ASSESSMENT OF ADVANCED ENGINE TECHNOLOGY FOR THE UNIVERSITY OF VIRGINIA TRANSIT SYSTEM

Final Report
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16. Abstract

This report discusses the possibility of using an alternative engine and fuel technology for a transit system utilizing the University of Virginia's new Groundswalk route. This alternative technology can replace the conventional diesel engine and prove superior in specified characteristics deemed important for use in the University Transit Service. The conclusions reached in this study are applicable to a conventional bus design and for minibus and other multi-passenger vehicles operating off a track.

The following is a list of the technologies considered in this reports: Electric Buses, Hybrid Electric Diesel Buses, Fuel Cell Buses, and Natural Gas Buses (Liquefied Natural Gas and Compressed Natural Gas). In evaluating each of these technologies, parameters were set by which to evaluate the usefulness of each for the Groundswalk Shuttle System. Considering the proximity of the proposed route to the University Circle neighborhood, the level of bus emissions and noise pollution are considered to be very important in selecting a technology. Other considerations taken into account in the selection process are: availability of technology in 2002-2003 timeframe, capital cost of vehicle, capital cost of refueling station, operating costs, costs of changes in maintenance bays, and weight and size flexibility.

It is the recommendation of this report that hybrid electric diesel and compressed natural gas technology be fully considered for use on the Groundswalk route and the University Transit Service. Before a decision can be made, each technology must be evaluated according to the evaluation of the bus routes and specific needs for a growing University. A more detailed study into benefits of each technology as compared completely to the needs of the University Transit Service should be done before any action is taken.

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Executive Summary

This report discusses the possibility of using an alternative engine and fuel technology for a transit system utilizing the University of Virginia's new Groundswalk route. This alternative technology can replace the conventional diesel engine and prove superior in specified characteristics deemed important for use in the University Transit Service. The conclusions reached in this study are applicable to a conventional bus design and for minibus and other multi-passenger vehicles operating off a track.

The conventional diesel bus in the mainstay of the transit industry and the alternative technologies discussed in this report are those that have proven or have the potential to be viable replacements. The following is a list of the technologies considered in this reports:

- Electric Buses
- Hybrid Electric Diesel Buses
- Fuel Cell Buses
- Natural Gas Buses (Liquefied Natural Gas and Compressed Natural Gas)

In evaluating each of the above technologies, parameters were set by which to evaluate the usefulness of each for the Groundswalk Shuttle System. Considering the proximity of the proposed route to the University Circle neighborhood, the level of bus emissions and noise pollution are considered to be very important in selecting a technology. Other considerations taken into account in the selection process are:

- Availability of Technology in 2002-2003 Timeframe
- Capital Cost of Vehicle
- Capital Cost of Refueling Station
- Operating Costs
- Costs of Changes in Maintenance bays
- Weight and Size Flexibility

By evaluating each of the above parameters and the properties of the stated technologies, two were ultimately selected for consideration. The technologies most suited for incorporation into the University of Virginia transit system are hybrid electric diesel and compressed natural gas. Each of these transit modes has the necessary characteristics to be used as a more forward-looking and community friendly transit system. Tables 1 and 2 in the report highlight the emissions and the selection parameters and how the two selected technologies compare to the conventional diesel.

It is the recommendation of this report that hybrid electric diesel and compressed natural gas technology be fully considered for use on the Groundswalk route and the University Transit Service. Before a decision can be made, each technology must be evaluated according to the evaluation of the bus routes and specific needs for a growing University. A more detailed study into benefits of each technology as compared completely to the needs of the University Transit Service should be done before any action is taken.

I. Introduction

Groundswalk, the name given to the 3-mile pedestrian route that was designed to connect North, Central, and West Grounds, is part of the new Master Plan adopted by the Board of Visitors for the University of Virginia. While this new connection is intended for pedestrian and bicycles only, it seems well suited for mass transit purposes that would prove very beneficial to the University community. A significant roadblock to the transformation of Groundswalk into a mass transit thoroughfare is its proximity to the University Circle neighborhood and the residents' objections to the use of the University Transit Service's standard 35-foot diesel buses. These objections concern both the noise and the emissions produced from the conventional diesel powered buses.

In order to use this route for transit purposes, it was decided that research into the feasibility of alternatives to conventional diesel buses was necessary. During the Summer of 2000, the Office of the Architect for the University, with the Center for Transportation Studies, hired three undergraduate engineering students, two from civil engineering and one from chemical engineering, to investigate the possibility of adopting alternative travel modes and/or alternative fuel technology for use on the University of Virginia's Groundswalk. This report will highlight alternative engine technologies available for use and describe the selection process in determining which technology will best suit the needs of the University and the surrounding communities. It was assumed that large buses are the transportation modes of the future, but the conclusion also apply to minibuses, vans, and other multi-passenger vehicles operating off a track.

II. Review of Bus Engine Technology Options

Conventional Diesels Buses

Conventional diesels are the standard by which all of the alternative modes of transport are to be compared. Diesel powered buses are available from every major manufacturer and serve as the staple for the mass transit community. Diesel engines are currently being employed in all of the buses owned by the University Transit Service and they are the predominant heavy-duty engine technology used throughout the world. Diesel engines have been used for over 100 years and the technology has been refined and found to be extremely reliable. Fuel for these engines is compression ignited and the engines achieve a high efficiency.[1] The main objections concerning diesel buses and the catalyst that prompted this report are noise and exhaust emissions. Diesel fuel is a petroleum product made up of very complex hydrocarbons and contains contaminants such as sulfur. The burning of this fuel produces high levels of particulate matter, toxics, oxides of nitrogen, carbon monoxide, and greenhouse gases. The running of a diesel engine is also extremely noisy, especially during acceleration. The benefits and the drawbacks of the conventional diesel engine as it compares with the available alternatives will be further considered in the selection section of this report.

Electric Buses

An electric bus does not have an internal combustion engine, but one or more electric motors that propel the bus using stored electric energy. The predominant storage device currently in use for electric buses is the battery. There are many different types of batteries in use, including: lead acid, nickel cadmium, nickel metal hydride, and lithium ion.[2] Electricity stored in these batteries is produced at central power plants and it is carried in the same manner as electricity delivered to a home or business. The stored electric energy from these batteries is then converted to mechanical energy by the motors. This is different from traditional engines that require combustion to release energy stored in its fuel.[3] Because electric buses do not require combustion to produce power, they have zero tailpipe emissions. Another benefit to using electric buses over traditional combustion engines is the requirement for less preventative maintenance due to the fewer moving parts of an electric bus. Batteries also allow for the use of regenerative braking, which uses the energy required to stop the bus and the motors of the bus as a generator to recharge the batteries and increase the bus's range. Benefits of electric buses come with unavoidable drawbacks. When batteries are used as energy storage devices, the range of the bus is severely reduced as compared to diesel buses, from over 400 miles to between 60 to 100 miles. Battery packs are also very heavy and their addition to a bus can put great strain on the structural integrity of the bus.[4] The feasibility of using an electric bus will be discussed in the selection section of this report.

Hybrid Electric Diesel Buses

Hybrid electric diesel buses combine the internal combustion engine of a conventional diesel bus with the batteries and electric motors of an electric bus. There are two different configurations for hybrid electric diesel buses, parallel and series. For a parallel setup, the primary diesel engine and the electric propulsion are connected directly to the vehicle's wheels. In this configuration, the primary power unit is used for highway driving, while the electric motor provides additional power for hill climbs, acceleration, and periods of high-energy demand. A series configuration has the primary unit connected to a generator that produces electricity, which is either stored in the batteries or sent to the motors that propel the bus.[5] There are several different options to use for the diesel fuel in the hybrid electric diesel buses. These buses can use conventional diesel fuel, biodiesel fuel, or ultra clean diesel fuel. Biodiesel and ultra clean diesel are specialty diesel fuels that carry a much greater cost compared to conventional diesel. Biodiesel is made from vegetable oils, such as soybean and rapeseed, and it is a renewable resource. Ultra clean diesel is conventional diesel fuel that is refined and made almost completely free of sulfur. Both of these diesel alternatives are newer technologies that are a long way from commercial availability. Further research is necessary to weigh the possible benefits of using these diesel alternatives in a hybrid electric diesel bus, but it can be assumed that their use will carry some emission benefits. Emissions for buses using the series configuration are primarily cut because the internal combustion engine is operated at a constant load to generate power for the batteries, thus reducing the emissions created during acceleration. This average load leveling also allows for greater fuel efficiency, lower noise, and better fuel economy. Buses with a parallel configuration reduce emissions in a similar manner. In this configuration, the batteries assist in providing power to the motors at times, such as passing or hill climbing, when conventional diesel engines require greater loads and thus higher emissions.[6] All hybrid electric diesel buses can take advantage of regenerative braking, like electric buses, which provides for greater range and reduced brake service costs. Moreover, there is no need to build costly refueling stations as there is with some other alternative fuels. Hybrid electric diesel buses have inherent drawbacks. These buses have a higher capital costs than standard diesel, which is estimated at more than $100,000 dollars more per bus. As with electric buses, the battery packs pose great restrictions on the bus due to their size and weight. Hybrid electric diesel technology is new and still under development. Manufacturers are in the pre-production stages currently, but it is safe to assume that within the next couple of years, limited models will be available for purchase with full availability following in the near future.[7]

Fuel Cell Powered Buses

Fuel cell power is the newest and most advanced technology being developed for use in transportation. Currently, there are two types of transportation compatible fuel cells that are likely candidates to replace the internal combustion engine. These are the proton exchange membrane fuel cell (PEMFC) and direct methanol fuel cell (DMFC). The proton exchange membrane fuel cell is currently the more developed technology for use in buses. This fuel cell works by using stored or reformed hydrogen as the fuel. The hydrogen flows through the anode where the platinum catalyst facilitates the decomposition of the hydrogen molecule into hydrogen ions (protons) and electrons. The electrons provide useful electrical energy while the proton travels through the electrolyte to the cathode side to form water vapor by reacting with oxygen atoms in the air. [8] To make a bus using the PEMFC a zero emissions bus, pure hydrogen must be used. This hydrogen can be stored on the bus in either a compressed gas or liquid form.[9] Other fuels can be used in place of the hydrogen, as long as the fuel system is equipped with a reformer that converts the fuel into hydrogen. Using a reformer does create emissions, but they are far lower that that of a conventional diesel. Fuels that can be used in a reformer are methanol, gasoline, and other hydrocarbons.[10] The direct methanol fuel cell uses technology similar to the hydrogen PEMFC, but it does not need a reformer since the methanol reacts directly in the anode to make power and carbon dioxide. Water is produced in the cathode[11].

The use of fuel cells is thought to be the next evolution in transportation. Fuel cells are powerful energy providers that share qualities with internal combustion engines and batteries, without many of the drawbacks. Fuel cell buses run clean, quiet, and can operate as long as fuel is supplied. They have few moving parts, so reliability is high and because they do not generate power through combustion they have very low or no emissions depending on the fuel used.[12] Unfortunately, fuel cell buses are in the research and development stage and not yet in commercial production. Currently, researchers are working to overcome several major obstacles, including size and weight, high production costs, slow start-up, and difficulties in on-board fuel storage. Fuel cell buses offer many benefits over all the other engine technologies and these will be discussed along with the drawbacks in the selection section of this report.

Natural Gas Buses

Natural gas used as an alternative fuel can be stored as either liquefied natural gas (LNG) or compressed natural gas (CNG). These storage methods are necessary to store sufficient make natural gas to make the bus's range comparable to that of diesel buses. Each method has inherent benefits and drawbacks when used as an alternative fuel for buses. Natural gas is made up of a mixture of hydrocarbons with methane being the main component. This fuel is widely available and is delivered by gas pipelines currently deployed in much of the United States.[13] Natural gas can usually be purchased at a lower price than diesel and is less subject to global petroleum price changes; however, most energy price forecasts for the United States predict the price of natural gas to increase.

The newest development in the use of natural gas as an automotive fuel is liquefied natural gas. LNG is stored in a cryogenic liquid state at a temperature less than minus 200 degrees Fahrenheit. Its use is rather limited and the technology is not as highly developed as that of CNG. Liquefied of natural gas is being considered mainly because it has a higher energy density than compressed natural gas, thus taking up less space and relieving some of the weight problems associated with natural gas buses.[14] The use of natural gas, as LNG or CNG has the promise of very low emissions of ozone forming oxides of nitrogen, toxics, and particulates. With the benefits of using LNG come drawbacks are associated with this technology. Because of the need to store liquefied natural gas, there is a higher capital cost versus that of diesel buses, usually in the range of $55,000. The cost of using LNG is further increased by the high capital and operating costs of a refueling station. LNG stations typically cost more than stations made for CNG refueling and the cost of liquefying natural gas is higher than the cost compressing natural gas.[15]

Compressed natural gas buses are currently being manufactured by many of the top bus producers: these include Neoplan, Champion, NABI, New Flyer, Orion, Thomas Built, Blue Bird, Nova Bus, and El Dorado. As of March 2000, 3500 CNG buses were in operation in the United States, making CNG buses the most used alternative fuel technology considered in this report. CNG buses have been commercialized for many years and have achieved very low tailpipe emissions of ozone forming oxides of nitrogen, toxics, and particulates.[16] CNG engines generally run quieter than diesel engines at ranges between 6 to 14 decibels below that of a conventional diesel.[17] As with LNG buses, CNG buses have some disadvantages. CNG buses have a higher capital cost as compared to diesel buses, usually around $50,000 more. A compressed natural gas bus has a limited range, although most can achieve between 300 to 400 miles. In order to reach these ranges, CNG buses come equipped with heavy and expensive fuel tanks. These tanks place CNG buses in danger of structural damage similar to battery-powered electric vehicles. Another cost associated with CNG buses, as with LNG buses, is the cost of a refueling station and changes to maintenance bays.[18] These costs can prove to be rather high and are a major disadvantage to the use of natural gas buses. The following selection section will further discuss the benefits and disadvantages of natural gas buses as they relate to usage for the Groundswalk Shuttle System.

III. Selection of Best Engine/Fuel Option for University of Virginia's Groundswalk

Presented above was a review of five of the top bus engine technologies available or currently under development. Each technology was presented along with its inherent advantages and disadvantages and each is a viable option for use at the University of Virginia. As stated in the introduction, the use of a conventional diesel bus will not be considered for the Groundswalk Shuttle System due to the proximity and objections of the University Circle residents. But, the diesel bus must be considered as a means of comparison for bus replacement due to its favorable characteristics when used in transit operations. Diesel technology is the standard and thus any alternative must be superior to a diesel bus in those characteristics deemed most important for the fleet. In evaluating each of the available alternatives:

- Electric Buses
- Hybrid Electric Diesel Buses
- Fuel Cell Buses
- Natural Gas Buses

Parameters have to be set that will compare each of these technologies. The parameters chosen to compare the alternative modes are: emissions, availability of technology in 2002-2003 timeframe, capital cost of bus, capital cost of refueling station, operating costs, cost of changes in maintenance bays, and weight and size flexibility.

As each of the four alternative was evaluated on these parameters, two were immediately eliminated, each for different reasons. The first choice eliminated was the electric bus. This choice was eliminated even prior to the selection of the parameters due to the fact that the City of Charlottesville purchased a battery-powered bus in the past and its performance was very poor. The bus that was purchased had difficulty handling the hills of the town and once broke down on McCormick Road with its passengers being the

Board of Visitors of the University. Due to the poor performance and the fact that little progress had been made in this technology since those incidences, electric buses were eliminated. The second alternative to be eliminated is the fuel cell bus. This is due to the fact that fuel cell buses are still in the development phase. This technology has between 5 to 10 years before it will be ready for serious consideration as a replacement for the conventional diesel bus at the University of Virginia. The fuel cell bus does have much promise and should not be discounted as an option in the future, but realistically this technology is too risky to accept before it is fully developed. Because the University Transit Service is a private fleet, and thus responsible for all of its capital costs, it would be unwise to put too much money into an underdeveloped technology. The fuel cell bus will in all likelihood be the next evolution in transit buses, but that time is too far away to be considered for the Groundswalk at this time.

With the elimination of electric and fuel cell buses, the only remaining technologies to consider are hybrid electric diesel buses and natural gas buses. When considering natural gas, it should be decided which type of storage system should be used. When comparing CNG and LNG, it is clear that CNG is a better choice for use in transit buses. Although LNG has a greater energy density, it has many drawbacks that place CNG as the better choice. One such advantage for CNG is that its technology is far more developed and more widely used. This means that there is a larger base of experience from which a new CNG fleet can rely on, whereas LNG fueled buses are just in the demonstration phase. CNG is also cheaper when compared to LNG. This is shown in the cost to purchase the buses and to build and operate a refueling structure. With all of these facts under consideration, it is clear that CNG should be used if a natural gas bus is incorporated into the University Transit Service.

By reviewing the selection parameters and the characteristics of both hybrid electric diesel buses and CNG buses, it is concluded that either of these choices will prove very beneficial if used for the Groundswalk Shuttle System and the University Transit Service. Both of these technologies offer better characteristics to that of conventional diesels and the following tables will present a comparison between conventional diesel, hybrid electric diesel, and CNG buses. The Table 1 will show a comparison of the measured emissions of these buses under actual transit use. This table will be accompanied by an explanation of the emissions and what each pollutant does to the environment. Table 2 compares these technologies according to the selection parameters set forth.

Table 1: Emissions and Noise Pollution Comparison

Pollutant	Conventional Diesel Bus	Hybrid Electric Diesel Bus	Compressed Natural Gas Bus
CO	+	+++	++
NO_x	+	++	+++
NMOC	++	+++	+
PM	+	++	+++
Toxics	+	++	+++
CO_2, Methane	++	+++	+
Noise	+	++	++

+++ - Lowest Emissions
++ - Second Best
+ - Highest Emissions

- CO – Carbon Monoxide; gas product of combustion that usually is of local concern; CO has an affect on the blood's ability to transport oxygen in the human body; generally a concern for low lying areas and some large urban areas, such as New York City; emissions are usually associated with cold engine startup
- NO_x – Oxides of Nitrogen; including nitrogen monoxide and nitrogen dioxide; atmospheric ozone precursor which can cause many health problems
- NMOC – Non-Methane Organic Compounds; ozone precursor and possibly carcinogenic; produced through incomplete combustion and fuel evaporation; limited data available in literature
- PM – Particulate Matter; made up of a combination of carbon particles, sulfur compounds, and some metals from fuel, oil, or wear; PM is emitted in the form of very small particles that remain airborne where it can be inhaled and cause possible damage to humans; produced by varying factors including incomplete combustion, engine misfiring, lubricant combustion, and impurities in fuel
- Toxics – These include formaldehyde, butadiene, aromatics, etc.; these carry a severe health risk to humans
- CO_2, CH_4 – Carbon Dioxide, Methane; greenhouse gases feared to be the cause of global warming
- Noise – External noise pollution caused by the engine or motor of the bus; comparisons made using only qualitative information

Table 2: Status of Recommended Bus Technologies

Selection Parameter	Conventional Diesel Bus	Hybrid Electric Diesel Bus	Compressed Natural Gas Bus
Availability of Technology in 2002-2003 Timeframe	Available for all specifications; highly developed technology	Limited availability with relatively new technology; first buses manufactured will be 40-foot	Available for many specification, but not as available as Diesel; technology has been deployed for many years
Capital Cost of Bus	Lowest of the three options; estimated around $200,000	Although there are no hybrid diesels available right now, most estimates predict that incremental cost will be twice that of CNG over diesel	Estimated price increase over conventional diesel is about $25,000 to $50,000 depending on model and specifications
Capital Cost of Refueling Station	No additional capital cost because fueling structure is already in place	Additional costs will be the cost for batteries and tools necessary for the use of battery technology in the bus	Very high capital cost for a CNG fueling station; costs could be as high as $1 million to refuel a CNG fleet meeting UVA's needs***
Operating Costs	Relatively low and seen as the standard for comparison; from literature data, Diesel has the lowest operating costs	Low costs for fuel due to excellent economy, but undocumented costs of batteries may outweigh these gains; batteries have an undocumented life span for hybrid diesels, but most estimates are 1 to 2 years; little data available on the operating costs of hybrid diesel buses	CNG fuel tends to have a lower cost than that of diesel fuel, these gains are offset by higher maintenance costs that can be reduced through good understanding of CNG buses by mechanics and the use of preventative maintenance
Cost of Changes in Maintenance Bays	No changes to maintenance bays required	Costs of new diagnostic tools unknown, but will be a necessary expense; no additional safety measures need be taken, but costs for battery handling and disposal will be necessary	High capital costs for making maintenance sheds available for work on CNG buses, many safety measures must be taken to avoid accidents; cost estimates may run as high as $500,000
Weight and Size Flexibility	No real weight concerns, diesel buses have been around for a long time and seem well adapted for transit use	Weight concerns due to need to have more than one motor and additional weight of battery packs; hybrid diesel buses may run near gross vehicle weight limit and will therefore become subject to overloading and possible structural damage	Weight concerns due to heavy fuel tanks needed to store enough fuel to have a comparable range to that of diesel; this added weight pushes the bus towards its gross vehicle weight limit and may cause overloading and structural damage

*** - There are several companies (Pinnacle CNG Systems, Trillium, Pickens Fuel Corporation, etc.) that work with CNG fleets in building refueling stations. These companies build, own, and operate the refueling station and the fleet is only required to purchase a minimum amount of CNG and stay committed over a period of time. Further research needs to be done to determine the feasibility of this venture for the University. If it is feasible, it alleviates a large financial burden for switching to CNG. An example of what is required from Pinnacle CNG Systems is a 10-year contract in which the fleet is required to purchase 200,000 therms CNG per year (or 165,000 Gasoline Equivalent Gallons per year) by the third year of operation. UVA uses more than 170,000 Gasoline Equivalent Gallons per year with the current diesel fleet.

Through the information provided above, it can be seen that both of these technologies are legitimate choices for a new and more forward-looking transit system for the University. Each has the characteristics necessary to fulfill the needs of the University Transit Service and each is a likely candidate to be used as part of a Groundswalk Shuttle System. These two technologies provide the necessary characteristics to replace the current diesel fleet and each should be fully considered before any action is taken in adding them to the University of Virginia's transit fleet.

Appendix 1: Description of Advanced Engine/Fuel Technologies

--Fuel Cells

--Transportation Compatible Fuel Cells

- Phosphoric Acid (PAFC) – Most commercially developed fuel cell, used in many stationary operations and has been placed in buses at Georgetown University for demonstration
- Proton Exchange Membrane (PEMFC) – with hydrogen on the anode side and oxygen from air on the cathode side, with catalyst (platinum) and electrolyte in the middle; a PEM works by the catalyst encouraging a split in the hydrogen atom, the electron becomes useful electrical energy and the proton travels through the electrolyte to the cathode side to form water vapor with the oxygen atoms, currently the favorite to be used in transportation applications
- Direct Methanol (DMFC) – Very similar to PEM, but its catalyst can draw the hydrogen from liquid methanol, thus eliminating the need for a fuel reformer

--Fuels for Fuel Cells

- Fuel Cells run best on hydrogen; this creates a simpler fuel processing system, but raises issues with storage and safety
- Because hydrogen is normally a gas large volumes are required to store enough energy to provide comparable amounts of energy to diesel fuel
- A fuel cell system, which includes a fuel reformer, can utilize the hydrogen from any hydrocarbon fuel from natural gas to methanol, and even gasoline
- When using a hydrocarbon as a fuel, a reformer is needed to create hydrogen rich gas mixtures; these systems can be very complicated and add extra weight to the bus
- Methanol appears to be currently the most feasible fuel option for the fuel cell; methanol is a liquid under normal conditions and is produced from natural gas or renewable biomass

--Benefits of Fuel Cells

- Fuel cells are a great power provider that have many of the same qualities as internal combustion engines or batteries, without the drawbacks; Fuel cells are clean, quiet, and can operate as long as fuel is supplied; there are no moving parts so reliability is high; they have very low or no emissions
- Fuel cells that can run on only hydrogen from a renewable source will emit nothing but water vapor; but fuel cell running on other hydrocarbons will have very low emissions

--Drawbacks to Fuel Cells

- Major hang ups for fuel cells include, size and weight incompatibilities, high production costs, slow start-up, difficulties in on-board fuel storage

--Demonstration and Development

- Work is currently being done to make fuels cells viable options for transportation engines; at the forefront of this development is Ballard Power Systems and its affiliate Xcellsis Fuel Cell Engines
- Commercial production of a bus powered by Xcellsis engines and Ballard fuel cells is expected to begin in 2002
- Ballard and Xcellsis will be demonstrating 25 of their fuel cell buses in Palm Springs, CA between 2000 and 2003 beginning this summer

--Hybrid Electric

--Definitions of Hybrid Electric Vehicles

- Hybrid Electric Vehicles (HEVs) combine the ICE of a conventional vehicle with batteries and electric motors from electric vehicles
- There are two different configurations for HEVs

- Parallel – The primary engine and the electric propulsion are connected directly to the vehicles wheels; the primary is used for highway driving, while the electric motor provides added energy for hill climbs, acceleration, and periods of high energy demand
- Series - primary unit is connected to a generator that produces electricity; the electricity is either stored in the batteries or sent to the motor that powers the wheels

- There are three different classifications of HEVs
  - Power-Assist – driven primarily by a larger engine, with a smaller battery storage capacity
  - Range-Extender – Large battery capacity and a smaller engine used primarily for on-board recharge or to "limp home"
  - Dual-Mode – Set up to allow vehicle to run comfortably on either all battery or all engine power, or on some combination of the two

--Fueling Options

- HEVs can also be powered by fuel cell technology in combination with batteries. Flywheels and ultra capacitors are being considered for energy storage but these are at the early stages of development.
- The primary unit of the HEV can be fueled by various alternative fuels or conventional diesel

--Benefits of HEVs

- The use of hybrid technology allows for the possibility of using regenerative braking, which is a way of recovering the energy of stopping and storing it for use in propulsion; this also provides the benefit of reduced brake service costs
- Because the HEVs' ICE is used to generate power for the batteries, it can be run to accommodate an average load, thus increasing fuel efficiency and decreasing emissions
- No need to build costly refueling stations and no additional costs for changes in maintenance buildings

--Drawbacks to HEVs

- Hybrid Electric Buses will have a higher capital costs than standard diesel or other alternative fuel buses
- Battery packs with the ability to store enough energy are extremely heavy and can pose great restrictions on the bus

--Demonstration and Development

- HE Buses are currently in developmental stages with no models currently available commercially, though Orion Buses is pushing hard to have their hybrids out very soon and have even begun taking orders
- Recent demonstration of HE buses occurred in New York; these buses were Orion Low Floor Buses that use AC induction motor powered by batteries that are constantly recharged by a diesel generator and regenerative braking; the generator is small and runs at constant speed, resulting in low noise, less emissions and low fuel cost
- The Advanced Technology Transit Bus (ATTB) Program, a joint program between Los Angeles and Houston, has been exploring the capabilities of Hybrid Electric Buses; this program incorporates an ICE-generator set in concert with a high power-density flywheel to drive electric wheel motors

--Electric (Battery Powered)

--Electric Vehicles and Batteries

- Contain no engine at all and are propelled by electric motors fed electricity from batteries
- Common batteries used in transportation
  - Lead Acid
  - Nickel Cadmium
  - Nickel Metal Hydride

- Lithium Ion
- Electricity used for fuel is produced at central power plants and it is carried in the same manner as electricity delivered to you home or business
- Recharging an Electric bus can take between 6 to 8 hours; with current attempts to build faster charging systems to do the job in 2 hours or less

--Benefits
- Electric Vehicles are zero emission vehicles (ZEVs) with absolutely no tail pipe emissions
- "Fuel" costs for EVs can be much lower than diesel costs and the use of off-peak recharging can make this cost even less expensive
- Maintenance costs can be a lot lower due to the existence of fewer moving parts in an EV
- Electric buses can make use of the regenerative braking capabilities to recharge batteries and increase bus range

--Drawbacks
- Electric vehicles (EVs) can have a very high initial capital cost
- Electric buses have many drawbacks including
    - Relatively heavy weights due to battery packs that can weigh several thousand pounds; DC batteries weigh about 1,000 pounds, while AC batteries weigh over 3,000 pounds
    - Low ranges that restrict the usage of the buses and the types of routes they can run

--Demonstrations
- Chattanooga Area Regional Transportation Authority (CARTA) is a prime location where electric buses are being used in regular transit operation; CARTA owns and operates (as of August 1997) 16 electric buses; their buses have both DC and AC systems; range is from 45-60 miles; they claim lower fuel and maintenance costs per mile traveled over diesel

Alternative Fuels

–Compressed Natural Gas (CNG)

--What is CNG?
- Mixture of hydrocarbons, methane being the main component
- Natural Gas is currently used in many non-transportation industries
- Natural Gas is delivered mainly through gas pipelines currently deployed in much of the United States
- CNG is odorless and odorants must be added to assist in detecting leaks or spills

--Bus Application
- A compressor station typically costs between $1,000 and $4000 per vehicle, with most stations found in reports costing well over $1 million
- Many different bus manufacturers are making CNG buses available for commercial purchase: these include Neoplan, Champion, NABI, New Flyer, Orion, Thomas Built, Blue Bird, Nova Bus, and El Dorado
- As of March 2000, 3500 CNG buses were in operation in the US
- CNG buses have been commercialized for many years now and can achieve vary low emissions of pollutants such as particulates and oxides of nitrogen

--Advantages
- Very low tailpipe emissions of ozone forming oxides of nitrogen, toxics, particulates
- CNG engines generally run quieter than diesel engines
- Through an analysis of the well-to-wheels fuel cycle emissions of natural gas done in April 2000 by the Office of Transportation Technologies, part of the Department of Energy, it was found that:

carbon monoxide emissions can be 70% lower than that of diesel, non-methane organic gas is cut by 87%, nitrogen oxides by 87%, and 20% for carbon dioxide

- Natural gas can usually be purchased at a lower price than diesel and is not as subject to global petroleum price changes; however, most energy price forecasts for the United States predict the price of natural gas to increase
- CNG contains very no or very low amounts of sulfur, nitrogen, aromatics, and particulates
- Per unit of energy, natural gas contains less carbon than any other fossil fuel and thus produces lower carbon dioxide emissions during combustion

--Disadvantages

- CNG buses have a higher capital cost as compared to diesel buses
- Bus range is limited when using CNG is the fuel; fuel system volume is required to be about 5 times that of diesel to get the same range
- Fuel tanks for CNG buses are much heavier and more expensive;
- Methane is emitted from CNG engines and this serves as a green house gas
- CNG is lighter than air and will rise to collect under an enclosed ceiling, this necessitates that upgrade on maintenance sheds in order to eliminate this safety concern

--Liquefied Natural Gas (LNG)

--What is LNG?

- Contains many of the same chemical characteristics as CNG, but it stored in a cryogenic liquid state
- Odorants cannot be added to LNG, so buses and maintenance sheds would be required to install methane detectors

--Bus Applications

- Dallas Area Rapid Transit owns 141 LNG buses and reports on its experiences are soon to be published
- LNG buses are offered by many of the same bus manufacturers as CNG

--Advantages

- Very low emissions of ozone forming oxides of nitrogen, toxics, and particulates
- LNG has a much higher energy density than CNG and thus takes up less space and relieves some of the weight problems for natural gas buses
- LNG contains very no or very low amounts of sulfur, nitrogen, aromatics, and particulates

--Disadvantages

- LNG buses have a high capital cost versus diesel buses
- Fuel system volume is required to be about 2 times that of diesel to get the same range
- Contact with cryogenically cooled LNG can have a potential to cause frostbite if it comes into contact with human flesh\
- The capital and operating expenses associated with the liquefaction of natural gas are high; the refueling facility is also expensive when compared with conventional diesel fueling

--Methanol

--What is Methanol?

- Methanol is an alcohol fuel produced in a process using natural gas as a feedstock
- One of the fuels considered to be a viable option for fuel cell engines
- Methanol is currently being used in either neat form (M100, 100% methanol) or M85 (85% methanol and 15% gasoline) in internal combustion, spark ignition engines
- Methanol is best suited for spark ignition engines due to its high octane level

--Advantages

- Its high octane level allows for greater engine power
- Easier to ship to fuel suppliers because it is a liquid at normal conditions, thus making the fueling process more like that of conventional diesel and gasoline

--Disadvantages

- Lower range when using methanol over diesel as fuel
- Its energy density is half that of gasoline, with the same volume
- Methanol can be very corrosive to many metals, rubberized components, gaskets, and seals

--Ethanol

--What is Ethanol?

- Ethanol is another alcohol fuel that is mainly produced through the fermentation of grain crops
- Using ethanol as E85 or E95 (85% or 95% ethanol and 15% or 5% gasoline) are currently being explored for use as alternative fuels for internal combustion engines
- Used mainly in light duty vehicles

--Bus Applications

- Greater Peoria Mass Transit in Peoria, Illinois uses ethanol fueled buses; supported by the local corn and ethanol industries, this program has been demonstrating and using ethanol buses on regular transit routes

--Advantages

- Very low emissions of ozone forming hydrocarbons and toxics
- The feedstock for producing ethanol absorbs carbon dioxide during its growth, thus reducing atmospheric levels of the greenhouse gas
- Ethanol has a very high octane value, giving the engine more power

--Disadvantages

- Ethanol can be corrosive to some metals, gaskets and seals
- Ethanol currently has a high cost
- Vehicle range is low when fueled by ethanol
- Concerns about ethanol include cold start ability, fuel quality, and materials compatibility

--Hydrogen

- Use is being considered for internal combustion engines and fuel cell vehicles
- Gas at normal temperature and pressure
- Storage options are to either compress in high pressure tanks, liquefy in cryogenic tanks, or to using chemical bonding with the storage material
- There is a very limited pipeline distribution set up for hydrogen, therefore it must be shipped in canisters or in tanker trucks
- Hydrogen use is still in the developmental stage, with many possible problems to overcome; such as low energy density creating heavy tanks and reduced range, higher production costs, and supply issues

--Liquefied Petroleum Gas (LPG)

--What is LPG?

- Gas that contains mainly propane, propylene, butane, and butylene is varying mixtures
- Produced as a byproduct of natural gas processing and petroleum refining

- LPG is currently used mostly as a heating agent or cooking fuel
- LPG can be compressed to a liquid at a moderate pressure of 100 to 300 psi, making it much easier to store and transport

--Bus Applications
- Many bus manufacturers have produced LPG buses, but the market for them is currently falling; engine manufacturers still offer some engines that can be specified for use with LPG

--Advantages
- Most widely available form of alternative fuel
- LPG contains very no or very low amounts of sulfur, nitrogen, aromatics, and particulates

--Disadvantages
- LPG has a limited supply which will cause a raise in price with a rise in demand
- Progress needs to be made in LPG's ability to start in very cold and hot conditions
- LPG is extremely volatile and burns twice as hot as gasoline

--Dimethyl Ether (DME)
- Currently the newest of alternative fuels being considered for use in the transportation industry with a lot of research left to check its viability as a realistic alternative fuel
- It has great potential to be used in compression ignition engines (diesel engines) due to its high centane number and low particulates
- Cost of DME is unknown at this time and is availability
- DME contains very no or very low amounts of sulfur, nitrogen, aromatics, and particulates

--Biodiesel

--What is Biodiesel?
- Biodiesel is an ester produced from reacting vegetable oils, like soybean or rapeseed, with an alcohol, usually methanol
- It is currently being used as BD20 (20% biodiesel, 80% diesel)

--Advantages
- Biodiesel has many of the same properties as diesel, but produces fewer unburned hydrocarbons, carbon monoxide, and particulates
- The use of biodiesel requires no or few changes in engine configuration
- Biodiesel is biodegradable
- Reduces atmospheric greenhouse gases by absorbing the carbon dioxide when the feedstock is growing and returning it with no accumulation

--Disadvantages
- Biodiesel has a very high cost compared to other alternative fuels and diesel
- Biodiesel has been found to produce high level of nitrogen oxides

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