TRANSIT RESOURCE CENTER

Imperial County Alternatives Fuels Impact Analysis

Final Report

To:

Imperial Valley Association of Governments

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EXECUTIVE SUMMARY

STUDY PURPOSE

The purpose of this study is to provide the Imperial Valley Association of Governments (IVAG) and Imperial County the information necessary to make decisions on the propulsion systems and alternative fuel types for future Imperial County Transit buses. Several developments and processes have provided important rationales for this study:

- In June 2000, a new compressed natural gas (CNG) fueling station opened in El Centro with the capacity to fuel seven buses. The Air Pollution Control District (APCD) has encouraged Imperial County Transit to convert its fleet to CNG. Before deciding on the future fleet configuration, IVAG and Imperial County want to know what the cost will be to undertake, and sustain, a conversion to alternative fuels for Imperial County Transit.
- A Federal Transit Administration (FTA) Section 5309 grant of $247,000 was awarded to Imperial County to develop a CNG maintenance facility for buses. Unless the funds are utilized, they will be de-obligated in September 2004. IVAG needs to know the future bus fuel types before proceeding with the grant.
- IVAG is undertaking a separate study of the design of a local bus system within the City of El Centro. The propulsion system and fuel types for this proposed new service need to be evaluated.
- IVAG is putting the operations and maintenance contract for Imperial County Transit out to bid in mid-2003. IVAG needs to know the propulsion system and fuel type to include in its bid package.

This study was intended to provide decision-makers with the information necessary to make informed decisions on each of the above issues. No recommendations are made on a specific propulsion system or fuel type for future bus procurements.

AIR QUALITY STATUS

Imperial County is in the Salton Sea air basin, as defined by the California Air Resources Board (ARB). Both the State of California and the Federal Government have established air quality standards. The air quality standards have been established for determining the "concentration above which the pollutant is known to cause adverse health effects to sensitive groups within the population, such as children and the elderly."

Two important standards are for PM10 and Ozone. Particulate matter (PM) is a complex mixture that consists of dry solid fragments, solid cores with liquid coatings, and small droplets of liquid. Imperial County is in a moderate nonattainment area for PM10 for state standards and is in an attainment area for federal standards. The State Air Resources Board projects an increased trend in PM10 emissions.

Ozone is a colorless gas with a pungent odor and is the chief component of urban smog. Ozone is not directly emitted as a pollutant, but is formed in the atmosphere when hydrocarbon and NOx precursor emissions react in the presence of sunlight. For ozone, the Salton Sea Air Basin is designated a moderate nonattainment area for state standards and is in a transitional (moderate) category under federal standards. Per the California Health and Safety Code, the APCD can adopt "reasonably available transportation control measures sufficient to substantially reduce the rate of increase in passenger vehicle trips and miles traveled per trip if the district contains an urbanized area with a population of 50,000 or more."[1] Such transportation control measures could include the requirement for alternative fuel buses at a future date.

ARB is forecasting a downward trend in NOx emissions, the precursor to ozone. In 1995, 45 tons per day were emitted and the emissions are projected to decline to 34 tons per day in 2010.[2]

OVERVIEW OF PROPULSION SYSTEMS AND ALTERNATIVE FUELS

A wide range of propulsion and fuel alternatives for buses was evaluated for application in Imperial County. These include:

- Internal combustion engine: diesel, compressed natural gas (CNG), liquefied natural gas (LNG) fuel and alcohol based fuels
- 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 compressed natural gas were selected for further detailed study.

CLEAN DIESEL

Diesel engines offer high efficiency, low maintenance and long life, but concerns over harmful exhaust emissions have resulted in a significant research and development effort 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.

Exhaust from diesel-fueled engines has been reduced significantly during the last 10 years.[3] Lower emissions levels can be attributed to three major factors:

- increasingly stringent emission regulations for buses

[1] California Health and Safety Code 40918 a3.
[2] ibid.
[3] American Public Transportation Association

- 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 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.

In order to reduce emissions of diesel even further to provide the cleanest possible diesel, two strategies are currently available:

- Diesel aftertreatment technology
- Ultra low sulfur diesel fuel

When referring to the term “clean diesel” in this report it includes both the use of diesel aftertreatment technology and ultra low sulfur diesel fuel.

Diesel engine manufacturers face 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 are concentrating their efforts on reducing NOx emissions through in-engine modifications, while reducing PM emissions through the use of so called “aftertreatment” devices (i.e., add-on equipment that treats the exhaust gas after it leaves the engine). These devices typically take the place of the muffler as a direct replacement. They cost $6,500 per bus and can easily be installed on older buses.

An oxidation catalyst is one aftertreatment device currently used in diesel engines to help reduce PM emissions to levels that 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). Similar to the oxidation catalyst, the PM filter replaces the standard muffler. PM filters work by “trapping” the solid particulate matter contained in the exhaust stream using a precious metal catalyst that oxidizes the collected particulate matter. Use of PM filters, however, requires diesel fuel with low sulfur levels, which is not commercially available yet in all areas, including Imperial County.

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 <u>it requires low sulfur diesel fuel</u> 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 also 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]

The EPA will mandate ultra-low sulfur fuel in 2006, similar to the way unleaded fuel was mandated for automobiles. Until then, however, ultra-low sulfur fuel may not be available in all areas. According to several diesel fuel suppliers, ultra-low sulfur fuel is currently not available in El Centro. It is only being refined by ARCO in Los Angeles and the distribution network is not available. In discussions with the current supplier of fuel for Imperial County Transit, the fuel can be ordered and trucked to El Centro. A specific price proposal would need to be prepared, but the supplier estimated the cost would be approximately 4-6 cents more per gallon.

COMPRESSED NATURAL GAS

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

Pros:

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

Cons:

- Engine-tuning sensitive to emissions performance
- On-board fuel storage requires 3,600 psi capability, which adds up to 3,000 lbs. per vehicle
- Fast-fill, off-board fuel dispensing (which is needed to match fuel rates of diesel) requires compression
- Facility safety requirements for dispensing, as well as indoor maintenance
- Incremental costs over diesel: $30,000 to $35,000 per vehicle
- Bus maintenance costs about 15% higher than diesel
- 30% less fuel efficient compared to diesel[5]

[4] ibid.
[5] *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%.

The cost difference between manufacturing diesel and CNG buses has declined over the years. For recent bus procurements, the cost per bus for a standard high floor 40 foot, 12-year rated CNG bus is about $325,000, compared to $295,000 for a standard diesel bus. Vehicle specifications, smaller order size and manufacturing competitiveness can increase or decrease the price by 10% or more. The Air Pollution Control District has a program for subsidizing the difference between diesel and CNG vehicle costs. The program is subject to fund availability.

SUMMARY OF COSTS

Exhibit ES-1 provides a summary of the capital and operating and maintenance costs for diesel, clean diesel, and CNG for a combined fleet of 15 buses for Imperial County Transit and the prospective El Centro Shuttle. CNG has the most expensive capital costs, with a replacement cost of $4.8 million for new buses and $4.0 million for remanufactured buses. For clean diesel, new clean diesel buses would cost $339,000 less than CNG for new buses, and $1.51 million less for remanufactured buses.

The operating and maintenance costs are generally equivalent between clean diesel and CNG. Historically, CNG fuel costs have been lower than clean diesel but are about 30% less fuel efficient. CNG maintenance costs have been about 15% higher, on average, than for diesel buses.

Exhibit ES-1
Comparison of Diesel, Clean Diesel, and CNG costs

	Diesel	Clean Diesel	CNG
Capital Costs			
Vehicle Replacement			
New Buses	$ 4,350,000	$ 4,350,000	$ 4,800,000
Remanufactured Buses	$ 2,375,000	$ 2,375,000	$ 4,000,000
Facility Improvements	N/A	N/A	$ 15,000
PM Filter Related Cost	N/A	$ 126,000	N/A
Subtotal, Capital Costs			
New Buses	$ 4,350,000	$ 4,476,000	$ 4,815,000
Remanufactured Buses	$ 2,375,000	$ 2,501,000	$ 4,015,000
Operating and Maintenance Costs (Annual)			
Fuel Costs	$ 177,449	$ 183,502	$ 142,187
Added training costs	N/A	N/A	$ 5,000
Maintenance Costs	$ 340,286	$ 345,536	$ 391,329
Subtotal Operating Costs	$ 517,736	$ 529,038	$ 538,516

COMPARISON OF EMISSION BENEFITS

Exhibit ES-2 below compares the emissions from 1989 model year (MY) diesel buses to newer 1998-01 MY buses with standard diesel engines, clean diesel engines (PM filter and ultra-low sulfur diesel fuel), and CNG engines. MY1998 to 2000 engines are used in the comparison because they were certified to the same emissions standards. The EPA regulations changed for 2002 MY buses, but there are no known emissions data available for these newer buses. The results from two buses were included in the chart to show the emission differences between buses (emissions vary from bus to bus due to slight engine manufacturing variations and other factors). The emissions are expressed in grams per mile.

Exhibit ES-2
Diesel/CNG Emissions Comparison
Illustrative Example from Central Business District

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+	0.22* Bus 1 0.21* Bus 2	0.04* Bus 1 0.01* Bus 2	0.09* Bus 1 0.01**Bus 2
NOx	40-45 +	25.6* Bus 1 23.3* Bus 2	26.4* Bus 1 23.8* Bus 2	44.0* Bus 1 16.5** Bus 2
CO	N/A	1.8* Bus 1 2.1* Bus 2	0.2* Bus 1 0.1* Bus 2	20.0* Bus 1 11.3** Bus 2

Notes:
All emissions expressed in grams per mile (gm/mi) using a central business district (CBD) route profile. While Imperial County Transit is not in a CBD, the only available test data is from a CBD environment. Results should be viewed as illustrative and not representative of Imperial County. 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 ES-2 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. CNG engines normally exhibit lower NOx emission levels compared to diesel when they are tested as new engines operating in optimum mechanical condition. However, when engines accumulate mileage in revenue service and fuel and ignition adjustments begin to deteriorate, NOx emission can be higher in some CNG buses.

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 both CNG and diesel comply with current EPA requirements, CNG emissions have typically exceeded those of standard diesel engines and therefore have enjoyed a slight advantage over diesel with respect to emissions reduction. This all changed with the introduction of clean diesel engines equipped with PM filters and ultra-low sulfur fuel.

Since the 2007 EPA emission standards are below those that current CNG or diesel engines are capable of achieving, both 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 other devices) and CNG engines equipped with aftertreatment devices will virtually have the same emissions levels. Because of the extremely low levels of emissions expected from both engines in 2007, it will be nearly impossible to detect any differences in emissions levels because any differences will be below the capabilities of the measuring equipment.

1. BACKGROUND

This introductory chapter provides the purpose of the study, its rationale and the background context for the analysis of alternative fuels for the transit fleet in Imperial County.

STUDY PURPOSE

The purpose of this study is to provide the Imperial Valley Association of Governments (IVAG) and Imperial County the information necessary to make decisions on the propulsion systems and alternative fuel types for future Imperial County Transit buses. Several developments and processes have provided important rationales for this study:

- In June 2000, a new compressed natural gas (CNG) fueling station opened in El Centro with the capacity to fuel seven buses. The Air Pollution Control District (APCD) has encouraged Imperial County Transit to convert its fleet to CNG. Before deciding on the future fleet configuration, IVAG and Imperial County want to know what the cost will be to undertake, and sustain, a conversion to alternative fuels for Imperial County Transit.
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This study was intended to provide decision-makers with the information necessary to make informed decisions on each of the above issues.

BACKGROUND OVERVIEW

This section discusses several distinct elements that are important to the review of alternative fuels in Imperial County:

<u>Operational characteristics</u>, including the route design, number of trips made, service frequency, the span of service, and operating speeds 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.

<u>Fleet characteristics</u> 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. The compressed natural gas facility in El Centro is described in detail in Chapter 4.

Air quality status provides an important rationale for considering alternative fuels in Imperial County. The existing status and trends for the future are described in this section.

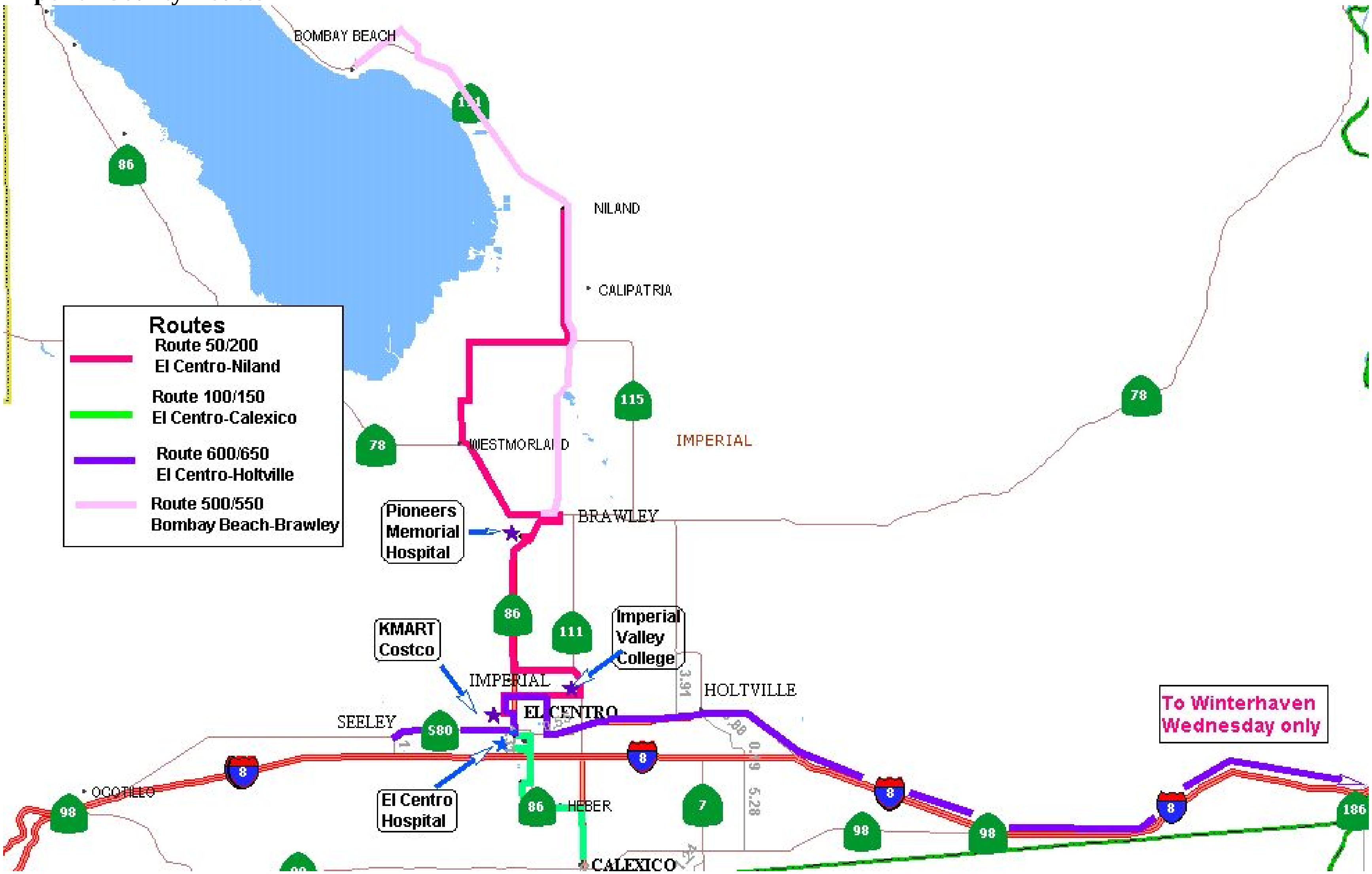
Regulatory factors influence the purchases of buses throughout most of California. While Imperial County is not included in the Air Resources Board Public Transit Bus Fleet Rule, the potential implications of the regulation are reviewed at the end of this section.

EXISTING IMPERIAL COUNTY TRANSIT OPERATIONS

Imperial County Transit operates an intercity bus service in Imperial County. Exhibit 1-1 shows the existing route structure. The following is a summary of the existing service levels for this intercity service:

Route 50: Niland-El Centro- 6 inbound trips
Route 200: El Centro-Niland- 7 outbound trips
Route 150: Calexico-El Centro- 11 inbound trips
Route 100: El Centro-Calexico- 10 outbound trips
Route 500: Bombay Beach-Brawley- 1 trip on Thursdays only
Route 550 Brawley-Bombay Beach- 1 trip on Thursdays only
Route 600: El Centro-Holtville- 4 outbound trips (includes Winterhaven on Wednesdays only)
Route 650 Holtville-El Centro- 5 inbound trips (includes Winterhaven on Wednesdays only)

Exhibit 1-1
Imperial County Routes



Services operate generally between 6:00 am and 8:00 pm on weekdays, and between 6:00 am and 5:00 pm on Saturdays. No Sunday service is provided.

The total number of miles that Imperial County Transit vehicles travel varies widely, as shown in Exhibit 1-2. Two vehicles travel more than 300 miles, and five vehicles traveled less than 200 miles on the sample day.

Exhibit 1-2
Total Vehicle Miles Traveled,
Sample Day

Vehicle No.	Total Miles
41	50
98	73
100	190
101	176
102	315
117	233
128	332
174	164

Buses travel at different speeds, depending on the road conditions. Within cities like El Centro and Calexico, buses travel between 25 and 35 mph, generally on major arterial streets. On major highway stretches, buses travel 55 mph. The average speed of service is slowed by the number of stops within the cities. Two sample routes typify the number of stops per route. For Route 150 between Calexico and El Centro, the following is the number of stops by city:

Calexico:	10
Heber	2
El Centro	9

For Route 200 between El Centro and Niland, the following is the number of stops by city:

Niland	1
Calipatria	1
Westmorland	1
Brawley	9
Imperial	2
El Centro	5

The review of these operational characteristics reveals that Imperial County Transit operates a long span of service with two vehicles operating more than 300 miles. In the early years of CNG bus development, vehicle range was a common concern. Improvements have been made, based on the experience with the actual operating experience of recent orders of CNG buses. New Flyer can get a maximum of 7 CNG tanks on their 40-foot buses, each with a maximum of 3,600 psi per tank, which provides a theoretical vehicle range of over 400 miles. It should be noted, however, that fuel economy depends on so many variables that the actual range would need to be calculated. Vehicle range is discussed in more detail in Chapter 4.

EXISTING FLEET CHARACTERISTICS

Imperial County has a fleet of ten 40-foot Gillig Phantom diesel vehicles. The vehicles are all provided by Laidlaw, Inc. under contract to Imperial County. All buses are 1988 models and average a total of 600,000 miles each per vehicle. The useful life of a transit vehicle is normally 12 years, so the vehicles are due for replacement. Fleet specifications are anticipated to be part of a Request for Proposal in mid-2003, when the existing operations contract is rebid.

Laidlaw also utilizes one cutaway bus in its service. There are therefore 11 total vehicles. The peak number of vehicles operating at any one time is 7 vehicles.

AIR QUALITY STATUS

Imperial County is in the Salton Sea air basin as defined by the California Air Resources Board (ARB). Both the State of California and the Federal Government have established air quality standards. The air quality standards have been established for determining the "concentration above which the pollutant is known to cause adverse health effects to sensitive groups within the population, such as children and the elderly."

Two important standards are for PM10 and Ozone. Particulate matter (PM) is a complex mixture that consists of dry solid fragments, solid cores with liquid coatings, and small droplets of liquid. These tiny particles vary greatly in shape, size and chemical composition, and can be made up of many different materials such as metals, soot, soil and dust. PM10 is measured and expressed as the amount of particles 10 microns diameter or less contained in a cubic meter of air ($\mu g/m^3$).

Imperial County is in a moderate nonattainment area for PM10 for state standards and is in an attainment area for federal standards. The State Air Resources Boards projects an increased trend in PM10 emissions. In 1995, there were 253 tons per day emitted, while in 2010 the ARB is projecting an increase to 275 tons per day.[1] The addition of two large power plants in Mexicali will add to a statewide trend of increased PM10 emissions from stationary sources. It should be noted that exhaust emissions from diesel vehicles dropped statewide by 60 percent from 1990 to 2000 due to more stringent emission standards and the introduction of cleaner burning diesel fuel.

[1] ARB Almanac 2001 p. 214

Ozone is a colorless gas with a pungent odor and is the chief component of urban smog. Ozone is not directly emitted as a pollutant, but is formed in the atmosphere when hydrocarbon and NOx precursor emissions react in the presence of sunlight. Meteorology and terrain play major roles in ozone formation. Ozone impacts lung function by irritating and damaging the respiratory system. In addition, ozone causes damage to vegetation, buildings, rubber, and some plastics.

For ozone, the Salton Sea Air Basin is designated a moderate nonattainment area for state standards and is in a transitional (moderate) category under federal standards. Per the California Health and Safety Code, the APCD can adopt "Reasonably available transportation control measures sufficient to substantially reduce the rate of increase in passenger vehicle trips and miles traveled per trip if the district contains an urbanized area with a population of 50,000 or more."[2] Such transportation control measures could include the requirement for alternative fuel buses at a future date.

ARB is forecasting a downward trend in NOx emissions, the precursor to ozone. In 1995, 45 tons per day were emitted and the emissions are projected to decline to 34 tons per day in 2010.[3]

As is discussed in more detail in Section 3 of this working paper, clean diesel fuel systems for buses have made significant progress in reducing particulate matter (PM) emissions. However, the trend of increased PM10 emissions in the Salton Sea air basin may increase regulatory pressure to have even further reductions in diesel bus emissions. Urban transit systems, for example, will only be able to purchase zero emission buses by the year 2008.

STATUS OF PUBLIC TRANSIT BUS FLEET RULE

Imperial County Transit is currently not part of the ARB Public Transit Bus Fleet Rule, but most California transit agencies are included. In February 2000, the Air Resources Board approved the "Public Transit Bus Fleet Rule and Emission Standards for New Urban Buses," (hereinafter referred to as the Bus Fleet Rule). The discussion is included here because, under certain conditions, the City of El Centro could become subject to the Bus Fleet Rule in implementing the shuttle program. It is also possible that the Air Resources Board could broaden the definitions of eligibility such that Imperial County Transit would be included. It should be stressed that no current amendments to the rule are pending that would include Imperial County Transit. However, two similar transit systems, in terms of vehicles utilized and intercity city operations, the Humboldt Transit Authority in the Eureka area and the San Luis Obispo Regional Transit Authority (SLORTA), are currently subject to the Bus Fleet Rule. If Imperial County Transit were under the ARB transit bus regulation, it would have a significant impact on the type of bus Imperial County Transit could purchase in the future.

[2] California Health and Safety Code 40918 a3.
[3] ibid.

The multi-faceted Bus Fleet Rule sets fleet requirements applicable to transit agencies, and sets more stringent mid- and long-term emission standards for new urban bus engines, applicable to manufacturers. Transit agencies were required to choose between diesel and alternative fuel compliance paths in 2000. The fuel path selected determined the compliance schedule and reporting requirements. The fleet rule was designed to provide transit agencies with flexibility in meeting N0x standards while achieving near-term PM reductions and promoting advancement of PM control technology.

The following are some of the main features of the regulation:

- Beginning in 2008, all bus purchases must be zero emission buses.
- Beginning with engines produced after October 1, 2002, new engines used in urban transit buses must meet a PM standard of 0.01 grams/brake horsepower hour (g/bhp-hr).
- Requires the reduction of NOx from 4.0 g/bhp-hr to 0.5 g/bhp-hr, starting with new, 2004 year engines. In 2007, NOx emissions from new engines are reduced again to 0.2 g/bhp-hr.
- Requires utilization of ultra low-sulfur fuel.
- Requires utilization of diesel particulate filters with a schedule for particulate matter reduction.
- Provides exemptions to transit agencies with fewer than 20 buses. For example, agencies located in areas that are meeting the Federal ozone 1-hour standard can delay implementation of the low sulfur fuel to 2006. New regulations also allow small agencies to apply for financial hardship.

The regulation is only applicable to urban buses. The following is the verbatim definition from the Air Resources Board:

> *"Urban bus" means a passenger-carrying vehicle powered by a heavy heavy-duty diesel engine, or of a type normally powered by a heavy heavy-duty diesel engine, with a load capacity of fifteen (15) or more passengers and intended primarily for intra-city operation, i.e., within the confines of a city or greater metropolitan area. Urban bus operation is characterized by short rides and frequent stops. To facilitate this type of operation, more than one set of quick-operating entrance and exit doors would normally be installed. Since fares are usually paid in cash or token, rather than purchased in advance in the form of tickets, urban buses would normally have equipment installed for the collection of fares. Urban buses are also typically characterized by the absence of equipment and facilities for long distance travel, e.g., restrooms, large luggage compartments, and facilities for stowing carry-on luggage.*[4]

Apparently, Imperial County was not included because its operations were not characterized by short rides and frequent stops and were not considered urban.

[4] Correspondence to all transit agencies from Air Resources Board, December 20, 2001.

However, if Imperial County Transit were to continue to add stops, the Air Resources Board may decide the buses are urban buses, since the ten existing 40 foot Gillig Phantom buses are considered heavy heavy-duty diesel engines.

The City of El Centro shuttle system would be subject to the fleet rule if it were to utilize 40-foot buses. The utilization of small buses of 30 feet and under generally exempts agencies from the fleet rule, since the engines utilized are not considered heavy heavy-duty diesel engines.

The Transit Fleet Rule allowed the 68 transit agencies to select either a diesel or an alternative fuels path for compliance. 42 of the 68 transit agencies in California subject to the rule chose the diesel path.

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 natural gas (LNG) 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 compressed natural gas were selected for further detailed study. Those options receive significant detailed cost analysis in Chapters 3 and 4. Chapter 5 summarizes the differences between diesel, clean diesel and CNG. 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 LNG, 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 Imperial County, one must keep in mind that the basic operating characteristics of the internal combustion engine -- regardless if it operates on diesel, gasoline, CNG, or LNG fuel -- has not changed since it 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
- reduced sulfur level content in diesel fuel

[1] American Public Transportation Association

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.

<u>Natural Gas</u>

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 <u>cannot</u> 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

Compressed natural gas 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 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 that require battery power to operate, severely affect 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 ICT's long route and vehicle mileage requirements, 100% electric vehicles are not a realistic option for ICT.

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 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.

It will probably be another three years before a 40-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 Imperial County.

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.

3. CLEAN DIESEL

Diesel engines offer high efficiency, low maintenance and long life, but concerns over harmful exhaust emissions have resulted in a significant research and development effort 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.

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
- 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 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.

In order to reduce emissions of diesel even further to provide the cleanest possible diesel, two strategies are currently available:

- Diesel aftertreatment technology
- Ultra low sulfur diesel fuel

When referring to the term “clean diesel” in this report it includes both the use of diesel aftertreatment technology and ultra low sulfur diesel fuel.

Exhaust Gas Recirculation (EGR) is a third strategy to further reduce NOx emissions. Although viable for new engine applications, EGR is only in its development stages for retrofit applications. All three strategies are discussed below.

<u>Diesel Aftertreatment Technology</u>

Diesel engine manufacturers face 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 are concentrating their efforts on reducing NOx emissions through in-engine modifications, while reducing PM emissions through the use

[1] American Public Transportation Association

of so called "aftertreatment" devices (i.e., add-on equipment that treats the exhaust gas after it leaves the engine). These 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 help reduce PM emissions to levels that 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). Similar to the oxidation catalyst, the PM filter replaces the standard muffler. PM filters work by "trapping" the solid particulate matter contained in the exhaust stream using a precious metal catalyst that oxidizes the collected particulate matter. Use of PM filters, however, requires diesel fuel with low sulfur levels, which is not commercially available yet in all areas. Use of standard diesel fuel destroys the emission-reduction capabilities of the PM filter.

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.

There are two known suppliers of PM filters that have been certified by the EPA: Engelhard DPX and Johnson Matthey CRT. Engelhard's DPX PM filter is offered directly through DDC as an actual DDC part, while the Johnson Matthey CRT is offered through its own distribution network. Both have similar warranties, 100,000 miles for workmanship and 150,000 miles for emissions. PM filters are expected to be offered as standard equipment when the use of ultra-low sulfur diesel fuel will be mandated by 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 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 also 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 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.

The EPA will mandate ultra-low sulfur fuel in 2006, similar to the way unleaded fuel was mandated for automobiles. Until then, however, ultra-low sulfur fuel may not be available in all areas. According to several diesel fuel suppliers, ultra-low sulfur fuel is

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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.

currently not available in El Centro. It is only being refined by ARCO in Los Angeles and the distribution network is not available. In discussions with the current supplier of fuel for Imperial County Transit, the fuel can be ordered and trucked to El Centro. A specific price proposal would need to be prepared, but the supplier estimated the cost would be approximately 4-6 cents more per gallon.

Exhaust Gas Recirculation

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 most of these technologies are not yet ready for commercial use. Of all the technologies that reduce NOx, Exhaust Gas Recirculation (EGR) holds the most promise. 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 development stage. The first demonstrations of EGR retrofits for transit buses are now 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 a clean diesel technology approach 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 both CNG and diesel comply with current EPA requirements, CNG emissions have typically exceeded those of standard diesel engines and therefore have enjoyed a slight advantage over diesel with respect to emissions reduction. This all changed with the introduction of clean diesel engines equipped with PM filters and ultra-low sulfur fuel. As shown in Exhibit 3-1 below, the emissions of clean diesel are now equivalent with CNG.

Since the 2007 EPA emission standards are below those that current CNG or diesel engines are capable of achieving, both 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 other devices) and CNG engines equipped with aftertreatment devices will virtually have the same emissions levels. Because of the extremely low levels of emissions expected from both engines in 2007, it will be nearly impossible to detect any differences in emissions levels, because any differences will be below the capabilities of the measuring equipment.

Summary of Cost of Clean Diesel Compared to Existing Conditions

Exhibit 3-1 provides a summary of the cost difference between diesel and clean diesel for both Imperial County Transit and an El Centro Shuttle program (as proposed). The combined capital costs for PM filters would be $126,000, including installation. The annual operating and maintenance cost difference between diesel and clean diesel is $11,302.

Exhibit 3-1
Diesel versus Clean Diesel Costs

Capital Costs						
Service	Imperial County Transit		El Centro Shuttle		Total	
Fuel Type	Diesel	Clean Diesel	Diesel	Clean Diesel	Diesel	Clean Diesel
Number buses: 12-year	10	10	5	5	15	15
Vehicle type	40 ft. high	40 ft high	30 ft. low	30 ft. low		
Add PM Filters only	None	$ 65,000	None	$ 32,500	None	$ 97,500
Spares	None	$ 13,000	None	$ 6,500	None	$ 19,500
Installation	None	$ 6,000	None	$ 3,000	None	$ 9,000
Total capital costs	None	$ 84,000	None	$ 42,000	None	$ 126,000
Operating and Maintenance, Annual						
Fuel costs	$ 104,572	$ 107,709	$ 72,877	$ 75,792	$177,449	$ 183,502
Maintenance PM Filter	None	$ 3,500	None	$ 1,750	None	$ 5,250
Total Operating and Maintenance	$ 104,572	$ 111,209	$ 72,877	$ 77,542	$177,449	$ 188,752
Total, Capital and Operating	$ 104,572	$ 195,209	$ 72,877	$ 119,542	$177,449	$ 314,752

4. COMPRESSED NATURAL GAS

GENERAL PROPERTIES OF COMPRESSED NATURAL GAS

To obtain the volume needed to achieve vehicle range similar to diesel, compressed natural gas (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
- Vehicle performance can be made similar to diesel

Cons:

- Engine-tuning sensitive to emissions performance
- On-board fuel storage requires 3,600 psi capability, which adds up to 3,000 lbs. per vehicle
- 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
- Facility safety requirements for dispensing; also indoor maintenance
- Incremental costs over diesel: $30,000 to $35,000 per vehicle; bus maintenance costs about 15% higher than diesel
- 30% less fuel efficient compared to diesel[1]

Exhibit 4-1 summarizes the properties of CNG and their implications for bus use.

[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%.

Exhibit 4-1
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 do not require similar precautions.

EXISTING CNG FUELING STATION

The first CNG facility was opened in Imperial County in June, 2000. The facility is located at 255 E. Commercial Avenue in El Centro. The facility has the following features:

- Twin 150 SCFM Compressors
- 30,000 Cubic Foot Storage Capacity
- 24 Hour Public Access Card Lock
- 2 Nozzle Fast Fill Dispensers
- 3 minute fill time for sedans and pickups
- 24 Light Duty Vehicle “Slow Fill” Positions
- 7 Transit Bus “Slow Fill” Positions
- Adequate parking for personal vehicles in secure fenced enclosure

The facility was built with reinforced pavement and electronic gates to accommodate a transit fleet. To date, no transit buses have utilized the “slow fill” fueling stations in regular operations. Slow fill operations enable more fuel to be compressed into the storage tanks, extending the range of the vehicles. The twin compressors provide necessary redundancy to enable the fueling station to operate if one compressor is inoperable.

The CNG facility is currently utilized by private autos in the fast fill stations as well as 18 County fleet vehicles, 8 Southern California Gas Co. vehicles, and 9 other commuter vans and vehicles from Caltrans and state prisons. According to APCD staff, arrangements can be made through a user agreement to assure Imperial County Transit that they will have sufficient fueling station capacity.

The California Energy Commission and Imperial County Air Pollution Control District have provided funding for a new public access CNG station at the Calexico Unified School District. The project is currently out to bid. APCD is also exploring a fast fill facility in Brawley.

The review of the fleet and infrastructure reveals that there is current infrastructure to handle the peak pullout of Imperial County buses. However, capacity of the slow fill positions may be a future issue if the fleet of CNG vehicles were to significantly expand. It may be feasible to expand the number of slow fill positions.

CAPITAL COSTS

The capital cost differences between diesel and CNG buses are reviewed below. Because Imperial County already has its own CNG fueling station, the most significant cost difference is the vehicles themselves. Agencies can purchase or lease new buses, purchase used buses, or convert from a diesel to a CNG vehicle. After vehicle cost differences are shown, required modifications to the standard maintenance facility are highlighted.

It is commonly recognized that CNG buses cost more than diesel buses. The Air Pollution Control District has a program for subsidizing the difference between diesel and CNG vehicle costs. The program is subject to fund availability.

New Buses

The cost difference between manufacturing diesel and CNG buses has declined over the years. For recent bus procurements, the cost per bus for a standard high floor 40 foot, 12-year rated CNG bus is about $325,000, compared to $295,000 for a standard diesel bus. Vehicle specifications, smaller order size and manufacturing competitiveness can increase or decrease the price by 10% or more.

In general, low-floor option buses will add about $5,000 to the cost of a bus. The cost difference between a 30-foot, 12-year rated bus and a similar 40-foot bus is about $20,000 less. For the El Centro shuttle, a new 12-year rated 30 foot low floor diesel bus would be approximately $280,000 and a 30-foot low floor CNG bus would be about $310,000.

Used Buses

The used market for CNG 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 bus vendors do not have 30- and 40-foot CNG buses available. Many agencies have converted public transportation fleets to alternative fuels, and therefore the availability of used high-floor diesel vehicles is excellent.

CNG Conversion from Diesel Vehicles

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

- Rewiring the bus
- Installing a new floor
- Reupholstering all seats and repairing all seat frames
- Installing all new lower inside panels and repainting
- Installing new engines and repainting
- Installing new CNG tanks
- Repairing and repainting exterior
- Reworking radiator to operate in temperatures up to 130 degrees

The total cost for the conversion to a CNG bus is about $275,000, about $50,000 more than a new CNG bus. A remanufactured diesel bus costs about $165,000. The conversion company claims that the remanufactured bus will be good for another 12 years. However, there is not enough industry experience with conversions to validate this claim.

Vehicle Range

In the early years of CNG bus development, vehicle range was a common concern. Improvements have been made, based on the experience with recent orders of CNG buses. New Flyer can get a maximum of 7 CNG tanks on their 40-foot buses, each with a maximum of 3,600 psi per tank, which provides a theoretical vehicle range of over 400 miles. It should be noted, however, that fuel economy depends on so many variables that the actual range would need to be calculated. It should also be noted that agencies have not always been able to completely fill the tanks and therefore have achieved less range. In the example given for New Flyer, additional CNG tanks would not be possible.

The Los Angeles MTA claims that CNG bus manufacturers provide them with a 400-mile range. According to LA, they specified a 400-mile range in their last 40-foot CNG order and made the manufacturer (NABI) qualify to that mileage (and they did). Typically, however, LA operates CNG buses to a maximum of about 350 miles per day, but claims that there is enough fuel left in the tanks to reach another 50 miles. This range would be sufficient for Imperial County trips.

Improvements to Maintenance Facility

Imperial County Transit utilizes a turn-key contracting arrangement for vehicle maintenance. The contractor provides the maintenance facility. The size and characteristics of the facility are not known. Assuming the El Centro shuttle bus goes forward and is part of the same contract, a three-bus bay facility for 15 total vehicles is assumed. The following are general guidelines for the type of improvements that would be necessary to make at a private contractor garage in order to accommodate compressed natural gas.

Ventilation

Natural gas is lighter than air and collects at the ceiling. The hazard-zone extends to the ceiling and requires a ventilation system to remove natural gas if there is leakage. The following are general requirements:

- Install gravity or powered ventilations at the high points in the ceiling. The number and size of the fans should be capable of rapidly removing a quantity of natural gas greater then the total quantity in a full tank.
- Revamp any ceiling areas that will collect a pocket of natural gas.
- Keep doors open, if possible, while working on vehicles.
- Ventilation fans should provide six (6) changes per hour as required by (OSHA). The air should be introduced at floor lever and exhausted at the ceiling. The design should ensure that all portions of the ceiling are exhausted so that it will not leave any pockets of natural gas in the ceiling.
- Add emergency ventilation to provide a total of ten (10) to twelve (12) air changes per hour. Emergency ventilation should be activated automatically through the gas detection system, as well as manually.

Heating and electrical units

- All maintenance shop heaters should be replaced with non-flammable infrared heaters.
- All light fixtures and electrical outlets should be explosion-proof.

Gas Detection

- Handheld gas detectors could be used prior to work, 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.
- A permanent gas detection system should be installed in the building with interlocks to open outside doors, and start ventilation fans, sound alarms and disable certain equipment. Currently the industry trend is to use Infra-Red (IR) detectors, as they typically operate more quickly and require much less

maintenance than Catalytic systems. This system cannot be used to replace other modifications, like removal of open flame heaters.

The precise cost for such modifications would, of course, depend on the facility provided by the contractor. For budgeting purposes, $15,000 would likely provide sufficient modifications for a proper ventilation system, a gas detection system, and replacement of light fixtures and electrical outlets.

OPERATIONS AND MAINTENANCE COSTS

Fuel Costs

Fuel costs are typically lower for CNG vehicles than diesel vehicles. Despite the lower fuel economy of CNG, the estimated annual fuel costs for Imperial County Transit would be about $18,000 less for CNG. It should be noted that the fuel costs are 2002 numbers and the cost of both CNG and diesel fuel has been increasing.

Fuel Cost Input	CNG	Diesel
Annual Bus Miles	342,000	342,000
Mpg	4.2	5.2
Fuel per year	81,429	65,769
Cost of fuel per gallon (equivalent, 2002)	$1.06	$1.59
Annual Estimated cost	$86,314	$104,572
Fuel Cost per bus mile	$0.252	$0.305

Maintenance Costs

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. This report 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 CNG and diesel buses is about the same.

The most exhaustive study on maintenance costs of compressed natural gas came from the United States General Accounting Office in December 1999.[2] In that study, six of seven transit agencies that provided objective operating cost data reported higher maintenance costs for CNG buses compared to diesel buses. For example, Pierce Transit reported 16% higher engine maintenance costs. Only Sunline Transit reported lower maintenance costs with CNG vehicles.

[2] United States General Accounting Office, Mass *Transit: Use of Alternative Fuels in Buses* Washington D.C. December 1999.

In Los Angeles, where 1,355 CNG buses are operated, the agency estimated at a recent conference that "annual maintenance costs are 15-20% higher than diesel buses."[3] Overall, the reasons for the increased costs are because the CNG engines are inherently more complex than diesel engines and require:

- Spark plugs, ignition wire sets, coils, etc.
- Carburetor type fuel mixing systems
- Additional fuel system components
- Gas detection
- Higher engine maintenance and rebuild costs

While recognizing that the published data is not conclusive, the compilation of the GAO report, the TCRP, and the discussions with maintenance practitioners, point to approximately a 15% additional maintenance cost for CNG over diesel buses.

Based on Imperial County Transit budget records, maintenance costs for CNG would be about $37,000 per year more for CNG than for diesel vehicles. This is a reasonable budget figure to include for the first three years of CNG operations.

Training Costs

The transition to CNG would initially require16-24 more hours for each mechanic, assuming they already have basic gasoline engine training. A budget of $5,000 for a transit system the size of Imperial County Transit would not be unreasonable.

Training course to include:

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

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

Summary of Cost Difference Between Diesel and CNG

Exhibit 4-2 provides a summary of the cost difference between CNG and Diesel buses. For new buses, the difference between CNG and diesel for both Imperial County Transit and the El Centro Shuttle is $450,000. The operating and maintenance costs between

[3] J. Drayton, LAMTA, proceedings of World Bus and Clean Fuels Summit sponsored by the International Quality and Productivity Center (IQPC) and held in Los Angeles, California, in June 2000.

diesel and CNG are about the same. The difference of $20,780 shown in Exhibit 3 is well within the margin of error of the estimates. However, depending on where the maintenance facility is located, the logistical costs of having to move the buses to the CNG facility for fueling and back to the maintenance yard could cost up to $60,000 annually. This is based on an estimate from the existing contractor for the extra labor and operating costs to move vehicles back and forth from their existing airport facility and the CNG fueling station. This cost would be significantly less if the operator facility and the CNG fueling facility were in close proximity.

Exhibit 4-2: Cost Difference between Diesel and CNG buses

Capital Costs

Vehicle Replacement(total costs)	Imperial County Transit		El Centro Shuttle		Combined Fleet		Cost Difference
Fuel Type	Diesel	CNG	Diesel	CNG	Diesel	CNG	
Number buses: 12-year	10	10	5	5	15	15	
Vehicle type	40 ft. high	40 ft high	30 ft. low	30 ft. low	Mix	Mix	
New Bus	$2,950,000	$ 3,250,000	$1,400,000	$1,550,000	$4,350,000	$4,800,000	$450,000
Remanufactured Bus	$1,650,000	$ 2,750,000	$ 725,000	$ 1,250,000	$2,375,000	$4,000,000	$ 1,625,000
Facility Improvement	N/A	$ 15,000		$ 12,000	N/A	$ 15,000	

Operating and Maintenance Costs (Annual)

Fuel Costs	$ 104,572	$ 86,314	$ 72,877	$ 55,873	$ 177,449	$ 142,187	$ (35,263)
Maintenance costs	$ 252,064	$ 289,874	$ 88,222	$ 101,456	$ 340,286	$ 391,329	$ 51,043
Additional training costs		$ 5,000		$ 3,000		$ 5,000	$ 5,000
Subtotal basic costs	$ 356,636	$ 381,188	$ 161,100	$ 160,328	$ 517,736	$ 538,516	$ 20,780

Potential additional costs (depends on location of maintenance facility)

Bus logistics	None	$40,000		$20,000		$60,000	$60,000

5. SUMMARY COMPARISON

SUMMARY OF COSTS

Exhibit 5-1 provides a summary of the capital and operating and maintenance costs for diesel, clean diesel, and CNG for a combined fleet of 15 buses for Imperial County Transit and the prospective El Centro Shuttle. CNG has the most expensive capital costs, with a replacement cost of $4.8 million for new buses and $4.0 million for remanufactured buses. For clean diesel, new clean diesel buses would cost $339,000 less than CNG for new buses, and $1.51 million less for remanufactured buses.

The operating and maintenance costs are generally equivalent between clean diesel and CNG. Historically, CNG fuel costs have been lower than clean diesel, but maintenance costs have been more.

Exhibit 5-1
Comparison of Diesel, Clean Diesel, and CNG costs

	Diesel	Clean Diesel	CNG
Capital Costs			
Vehicle Replacement			
New Buses	$ 4,350,000	$ 4,350,000	$ 4,800,000
Remanufactured Buses	$ 2,375,000	$ 2,375,000	$ 4,000,000
Facility Improvements	N/A	N/A	$ 15,000
PM Filter Related Cost	N/A	$ 126,000	N/A
Subtotal, Capital Costs			
New Buses	$ 4,350,000	$ 4,476,000	$ 4,815,000
Remanufactured Buses	$ 2,375,000	$ 2,501,000	$ 4,015,000
Operating and Maintenance Costs (Annual)			
Fuel Costs	$ 177,449	$ 183,502	$ 142,187
Added training costs	N/A	N/A	$ 5,000
Maintenance Costs	$ 340,286	$ 345,536	$ 391,329
Subtotal Operating Costs	$ 517,736	$ 529,038	$ 538,516

COMPARISON OF EMISSION BENEFITS

Exhibit 5-2 below compares the emissions from 1989 model year (MY) diesel buses to newer 1998-01 MY buses with standard diesel engines, clean diesel engines (PM filter and ultra-low sulfur diesel fuel), and CNG engines. MY1998 to 2000 engines are used in the comparison because they were certified to the same emissions standards. The EPA regulations changed for 2002 MY buses, but there are no known emissions data available for these newer buses. The results from two buses were included in the chart to show the emission differences between buses (emissions vary from bus to bus due to slight engine manufacturing variations and other factors). The emissions are expressed in grams per mile.

Exhibit 5-2
Diesel/CNG Emissions Comparison
Illustrative Example from Central Business District

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+	0.22* Bus 1 0.21* Bus 2	0.04* Bus 1 0.01* Bus 2	0.09* Bus 1 0.01**Bus 2
NOx	40-45 +	25.6* Bus 1 23.3* Bus 2	26.4* Bus 1 23.8* Bus 2	44.0* Bus 1 16.5** Bus 2
CO	N/A	1.8* Bus 1 2.1* Bus 2	0.2* Bus 1 0.1* Bus 2	20.0* Bus 1 11.3** Bus 2

Notes:
All emissions expressed in grams per mile (gm/mi) using a central business district (CBD) route profile. While Imperial County Transit is not in a CBD, the only available test data is from a CBD environment. Results should be viewed as illustrative and not representative of Imperial County. 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 5-2 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. CNG engines normally exhibit lower NOx emission levels compared to diesel when they are tested as new engines operating in optimum mechanical condition. However, when engines accumulate mileage in revenue service and fuel and ignition adjustments begin to deteriorate, NOx emission can be higher in some CNG buses. Research shows that the emissions performance of CNG buses is quite sensitive to fuel system calibration. [1] A call to West Virginia University confirmed the higher average NOx levels for CNG buses. Its database of 1998 and newer MY CNG buses averaged NOx emission levels of 54.0 gm/mi.[2] 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 breakdown or fail). The New York City buses shown in Exhibit 1 had NOx levels in the 23-26 gm/mile range, 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)

[1] TCRP Report 38, op. cit.
[2] Telephone conversation with Ralph Nine, Program Coordinator, West Virginia University, April 2003.

APPENDIX A
FUELS NOT SELECTED FOR DETAILED STUDY

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.

<u>Pros</u>:

- 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

<u>Cons</u>:

- 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.[1] In Texas, the agency with the most experience with LNG is Dallas Area Rapid Transit (DART). DART reports LNG bus maintenance costs are 8-10% higher than diesel buses,[2] which is consistent with the national research results.

Exhibit 3-3 provides a summary of LNG properties and their implications for bus use.

Exhibit 3-3
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

[1] TCRP Report 38, Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations, Transportation Research Board, 1998
[2] Fuel for Thought, Bus Ride Magazine, March 2002

	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.

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 3-4 below summarizes the basic properties of Methanol and the implications for use as a bus fuel.

Exhibit 3-4
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.

<u>Pros:</u>

- 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 3-5 summarizes the basic properties of Ethanol and the implications for use as a bus fuel.

Exhibit 3-5
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

LIQUIFIED PETROLEUM GAS (LPG)

LPG, also known as propane because it is comprised primarily of propane with small amounts of propylene, butane, and light hydrocarbons. LPG is used in a variety of non-vehicle applications such as home heating and cooking, for recreational vehicle (RV) appliances, and for home barbecues. About 60% of LPG comes from natural gas processing, while the remaining 40% comes from petroleum refining. LPG is a gas at room temperature, but liquefies at pressures greater than 120 psi. The relatively low pressure makes it easy to transport and store the fuel as a liquid. The stored liquid fuel vaporizes easily to become a gas before entering the engine with clean-burning characteristics similar to those of CNG.

Exhibit 3-6 summarizes the basic properties of LPG and the implications for use as a bus fuel.

Exhibit 3-6
Propane Properties

Property	Implications for Bus Use
Relative Storage Volume	LPG requires more storage volume to achieve similar range as diesel
Engine Ignition	LPG is difficult to compression ignite and requires spark plugs or other ignition devices. Diesel engines are self-igniting and require no such equipment.
Flammability	LPG leaks and spills evaporate quickly. However, LPG is heavier than air and will “pool” near ground level while spreading laterally. LPG leaks represent a significant fire hazard, while diesel fuel spills do not.

Pros

- EPA certified engine available (Cummins, B Series, 5.9 L, 6 cyl., 195 hp)
- Fuel is non-toxic
- Fuel dispensing is much like diesel; filling rates (about 30 gallons per minute- gpm) comparable to diesel
- LPG burns with less carbon deposit formation than diesel, reducing internal engine wear

Cons

- Fuel stored under pressure, leaks considered fire hazard
- Skin contact with pressure-fed fuel can cause gas embolism in bloodstream
- Energy content of LPG is 83,500 Btu/gal, compared to 128,7000 Btu/gal for diesel
- Extra maintenance facility modification costs (about $360,000 unless facility is already designed for gasoline vehicle maintenance, increased ventilation to remove vapors at/near ground level, classified (explosion proof) electrical service in low-lying areas (less than 18"), fire protection upgrades.
- Extra fueling facility costs due to need for tanks strong enough to withstand 250-300 psi, tanks must be positioned away from other fuel dispensing areas, must be set back specific distances from other buildings, and fuel must be dispensed outdoors.
- Fuel requires an odorant to notice leaks (similar to CNG) – otherwise odorless in natural state
- Operator and maintenance training required

There have been several positive experiences with the use of 30-32 foot propane buses in Texas. In the Sherman/Dennison area, there are five small propane buses that are currently operating with three more on order. According to the operator, building the necessary fueling station and making the necessary maintenance facility modifications was not burdensome. The propane buses have been working well and get about five miles per gallon.

The largest user of propane buses in Texas has been VIA Transportation in San Antonio. VIA's bus fleet was powered by propane in the 1950s and 1960s and started using propane again four years ago in its service and paratransit fleets. In 1999 VIA purchased 66 new 30-foot propane-powered buses and 5 new propane-powered streetcars. [3]

[3] Alternative Fuel News: Vol. 2 No. 6. 1999

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

<u>Overview</u>

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. 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.

<u>Background on Hybrid-Electric Propulsion</u>

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.

<u>Energy Storage Devices</u>

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).

<u>Benefits</u>

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.

<u>Technology Status</u>

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.

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