requires spark plugs or other ignition devices. Diesel engines are self-igniting and require no such equipment.
Flammability	Ethanol is considered the safest of alternative fuels. However, higher flammability requires adequate ventilation in facilities. Ignition sources must be avoided at dispensing, storage and maintenance areas. Flames are more visible than methanol, but are still difficult to see. Diesel does not require such precautions.

Pros

- Lower PM and NOx emissions, but not as low as Methanol
- Fuel is non toxic (but is considered a hazardous fuel because of flammability)
- Made from renewable sources

Cons

- Expensive fuel, only hydrogen is more expensive
- Energy content of Ethanol is 76,400 Btu/gal, compared to 128,7000 Btu/gal for diesel
- As a hazardous material, requires special training and handing
- Limited fuel supply infrastructure
- Higher fuel volatility and flammability requires facility modifications similar to those required for gasoline; fuel vapors require adequate ventilation to prevent concentration and possible ignition
- Special fuel handling (safety) training is required
- Higher vehicle capital acquisition costs due to extra fuel capacity and higher engine cost
- Extra fueling facility costs (about $460,000) due to need for corrosion resistance fuel supply components, extra fuel capacity, and vapor recovery system
- Extra maintenance facility costs (about $360,000 unless facility is already designed for gasoline vehicle maintenance); increased ventilation, classified (explosion proof) electrical service in low-lying areas (less than 18”), fire protection upgrades, (oil/water separators do not work with alcohol fuels)
- Price of ethanol related to crop prices, which increases when crop yields are low

BATTERY ELECTRIC PROPULSION

Several manufacturers in the 22-30 foot range offer battery-electric buses, where propulsion is provided solely by battery power. Advantages included lower noise levels, zero exhaust emissions from the vehicle, and no problems associated with cold-starts. Additionally, infrastructure requirements for re-charging the batteries are minimal compared to CNG and LNG.

Principal disadvantages include reduced range and performance, and higher purchase price compared to IC-powered buses. Batteries require special maintenance, and need to be replaced about every two years. Although improvements in battery technology have been made, on-board systems such as heating, air conditioning, and air brakes require battery power to operate, severely affecting vehicle range. Agencies with short routes (i.e., downtown shuttle operation) may benefit from battery-electric propulsion, while agencies with longer routes will find battery technology more difficult, in that vehicles would need to return during the day for re-charging or swapping battery packs.

Because most of the Wichita Fall’s routes exceed 200 daily miles, 100% electric vehicles are not a realistic option.

HYBRID-ELECTRIC TRANSIT BUSES

Overview

Hybrid-electric propulsion, where an auxiliary power unit (APU) such as a conventional internal combustion (IC) engine is used together with an electric motor to turn, or help turn, the vehicle's wheels, is gaining popularity in US transit bus applications. Although alternatively- fueled engines and other APUs are also being used in conjunction with hybrid-electric propulsion, the most popular application nationwide is the diesel hybrid-electric application.

Proponents of diesel hybrid-electric propulsion feel that alternative fuels such as compressed natural gas (CNG) and liquefied natural gas (LNG) are interim solutions that will be abandoned once dedicated electric propulsion, such as fuel cells and improved batteries, are perfected. As a result, they seek not to make the substantial infrastructure investments needed for fueling stations and fuel storage, safety, and other considerations needed to support these fuels. If fuel cells are ultimately the solution to bus propulsion, then hybrids also become an interim solution. However, since hybrid propulsion involves an electric drive element, proponents view hybrids as a bridge technology that prepares them for electric drive technology while eliminating the infrastructure expenses and safety concerns associated with alternative gaseous fuels.

While agencies such as New York City Transit Authority (NYCTA) claim many benefits from hybrid buses and show that emissions from its diesel hybrids are virtually identical to CNG buses, they admit that there is a reduction in bus availability due to technical problems. Although agencies such as NYCTA have the engineering resources, a large spare ratio to replace hybrid buses when repairs/modifications are needed, and have the clout to have hybrid equipment/bus manufacturers respond quickly to technical problems, smaller agencies might not have these advantages.

Background on Hybrid-Electric Propulsion

Hybrid-electric propulsion combines the benefits of proven IC engine technology with zero-emissions and regenerative braking (recapturing energy through vehicle braking) benefits offered by battery-electric technology. Contrary to popular belief, the concept is not a new one. Dr. F. Porsche, founder of the legendary automobile company that bears his name, first worked at a company in 1901 that specialized in the production of hybrid-electric cars where an IC engine charged batteries that propelled the vehicle.

The electric-hybrid concept was revitalized as the auto industry sought to meet regulations imposed during the Clinton Administration that attempted to maximize fuel efficiency and minimize exhaust emissions. In the transit bus industry, diesel hybrids appeal to many agencies because the technology allows them to utilize existing infrastructure while significantly reducing emissions.

Energy Storage Devices

The electric drive system used in hybrid-electric vehicles can draw energy from a number of devices. While batteries are most common, the flywheel and super capacitor are other forms of energy storage devices. A flywheel stores energy mechanically using a wheel or disc that spins rapidly in a vacuum. An additional motor and controller is needed to convert the electrical energy to mechanical energy and back again.

Super capacitors store energy by electrostatically separating and accumulating charges physically between internal plates. In hybrid vehicles, a super capacitor acts more like a load-leveling device (distributing electrical energy evenly to the drive system) than an energy storage device.

This working paper will refer to batteries as the energy storage device used in hybrid-electric buses because it is the most common and perfected method. (Additional battery information is provided in the "Technology Status" section below).

Benefits

The long-term benefit of hybrid-electric technology is that it allows for efficient propulsion by:

1) using battery power to relieve the power requirements of the IC engine
2) capturing and reusing energy that would normally be wasted through braking (called regenerative braking), and
3) allowing the IC engine to operate more efficiently.

These efficiencies translate into lower emissions and fuel consumption. In regenerative braking, the electric motor is used as a generator when the vehicle brakes, recovering energy normally lost in braking and feeding it back to help recharge the batteries. Presently, heavy-duty hybrid buses are capable of recovering about 30 percent of the vehicle's kinetic energy during regenerative braking. An additional emission reduction and fuel economy benefit comes from operating the IC engine in a steady-state mode, as opposed to constantly increasing and decreasing engine speed (which consumes more fuel and emits more emissions). In some applications, the IC engine is automatically shut off when battery power is sufficient to propel the vehicle, thereby reducing fuel consumption and related emissions.

Series versus Parallel Designs

There are two types of hybrid-electric propulsion systems: series and parallel. In a series configuration, the electric motor alone drives the wheels and the IC engine is not mechanically connected to the wheels. In this case, the IC engine is used to keep the batteries charged. In a parallel configuration, the electric motor and IC engine are both connected to the vehicle's drive wheels. Each configuration has its complexities and permutations. However, in general, the series configuration is best suited for stop-and-go duty cycles, while the parallel configuration is best suited for operation at higher speeds. Additionally, series configurations are compatible with fuel cells, while parallel configurations are not.

Gas Turbines

Gas turbines can also be used as the "engine" (auxiliary power unit - APU) in a hybrid-electric vehicle. A gas turbine engine uses a continuous combustion process much like a jet engine to operate a generator, which in turn provides electrical energy to batteries that power the vehicle. These engines are lightweight and have the advantage of operating on a variety of fuels including diesel and natural gas. They are challenged, however, by high manufacturing costs, slow responsiveness, and reduced energy efficiency. Gas turbines are only used currently in smaller buses, not full-size traditional transit buses.

Gasoline Engine Hybrid

In partnership with ISE Research of San Diego, Omnitrans in San Bernardino has developed two gasoline hybrid electric vehicles. A gasoline engine serves as the auxiliary power unit. According to ARB testing, the gas electric hybrid bus releases .62 grams per mile the electric hybrid diesel releases 14.05 grams per mile, and an electric hybrid CNG bus releases 14.34 grams per mile.

The same emission reduction occurs when measuring particulate matter (PM) emissions. An electric/gasoline hybrid bus releases no measurable particulate matter. An electrical/diesel hybrid and CNG bus both release approximately .03 grams per mile.

These vehicles should be considered prototypes. It is currently unclear whether major bus manufacturers will manufactures gasoline hybrid-electric vehicles in the near future.

Technology Status

Hybrid-electric vehicles have made substantial progress in recent years. Benefits include smoother and quicker acceleration, more efficient braking, improved fuel economy, and lower emissions. The greatest single challenge involves the batteries. Current lead acid batteries are inexpensive and reliable, and have a significant recycling infrastructure and manufacturing capability. However, the downsides to lead acid batteries include increased weight, reduced efficiency and life, and the need for regular maintenance. Newer battery technologies such as nickel metal hydride, nickel-cadmium (NiCd) and zinc-air batteries show promise, but each has its own set of advantages and disadvantages. Italy has developed a new battery that looks very promising for buses. As of this date, there are about 200 full size buses in Europe that are successfully using this battery and are performing quite effectively. Advantages for newer battery technologies include reduced weight, greater energy capacity, longer cycle life, and less maintenance. Disadvantages include higher cost due to rarity in construction and low production volumes. Regardless of the type of new battery technology, considerable improvements are needed with respect to energy storage, life expectancy, and cost reduction.

Agencies with hybrid vehicles, such as Omnitrans in the San Bernardino area, have reported some operating issues with batteries. The main problem is that the batteries need to warm up to operating temperature. For performances, this process takes approximately 45 minutes after pull out, which results with lower speed of about 30 to 43 mph for the first 45 minutes of warm-up period.

Detailed life-cycle cost comparisons are difficult to make because the technology and experiences are so new. As the technology matures, costs are expected to come down. Until then, however, agencies can expect to pay a premium to obtain and operate hybrids. Capital acquisition costs are down to about $400,000 for a full-size bus. The second largest cost is lead-acid battery replacements, which adds between $20,000 and $50,000 to the cost of owning and operating a hybrid bus over its 12-year lifetime. Despite the fact that batteries are being charged on-board the bus, they continue to have a limited life (require replacement about every three years). (Note: ongoing developments in battery technology will most likely result in changes to battery costs).

The largest unknown is the cost of maintenance, because agencies continue to experience "teething" problems with this relatively new technology application. The New York City Transit Authority (NYCTA), which has one of the largest hybrid-diesel-electric fleets, is experiencing a 50 percent AM peak availability for its hybrid buses, compared to 85 percent AM peak availability for its diesel fleet. Concerning mean distance (miles) between in-service failures, the NYCTA hybrid-electric fleet averages 1250 miles between failures, compared to 2250 miles for the diesel fleet.

There is not enough operating experience with hybrids to quantify the maintenance costs. In practice, hybrids are more costly to maintain due primarily to the prototype nature of the new technology. In theory, hybrids should be less costly to maintain than traditional diesel buses. Hybrid buses eliminate transmission repairs and extend brake lining life, two high-cost maintenance areas. However, hybrids add new components such as traction motors and inverters, which tend to be highly reliable in other transportation applications. Hybrids also introduce high electrical voltages, which require additional safety awareness and training. Actual maintenance cost for hybrids could be 10% lower or ten percent higher – more experience is needed to provide an accurate evaluation.

Emissions

Emissions are somewhat difficult to measure accurately because the current procedure for measuring emissions is based on testing the engine alone, and does not account for the entire vehicle. However, tests conducted by NYCTA, based on grams of emissions emitted per mile, show that diesel hybrid-electric buses are comparable to its CNG fleet.

Concerning particulate matter (PM) emissions (solid black soot), one model diesel electric-hybrid bus actually emitted slightly less PM emissions than the CNG bus, while another diesel electric-hybrid bus emitted slightly higher PM emissions than the CNG bus. Concerning nitrous oxides (NOx) and carbon monoxide (CO) emissions, both diesel electric-hybrid bus models produced less emissions that the CNG counterpart.

Current Availability

Hybrid technology application is divided into two groups: smaller, 22-foot buses with a 7-year life; and larger, heavy-duty buses with a 12-year life. Concerning the smaller buses, AVS of Chattanooga, Tennessee, which offers 22-foot hybrid electric buses, has very recently filed for Chapter 11 protection because of various financial and technical problems. AVS is planning 32- and 38-foot bus configurations, but these are new buses and have not undergone Altoona testing and have undergone little, if any, revenue service experience.

Ebus of Downey, CA, also offers a 22-foot hybrid bus with 22 passenger seats and room for 10 standees. Like the AVS product, Ebus is available with a Capstone micro-turbine engine that can operate on diesel, CNG, propane and other fuels. The 22-foot Ebus is a 7-year bus and has undergone Altoona testing. About six 22-foot Ebus Hybrids have been delivered to three transit agencies to date.

Ebus is planning a larger version of its hybrid that will consist of the standard 22-foot unit with a separate 22-foot trailer unit. The so-called “2-Bus” will carry 44 passengers and is expected for sale by the end of 2003. Ebus is also working on a 30-foot hybrid with a capacity of 30-32 passengers, which is expected in 2004. Like AVS, the larger Ebus versions represent new designs that have not undergone Altoona testing or revenue service experience.

Another company, ISE Research, had converted four 30-foot El Dorado buses as hybrids for LADOT, but numerous technical problems caused the buses to remain out of service.

Based on the research, it appears that the transit market lacks hybrid buses in the 30- to 35-foot size category. Manufacturers of heavy-duty, 12-year transit buses are concentrating their hybrid application efforts on the 35-foot and larger market. According to Gillig, the packaging required to accommodate a hybrid system will not fit comfortably in a smaller, 30-foot bus.

While this is a promising technology, it is currently not readily available in the small bus category that the City of Wichita Falls utilizes.

Pros:

- Improved vehicle range compared to CNG or LNG
- Can utilize a CNG auxiliary power unit to take advantage of existing CNG fueling station.
- Can also allow continued use of diesel, while obtaining similar emissions reductions as CNG/LNG

- Improved fuel economy and efficiency reduces dependency on fossil fuels
- Does not require substantial infrastructure investments (compared to CNG or LNG)
- Electric nature of hybrid propulsion serves as a logical transition to fuel cells, which appears to be the next propulsion technology (gives agency and maintenance personnel needed experience as the transition is made to fuel cells)
- Hybrids have the potential to lower Life Cycle Costs (LCC) over the life of the vehicle (fuel economy savings, extended brake lining life due to regenerative braking, etc.). More industry experience is required before these costs are known for certain

Cons:

- Technology is still not yet proven with many unknowns
- Initial purchase price and overall operating costs are currently higher for hybrids (this may come down, or remain high, over time – too many unknowns)
- High voltage requires additional agency and maintenance training
- Energy storage technology (batteries, super capacitors, flywheels, etc.) still not perfected and have many technical obstacles to overcome; additional development is required
- If lead acid batteries are used, there are extra costs involved with battery replacements and maintenance requirements
- While infrastructure requirements are minimal compared to CNG, there are some that may be significant depending on fleet size and on-board energy storage technology used. Potential infrastructure considerations include special diagnostic equipment, battery handling (i.e., forklift, crane, etc.) and charging, and electrical service upgrades to the facility (all infrastructure modifications should be under $200K).
- Increased bus weight

FUEL CELLS

All of the propulsion alternatives being used and considered today by transit agencies (CNG, LNG and hybrids) can be viewed as interim solutions until fuel cells become available. The question becomes which alternative (if any) best suits the agency's financial and operational needs until fuel cells are actually developed and perfected.

The announcement by the Bush Administration on January 9, 2002 to subsidize fuel cell development is seen by many as the beginning of the end for IC engines. The announcement changes the question from "if" the IC will be replaced, to "when" the replacement will occur. According to the CEO of General Motors, "no car company will be able to thrive in the 21st century if it relies solely on internal combustion engines." Every major automaker worldwide is in the process of developing fuel cell vehicles, including the so-called Big 3 of America (GM, Ford, Daimler-Chrysler) and those of Japan (Honda, Nissan, Toyota).

Fuel cells operate by harnessing the energy from a chemical reaction that combines hydrogen and oxygen to form water. The energy released by the oxidation of hydrogen to water is directly converted to an electric current. Fuel cells may be fueled by hydrogen directly, or may use reformers to generate hydrogen from methanol, natural gas, or other hydrocarbons (HCs) with water.

An extremely complex technology, fuels cells can provide propulsion in a variety of ways. As a hybrid, the fuel cell acts like the "engine" in a conventional hybrid vehicle where electrical energy produced by the fuel cell is delivered to an energy storage/load leveling device (i.e., battery). As a pure fuel cell vehicle, electrical energy is delivered directly to the drive wheels.

SunLine Transit in California has received funding for a fuel cell bus demonstration project. This will provide the industry with research and development information on the potential use of fuel cells for bus propulsion.

Pros

- Promising technology has caught the attention of the Bush Administration, which will increase development activities
- Has the potential to eliminate many of the complications currently associated with engines and generators of hybrids
- Zero emissions (only water emission if hydrogen is used as fuel source)
- Studies have shown fuel cells to be 45% more efficient than traditional diesel engine

Cons

- There are several major technology hurdles to overcome if fuels cells are to become viable for transportation use
- Wide-scale use of fuel cells not expected for another 7-10 years
- Technology hurdles include how the hydrogen is to be supplied and stored on-board the bus. Others downsides include high cost, poor reliability, and large size and weight.
- Hydrogen infrastructure and safety concerns

APPENDIX B

WICHITA FALLS MPO
UPDATE OF THE WICHITA FALLS TRANSIT SYSTEM
2003 ALTERNATIVE FUELS STUDY

1. BACKGROUND

EXISTING WICHITA FALLS TRANSIT OPERATIONS

In 2003, the Wichita Falls Transit System (WFTS) operated six route deviation/demand response routes. In 2008, WFTS added a new route called "The Connector", which links the Sikes Senter Mall transfer point with the temporary downtown transfer station located at 4th and Burnett Streets. As of this writing, WFTS continues to operate all seven routes. WFTS operates routes One, Two, Four, and Seven Monday through Friday from 5:00am to 7:00pm and on Saturday from 10:00am to 5:00pm. Routes Three and Five operate Monday through Friday from 5:30am to 7:30pm and on Saturday from 10:30am to 5:30pm. Route Six, the Sheppard Express route, operates 7 days a week and has various hours. Exhibit 1-1 below profiles the operating characteristics of each route.

Exhibit 1-1

Wichita Falls Transit Operations Profile

Route	Description	Weekday Hours	Saturday Hours	Annual Passengers	Annual Miles
Route 1/Blue	Eastside	5:00am - 7:00pm	10:00am - 5:00pm	48,950	61,126
Route 2/Red	Central	5:00am - 7:00pm	10:00am - 5:00pm	40,654	61,450
Route 3/Green	Southeast	5:30am - 7:30pm	10:30am - 5:30pm	37,380	66,453
Route 4/Yellow	North	5:00am - 7:00pm	10:00am - 5:00pm	28,247	83,224
Route 5/Brown	Southwest	5:30am - 7:30pm	10:30am - 5:30pm	28,472	64,638
Route 6/Orange	Sheppard Express	6:30am - 9:30pm	9:30am - 11:30pm	108,012	142,619
Route 7/Purple	Downtown Connector	5:00am - 7:00pm	10:00am - 5:00pm	52,960	49,646

The data provided by the Wichita Falls Transit System clearly shows that Route Six, the Sheppard Express route, travels more than 350 miles every day between Sheppard Air Force Base and Sikes Senter Mall, thus making this route the most heavily used route in the system. Exhibit 1-2 shows the maximum daily number of miles traveled on all WFTS routes.

Exhibit 1-2

Maximum Daily Miles per Route

Route	Description	Maximum Daily Miles
Route 1/Blue	Eastside	222
Route 2/Red	Central	222
Route 3/Green	Southeast	238
Route 4/Yellow	North	300
Route 5/Brown	Southwest	231
Route 6/Orange	Sheppard Express	354
Route 7/Purple	Connector	179

In 2003, the average fuel consumption of diesel fuel per WFTS bus was 40 gallons per day with a tank capacity of 100 gallons. Today, the average fuel consumption is 44 gallons per day with a tank capacity of 111 gallons. The additional 4 gallon per day per bus fuel consumption is because WFTS replaced ten of its aging 30-ft, wheelchair lift buses with newer, more modern, 35-ft, kneeling, low-floor models.

As stated earlier, in 2008 WFTS added Route 7 “The Connector” to link together the Sikes Senter Mall and downtown transfer points. This new route contributes heavily to the increase in ULSD fuel consumption.

FLEET CHARACTERISTICS

Exhibit 1-3 below provides a profile of the 14-bus fleet operated by the Wichita Falls Transit System. The majority of buses are the new G27B102N4 low-floor buses that replaced the Transmark RE wheelchair lift buses in 2009.

Exhibit 1-3

WFTS Bus Fleet

Unit Number	Model Year	Vehicle Model	Engine	Vehicle Rating	Vehicle Replacement Year
460	2006	Transmark RE	Cummins ISB	10 year	2016
461	2006	Transmark RE	Cummins ISB	10 year	2016
462	2009	G27B102N4	Cummins ISL	12 year	2021
463	2009	G27B102N4	Cummins ISL	12 year	2021
464	2009	G27B102N4	Cummins ISL	12 year	2021
465	2009	G27B102N4	Cummins ISL	12 year	2021
466	2009	G27B102N4	Cummins ISL	12 year	2021
467	2009	G27B102N4	Cummins ISL	12 year	2021
468	2009	G27B102N4	Cummins ISL	12 year	2021
469	2009	G27B102N4	Cummins ISL	12 year	2021
470	2012	G27B102N4	Cummins ISL	12 year	2021
471	2012	G27B102N4	Cummins ISL	12 year	2021
476	2002	Transmark RE	Cummins ISB	10 year	2012
495	2004	Transmark RE	Cummins ISB	10 year	2014

EXISTING ALTERNATIVE FUEL INFRASTRUCTURE

There are only three alternative fuel types in Wichita Falls to choose from; they are Propane, Ethanol, and Biodiesel. In 2003, TxDOT developed a network of 200 propane-fueling stations statewide, including one in Wichita Falls. Today, there are four propane-fueling stations located in Wichita Falls.

2. OVERVIEW OF ALTERNATIVE FUELS

In 2003, The Wichita Falls Transit System completed a fuel study that consisted of these fuel alternatives:

- Internal combustion engine: diesel, compressed natural gas (CNG), and liquefied petroleum gas (LPG) fuel.
- Battery Propulsion
- Hybrid-Electric Propulsion

- Fuel Cells

Since 2003, these new technologies have come along:

- Biodiesel
- Diesel Exhaust Fluid (DEF)
    - DEF is added to Ultra Low Sulfur Diesel (ULSD) to produce a cleaner diesel burn

Biodiesel

Biodiesel is a domestically produced, renewable fuel that can be manufactured from new and used vegetable oils, animal fats, and recycled restaurant grease. Biodiesel's physical properties are similar to those of petroleum diesel, but it is a cleaner-burning alternative. Using biodiesel in place of petroleum diesel reduces emissions. Using biodiesel as a vehicle fuel increases energy security, improves public health and the environment, and provides safety benefits.

Biodiesel improves fuel lubricity and raises the cetane number of the fuel. Diesel engines depend on the lubricity of the fuel to keep moving parts from wearing prematurely. One unintended side effect of the federal regulations, which have gradually reduced allowable fuel sulfur to only 15 ppm and lowered aromatics content, has been to reduce the lubricity of petroleum diesel. To address this, the ASTM D975 diesel fuel specification was modified to add a lubricity requirement (a maximum wear scar diameter on the high-frequency reciprocating rig [HFRR] test of 520 microns). Biodiesel can impart adequate lubricity to diesel fuels at blend levels as low as 1%.

Biodiesel is nontoxic. It causes far less damage than petroleum diesel if spilled or released into the environment. It is safer than petroleum diesel because it is less combustible. The flashpoint for biodiesel is higher than 150°C, compared with about 52°C for petroleum diesel. Biodiesel is safe to handle, store, and transport.

The only Biodiesel fueling station in Wichita Falls is located at Sheppard Air Force Base.

Diesel Exhaust Fluid (DEF)

In 2012, the Wichita Falls Transit System began using DEF in its two new gillig buses to produce a cleaner burning fuel. It is a nontoxic solution of 67.5% purified water and 32.5% urea. When injected into hot exhaust as a fine mist and passed over a catalyst, DEF helps convert NOx into nitrogen gas and water vapor. It is stable, colorless, and odorless, and meets accepted international standards for purity and composition.

The raw materials used to produce DEF include natural gas, coal or other petroleum products. DEF and similar urea-based products are widely used today for a variety of agricultural and industrial needs. Fleet guard DEF meets ISO22241 specifications for purity and composition, while being:

- Non-toxic and non-polluting
- Non-flammable
- Stable and colorless
- Non-hazardous
- Does not require special handling

Battery Electric Propulsion

In 2003, the Alternative Fuel Study conducted by Transit Resource Center reported that due to WFTS vehicle mileage requirements, 100% electric vehicles were not a realistic option for Wichita Falls. [1]Now, in 2012, electric buses allow for longer-range capabilities. Because of the intense use of buses, this allows for a quicker recovery of the capital invested in expensive batteries. Transit buses have predictable routes so range anxiety is not much of an issue. These newer buses now have the capability to charge their batteries while on route and to utilize quick-charge stations while passengers board the bus. Since city governments own transit buses, it might be possible to incorporate non-financial benefits into the decision of purchasing electric buses.

The new EBus is a plug-in, hydrogen fuel cell bus. The cost is approximately $600,000 per vehicle or $495,000 with the purchase of four or more. The electric motor drives the rear axle instead of an internal combustion engine. The bus receives power from the battery system via an inverter. In a fuel cell bus, fuel cells can charge the battery system continuously with no requirement to connect to an external charger. However, the amount of hydrogen available limits the driving range. The bus can also charge the battery using an optional fast-charger and operate in battery-electric mode with the fuel cell turned off.

Hydrogen fuel continues to emerge as a long-term solution. Hydrogen fuel cell technology extracts the most common element, hydrogen, from natural gas or the electrolysis of water. The approximate mileage between charges is 45 miles and a quick charge takes approximately 30 minutes. The life expectancy of a fuel cell is 2,000 cycles. The 22-ft EBus starts at $295,000. The fast-charger costs $59,000 and can support multiple busses.

[1] Ebus.com and http://ebus.com/Brochure.pdf

Hybrid Electric Buses

Hybrid electric buses are good for transit systems requiring greater range than battery-electric propulsion. They offer an ultra-low emission micro-turbine as an onboard hybrid generator. The only limitation to range is the amount of fuel in the tank. There are two versions of the micro-turbine: one operates on HD-5 propane and the other on ultra low sulfur diesel (ULSD) fuel, the same fuel used by the WFTS fleet.

How much do hybrid buses cost? Small hybrid electric buses start at $325,000 but can cost up to $500,000 for the size needed by medium to large transit systems, a significant increase over a standard diesel transit bus, the cost of which is closer to $350,000.

Exhibit 2-1 is an overview of the primary components, main fuel source, energy content, and energy ratio of seven different types of natural gas and alcohol based fuels.

Exhibit 2-1

Overview of natural gas and alcohol based fuels. [2]

	Biodiesel	Compressed Natural Gas (CNG)	Electricity	Ethanol (E85)	Liquefied Natural Gas (LNG)	Liquefied Petroleum Gas (LPG)	Methanol (M85)
Chemical Structure	Methyl esters of C16-C18 fatty acids	CH4	N/A	CH3CH2OH	CH4	C3H8	CH3OH
Main Fuel Source	Soy bean oil, waste cooking oil, animal fats, and rapeseed oil.	Underground Reserves	Coal; however, nuclear, natural gas, hydroelectric, and renewable resources can also be used.	Corn, Grains, or agricultural waste	Underground Reserves	A by-product of petroleum refining or natural gas processing.	Natural gas, coal, or, woody biomass.
Energy Content per Gallon	117,000-120,000 Btu	33,000-38.000 Btu @ 3000 psi; 38,000-44,000 @ 3600 psi	N/A	~80,000 Btu	~73,500 Btu	~84,000 Btu	56,000-66,000 Btu
Energy Ratio Compared to Gasoline	1.1 to 1 or 90% (relative to diesel)	3.94 to 1 or 25% at 3000 psi; 3.0 to 1 @ 3600 psi		1.42 to 1 or 70%	1.55 to 1 or 66%	1.36 to 1 or 47%	1.75 to 1 or 57%
Liquid or Gas	Liquid	Compressed Gas	N/A	Liquid	Liquid	Liquid	Liquid

[2] Overview of fuels chart taken from http://www.afdc.energy.gov/afdc/pdfs/afv_info.pdf

3. CLEAN DIESEL

The Wichita Falls Transit System currently uses ULSD as its primary fuel source and has since 2006. Prior to 2006, WFTS operated the fleet on regular diesel fuel. In 2003, regular diesel fuel cost $.99 per gallon while ULSD cost $1.11 per gallon. Adjusting for inflation, the real cost for one gallon of ULSD fuel in 2012 was $2.98, which was almost identical to the nominal cost of a gallon of ULSD sold in 2003.

Exhibit 3.1 illustrates the effects of replacing older diesel buses with newer ULSD buses. Exhibit 3.2 charts the nominal versus real cost increase for diesel fuel adjusted for inflation.

Exhibit 3-1[3]

ANNUAL REDUCTIONS FROM REPLACING OLDER DIESEL BUSES WITH NEW BUSES		Number of Buses	Reduction in Annual Fuel Use	Reduction in Annual Emissions					
				NOx	PM	CO	HC	TOTAL CO2-e	
								CH4 & BC GWP_{100}	CH4 & BC GWP_{20}
			[DGE]	[kg]	[kg]	[kg]	[kg]	[MT]	[MT]
ANNUAL REDUCTION Per BUS	New Diesel	1	0	495.3	27.5	273.0	42.1	14.0	45.3
	New CNG	1	(990)	419.7	27.9	(60.8)	47.1	20.7	21.5
ANNUAL REDUCTION per $10 mill CAPITAL[1]	New Diesel	25.6	0	12,698.8	704.6	6,999.5	1,079.0	359.3	1,162.5
	New CNG	20.6	(20,376)	8,639.8	574.5	(1,251.2)	969.9	425.8	443.2

Note 1 Capital cost per bus, including cost of fueling infrastructure.

	Bus	Fuel Infra	TOTAL
Diesel =	$390,000	$0	$390,000
CNG =	$460,000	$25,800	$485,800
Source	*2010 APTA Database*	*NREL/TP-7A2-47919*	

[3] New Diesel is ULSD

Exhibit 3.2[4]

Real Prices Viewer

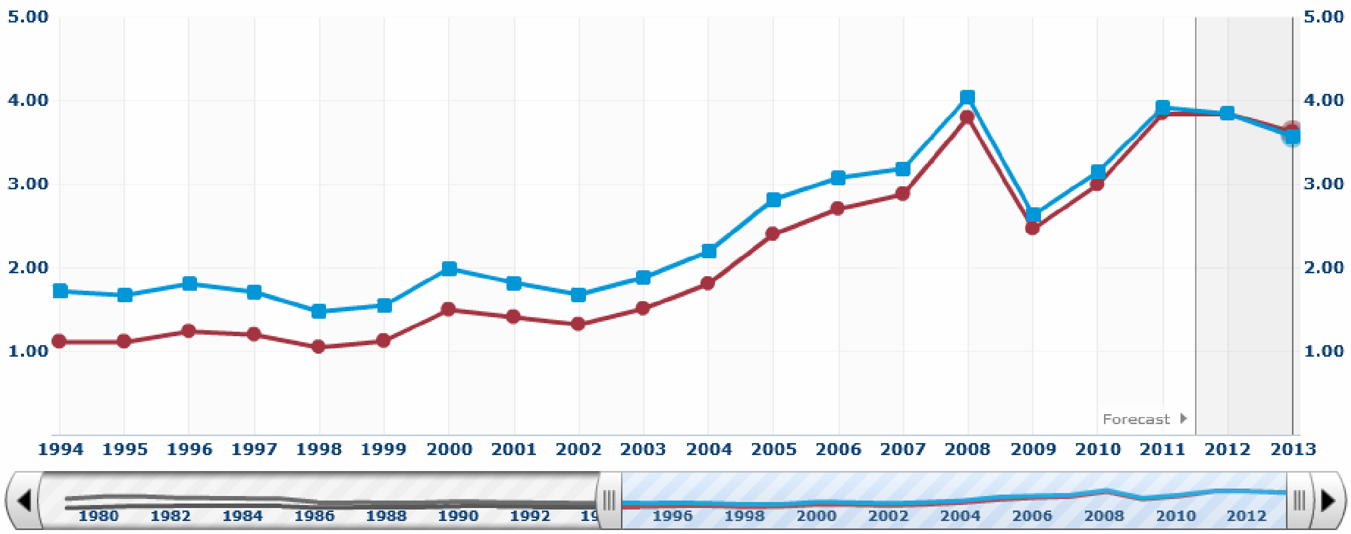
Real Petroleum Prices are computed by dividing the nominal price in a given month by the ratio of the Consumer Price Index (CPI) in that month to the CPI in some "base" period. The Real Petroleum Prices spreadsheet and charts are updated every month so that the current month is the base period in the monthly price series. Consequently, all real prices are expressed in "current" dollars and any current month price may be compared directly with any past or projected real prices.

Download all real and nominal price series to an Excel Spreadsheet (XLS file)

Price Series: Diesel Fuel Retail Prices

Period Type: Annual Quarterly Monthly

Date: 2013 **Nominal:** $3.62 **Real:** $3.58 Units: **Dollars Per Gallon**



[4] Chart taken from http://www.eia.gov/forecasts/steo/realprices/

CAPITAL COSTS

Exhibit 4-1 below illustrates actual Wichita Falls Transit System (WFTS) ultra low sulfur diesel (ULSD) fuel consumption costs compared to equivalent Compressed Natural Gas (CNG) costs. While CNG fuel costs less per gallon, consumption is more than double that of ULSD thus increasing annual fuel costs by more than $28,000 per year. The increased consumption would negate any cost savings from buying CNG fuel.

Exhibit 4-1

Fuel Cost Input	Clean Diesel	CNG
Number of Vehicles	14	14
Annual Miles	552,238	552,238
MPG	5.5	2.6
Gallons per Year	100,406	212,399
Cost of Fuel/Gal	$4.12	$2.08
Annual Fuel Costs	$413,672.72	$441,789.92

In 2003, the price for a 30-ft, wheelchair lift equipped, standard diesel bus was $230,000. In 2012, the price for a 35-ft, 500,000-mile, low-floor, ULSD bus was $350,000 while an equivalent 35-ft, Compressed Natural Gas (CNG) bus would cost $390,000. Exhibit 4-2 on the next page illustrates (1) the total capital cost differential between a 14-unit ULSD bus fleet – the current number of units operated by WFTS – and a 14-unit CNG bus fleet, and (2) the total annual operating and maintenance costs of the same units.

In terms of capital investment, it would cost the City of Wichita Falls an additional $560,000 to purchase the same number of CNG buses as ULSD buses. That is nearly the purchase cost of two new ULSD buses. Furthermore, on the capital side of the equation, it would require the City of Wichita Falls to spend $1,730,000 on the construction of a CNG fueling station and improvements to the existing bus repair facility. CNG fuel costs and increased maintenance costs would require an additional $165,000 per year investment as well. In summation, it would cost the City of Wichita Falls an additional $2.45 million to transfer from a ULSD bus fleet to a CNG powered fleet.

Exhibit 4-2

Capital Costs	Clean Diesel	CNG	Cost Difference
No. of 12-yr Buses	14	14	
Vehicle Type	35-ft. low-floor	35-ft. low-floor	
Vehicle Replacement/New	$4,900,000.00	$5,460,000.00	$560,000.00
CNG Fueling Station		$1,200,000.00	$1,200,000.00
Facility Improvements		$530,000.00	$530,000.00
Total Capital Cost Difference			$2,290,000.00
Operating & Maintenance Costs (Annual)			
Fuel Costs	$413,672.72	$441,789.92	$28,117.20
Maintenance Costs	$298,320.00	$435,225.00	$136,905.00
Training Costs		$10,500.00	$10,500.00
Total Annual Operating & Maintenance Costs			$175,522.20

Conclusion

In accordance with Subtask 5.4 of the 2012 Unified Planning Work Program, the Wichita Falls Metropolitan Planning Organization conducted an in-house update of the 2003 alternative fuels study for the Wichita Falls Transit System (WFTS). In 2012, WFTS began adding Diesel Exhaust Fluid to the Ultra-Low Sulfur Diesel buses making them operate on a cleaner form of fuel. In 2010, WFTS purchased eight new ULSD buses averaging about $365,000 per bus. The new ULSD fueled buses raised the level of service provided by WFTS while lowering Particulate Matter (PM) emissions. Customers appreciate the easy accessibility of the new buses, especially ADA handicapped and wheel chair bound passengers.

In comparison from 2003 to 2012, the only noteworthy changes to alternative fuels were in Biodiesel and Battery Electric Propulsion. The significant change for these two fuels was in the technology used to produce them. In the 2003 fuel study, Biodiesel was not available as a fuel alternative for the Wichita Falls Transit System. In fact, it was uncommon and quite expensive. Recent changes to this technology caused WFMPO to add this alternative to the study update for 2012. However, WFMPO found the cost was 50% to 150% more than ULSD diesel. Battery Electric Propulsion has seen improvement since 2003 but still has disadvantages such as reduced range and performance. This alternative is not viable for WFTS because of the requirement for a long-range vehicle. With no significant change in route range, and limited alternative fueling stations in Wichita Falls, the ULSD option is still the best option for WFTS.