Southwest Region University Transportation Center

Electric Bus Operations:
A Feasibility Study

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16. Abstract

This study determines the technical and economic feasibility of electric bus operations. A review of electric vehicle technology with an emphasis on battery-powered electric vehicles is performed, and the availability and use of electric buses are identified. A methodology is presented for selection of bus routes most suitable for electric bus operations using the Capital Metropolitan Transportation Authority as a case study. Costs and benefits of electric bus operations are identified an compared to the costs and benefits of compressed natural gas and diesel bus operations. Finally, recommendations are made regarding the feasibility of electric bus operations.

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by

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Research Report SWUTC/95/60057-1

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Austin, Texas 78705-2650

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EXECUTIVE SUMMARY

The battery-powered electric bus is a viable alternative for metropolitan transit authorities. Based on a case study of the Austin Capital Metropolitan Transportation Authority (Capital Metro), electric buses can be utilized for select routes. Feasibility criteria including range, maximum speed, ridership, and economics were used to evaluate the electric bus, natural gas bus, and diesel bus. Based on operational criteria, i.e. range, speed, and ridership, the electric bus is ideally suited for the Congress Capitol 'Dillo route in the central business district. Moreover, based on life-cycle economic costs, including the cost of pollutants, the electric bus is competitive with current diesel technology. The evaluation of electric buses in this study is based on commercially available technology, and not near-term or long-term technology. As advances continue to materialize in the electric vehicle industry, the cost of electric buses will decrease, and the operational attributes will improve. Given the growing concern over air quality and energy sustainability, the electric bus is an attractive alternative to current diesel technology.

ABSTRACT

This study determines the technical and economic feasibility of electric bus operations. A review of electric vehicle technology with an emphasis on battery-powered electric vehicles is performed, and the availability and use of electric buses are identified. A methodology is presented for selection of bus routes most suitable for electric bus operations using the Capital Metropolitan Transportation Authority as a case study. Costs and benefits of electric bus operations are identified an compared to the costs and benefits of compressed natural gas and diesel bus operations. Finally, recommendations are made regarding the feasibility of electric bus operations.

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CHAPTER 1. INTRODUCTION

Increasing air pollution and dependence on foreign oil in the United States has led to a growing interest in alternative fuel vehicles (AFVs). The transportation sector's significant contribution to these problems has prompted federal and state regulations which now require large public fleets to convert to AFVs. In the transit industry, a variety of AFVs are available which meet federal and state mandates. This study focuses on electric buses, one such alternative fuel, and attempts to determine the technical and economic feasibility of electric bus operations using Austin's Capital Metropolitan Transportation Authority (Capital Metro) as a case study.

DEFINITION

Capital Metro is currently operating diesel and compressed natural gas (CNG) fueled buses in their route services. The enactment of Senate Bill 740 in 1991 by the Texas legislature requires that vehicle purchases by public transit authorities be AFVs and that their fleet consist of at least 30 percent or more AFVs by September 1994, 50 percent by 1996, and if deemed effective in lowering emissions 90 percent by 1998. An AFV is defined as a motor vehicle capable of operating on natural gas, propane, methanol, ethanol, or electricity. In addition to the legislature's requirement, Austin's growing air pollution levels put the city in risk of exceeding National Ambient Air Quality Standards (NAAQS). As a public agency, Capital Metro has a responsibility to promote activities in the best interest of the public which it serves. The use of AFVs by transit authorities not only satisfies legal requirements, but also benefits the general public through a reduction in vehicle emissions and a reduced dependence on imported petroleum.

There are several types of alternative fueled buses currently available. CNG, liquefied natural gas (LNG), propane, and electric-powered buses are all in operation throughout the United States. While each type of alternative fueled bus is considered a low emission vehicle, only electric buses offer the advantage of zero tailpipe emissions.

Unfortunately, there are several technical and economic disadvantages of electric bus operations. Electric buses have a limited range, require several hours to recharge their batteries, and have a substantially higher capital cost than other types of alternative fueled buses. Before electric buses can be considered as a feasible alternative fueled vehicle for service in Capital Metro, the technical capabilities and costs of electric buses must be determined.

OBJECTIVES

The primary objective of this study is to evaluate the technical and economic feasibility of electric bus operations for Capital Metro. To meet this objective, several tasks are defined.

First, a review of electric vehicle technology is completed to determine the current state of technology. Electric vehicles were first developed in the late 1800s, but their popularity among the public has never been very high. This is primarily due to their limited range and performance characteristics in comparison to gasoline- or diesel-powered vehicles. Due to the increasing concerns over air pollution and energy security, there is renewed interest in electric vehicles. A great deal of research and development in the electric vehicle field has occurred in the last decade, and every effort was made to document the most recent advances in this study.

Manufacturers and users of electric buses are identified. Interest in electric buses has led to the creation of several companies dedicated primarily to the manufacturing of electric buses. Several brief case studies of experiences with electric bus operations are presented.

Capital Metro route services are described and a methodology is presented for selection of routes most suitable for electric bus operations. An initial evaluation of all routes serviced by Capital Metro identified five routes suitable for electric bus operations. From these five routes, an optimal route for implementation of electric buses is selected.

Finally, costs and benefits of electric buses are identified. Appropriate costs include capital costs, fuel costs, and maintenance costs. Total fuel-cycle emission reductions are calculated with associated values placed on individual pollutants to determine the social benefit of emissions reduction. The costs and emissions of battery-powered electric buses are compared with diesel-powered and CNG-powered buses currently in operation to determine the benefits of electric bus operations for Capital Metro.

BACKGROUND

The use of battery-powered electric buses in transit operations is relatively new. The Santa Barbara Metropolitan Transit District (MTD) was the first major transit agency to begin operation of electric buses on a fixed route, introducing their first bus in January 1991. MTD has yet to compile the data collected from their experiences into a comprehensive study of the feasibility of electric bus operations, describing their decision to introduce electric buses into service partially as a "leap of faith" (Doerschlag, 1994).

Studies by Gleason (1992) and Dugan (1994) describe, to a limited extent, the experiences, costs, and benefits of electric bus operations in Santa Barbara and Chattanooga, respectively. A report by the California Energy Commission (1991) attempts to identify the cost and availability of low emission motor vehicles and fuels (including electric vehicles), but focuses primarily on passenger vehicles and small trucks. Much of the data and information used in this study regarding recent technology and practical experience with electric buses was gathered through personal communications with manufacturers and representatives of transit agencies currently operating electric buses.

Estimates of pollutant damages due to emissions are based on studies by Small (1977), Haugaard (1981), the Massachusetts Department of Public Utilities (1989), and Ottinger, et. al. (1989). A discussion of these studies is included in Chapter 5. Total fuel-cycle emissions are estimated based on data collected on buses and a study of total fuel-cycle emissions by Darrow (1994).

OVERVIEW

This report consists of six chapters. Chapter 1 introduces the problem, objectives, and a brief background. Chapter 2 reviews the current state of electric vehicle technology. Emphasis is placed on battery-powered electric vehicles (EVs), although hybrid EV technology, fuel cell EV technology, and roadway electrification technology are also reviewed. Chapter 3 discusses the availability and use of battery-powered electric buses. A discussion of federal and state programs, and related financial incentives, promoting electric bus operations is also included. Chapter 4 presents a methodology for selecting bus routes appropriate for electric bus operation. Accordingly, Capital Metro routes are analyzed and recommendations are made on routes that are most suitable for electric bus operations. Chapter 5 discusses the costs and benefits of electric bus operations compared to Capital Metro's diesel and CNG bus operations. Costs determined in Chapter 5 include capital costs, fuel costs, and maintenance costs. Total fuel-cycle emissions are estimated and damage costs are determined for individual pollutants. Costs per mile of operation for an electric-powered bus, diesel-powered bus, and CNG-powered bus are determined based on capital costs, fuel costs, maintenance costs, and damage costs due to emissions. This report concludes with Chapter 6, which presents recommendations regarding the feasibility of electric bus operations.

CHAPTER 2. TECHNOLOGY

The purpose of this chapter is to describe current electric transportation technology. Four types of technology are considered: battery-powered electric vehicles (EVs), hybrid EVs, fuel cell-powered EVs, and roadway electrification systems. Because the focus of this study is on battery-powered electric buses, greatest attention is given to battery-powered EV technology. A brief review of current research and development in hybrid EVs, fuel cell-powered EVs, and roadway-powered EVs is also provided. This chapter concludes with a discussion of the energy consumption of battery-powered EVs, fuel cell-powered EVs, and roadway-powered EVs.

BATTERY-POWERED ELECTRIC VEHICLES

Battery-powered EVs use a large battery pack to supply electricity to an electric motor. Although EVs were developed before gasoline-powered vehicles, they have never been widely used by the public, primarily because the range of EVs is limited to under 161 km (100 miles).

EV motors have proven to be durable and efficient. They do not require cooling systems or tune-ups, and most models do not require transmissions. Brake life of an EV can be extended due to regenerative braking systems, which use the electric motor as a generator to slow the vehicle while returning electrical energy to the batteries. This also extends the range of the EV.

The conventional lead acid batteries used in EVs are heavy, expensive, and take as long as 8 hours to recharge. However, due to stricter air quality laws and policies to reduce reliance on foreign oil, EVs are again being considered as a viable technology to replace internal combustion engine vehicles (ICEVs). Due to the range issue and operating costs, the majority of EV research in recent years has focused on battery technology. The following sections describe some of the research and development that has occurred in EV technology.

Battery Technology

On January 30, 1991, Chrysler, Ford, and General Motors formed a partnership called the United States Advanced Battery Consortium (USABC). The consortium was designed to advance the state of battery technology, the limiting technology of EVs. Immediately after the signing of the partnership agreement in January, the USABC approached the electric utility industry and requested their participation. In the spring of 1991, the Electric Power Research Institute (EPRI), representing the electric utility industry, agreed to provide financial, technical, and management support for the USABC. In April 1991, the USABC proposed a 50/50 cost-shared program of advanced battery research and development with the United States Department of Energy (DOE). After several months of negotiation, a formal agreement was finalized, and on October 25, 1991, DOE joined the USABC (DOE, 1992). The total amount of funds dedicated to battery research from the auto industry, electric utility industry, and federal government amounts to $260 million over a four year period (EPRI, 1992).

The USABC's mid-term battery development objectives are to develop a battery with a specific energy density of 80 to 100 watt-hours per kilogram (wh/kg), a useful life of 5 years, a recharge time of under 6 hours, and a cost of less than $150 per kilowatt-hour (kwh) of capacity. The battery is also expected to sustain more than 600 charge/discharge cycles. Although batteries exist which meet several of the USABC's mid-term objectives, a battery has not been developed at this time which meets all of the objectives.

Long-term goals for battery development are to develop a recyclable battery with a specific energy of 400 wh/kg, a useful life of 10 years, a recharge time of 3-6 hours, and an operating cost of less than $100/kwh of capacity. Feasibility for the USABC's long term objectives are to be demonstrated by the end of 1994.

Table 2-1 presents several battery technologies that are currently being used or are expected to be used in the near future.

Table 2-1 Battery Technology

Battery Type	Energy Density (Wh/kg)	Power Density (W/kg)	Mass Production Cost ($/kWh)	Cost per Battery Pack[a]
Lead Acid	35	100	$200	$10,000
Advanced Lead Acid	52	355	$150	$7,500
Nickel-iron	53	100	$150	$7,500
Zinc-bromine	80	90	$150	$7,500
Sodium-sulfur	100	110	$200	$10,000

[a]Based on 50 kWh storage capacity of General Motor's G-Van battery pack.
Sources: SCEVC, 1992; DeLuchi, et. al., 1989.

Lead acid batteries have been the standard batteries used in EVs for the past century. They require approximately 8 hours to recharge and have an average life of 2-3 years. The technology of lead acid batteries has developed very slowly, and they are generally considered inadequate for practical applications in small EVs. General Motors's G-Van, a full size cargo van, and several models of electric buses are using lead acid batteries. Both the G-Van and the electric buses have the volume capacity to carry the large number of lead acid batteries required to provide a practical range of 64-129 km (40-80 mi) between charges.

Advanced lead acid batteries will most likely replace the standard lead acid batteries in the near future. Electrosource, Inc. of Austin, Texas, has developed the Horizon Electric Vehicle Battery, an advanced lead acid battery that can be recharged to 50 percent power in 8 minutes, and to 99 percent power in 30 minutes. This represents a dramatic decrease in charging time compared to conventional lead-acid batteries, which require about 8 hours for a full recharge. Although the Horizon battery is able to be recharged quickly, it's low energy density still limits an EV's range to under 161 km (100 mi). Electrosource estimates that the Horizon battery will have a range of approximately 137 km (85 mi) when installed in a mid-size van (Electrosource, Inc., 1993).

Advanced lead acid batteries differ from conventional lead acid batteries primarily in structure and construction. While conventional lead acid batteries use vertical lead plates, the Horizon advanced lead acid battery uses fiberglass reinforced woven lead mesh arranged horizontally. Other such technologies have been developed to increase the power and energy per unit of battery weight compared to conventional lead acid batteries.

Nickel-iron batteries are currently being used in the Chrysler TEVan, an electric minivan. Compared to conventional lead acid batteries, nickel-iron batteries have a higher energy density, provide a vehicle with a greater range while not increasing the volume and weight of the batteries, and can sustain more charge/discharge cycles. Disadvantages of the nickel-iron batteries include excessive hydrogen gassing during recharging, and a need to be watered more frequently than most batteries (which adds to the maintenance time required to operate an EV using nickel-iron batteries).

Zinc-bromine batteries are inexpensive and have a relatively high energy density. However, zinc-bromine batteries are bulky, complex, and have a short life. The power density for zinc-bromine batteries is fairly low, making them suitable only for smaller low performance vehicles.

Sodium-sulfur batteries offer a very high energy density and are almost maintenance free. Unlike most batteries, they do not require watering and do not emit gases while being charged. A disadvantage of the sodium sulfur batteries is that they must be kept at a temperature of 250°-350° C. When in use, the battery produces enough heat to maintain this temperature, but when it is idle, heat is no longer produced. To compensate, the batteries must be surrounded by insulation, which increases the weight of the vehicle. The life of the sodium-sulfur batteries will be shortened if the temperature is allowed to reach room temperature more than 20-30 times.

Charging Systems

Charging systems regulate the flow of electricity to batteries during recharging to prevent damage to the batteries due to overcharging. Most EV battery systems take about 8 hours to fully recharge, but advanced charging systems may be able to reduce this time by more than 90 percent. The range limitation problem of EVs is compounded by the slow recharge time for their battery packs. Trips outside the EV range require either an 8 hour recharge period or an auxiliary power source. Charging systems that allow batteries to be recharged in the same time it takes to refuel a conventional ICEV would reduce the problem of limited range to a mere inconvenience of having to spend a few minutes to recharge batteries each time the range of the EV has been exceeded.

Chrysler and Norvik Technologies Inc./Norvik Traction Inc. are developing the Smart Charging System, a quick charge system that will be able to provide a full charge to a completely discharged battery in about 25 minutes. The system is designed to be used with any type of battery and to eliminate overcharging, thus extending battery life. The Smart Charging System currently requires a 480 volt (AC) power supply when operating the system, which makes it unavailable for home use. The system may eventually be able to recharge a battery in as little as 10 minutes with expected technological improvements and an increase in the voltage of the power supply.

Improvements in battery technology will reduce charging time. The Electrosource Horizon Battery, discussed previously, can receive a 99 percent recharge in 30 minutes. Intense research and development in battery technology by the USABC and other organizations should continue to produce batteries with reduced charging time.

Rather than rely on quick charge technology, several EVs have been designed to use removable battery packs. Nordskog Industries, Inc., for example, has developed a bus with a removable battery pack that will allow the bus to replace a discharged battery pack with a fully recharged pack in as little as 10 minutes. Removable battery packs allow the bus to service a route for a longer period of time with only a brief interruption in service to change the battery pack. The main disadvantage of using the removable battery packs is the investment required to purchase a second battery pack for each vehicle. The battery packs, which weigh from 181 kg (400 lbs) for very small automobiles to over a thousand kilograms (several thousand pounds) for buses, will also require investment in specialized lifting equipment to aid in their installation and removal.

Development

Virtually every major automobile manufacturer has been developing EVs that rely solely on batteries for power. Some of the front runners in development include the General Motors Impact, the Ford Ecostar minivan, the Chrysler TEVan minivan, and the General Motors full size G-Van.

The General Motors Impact is a small, two-seat commuter car with performance characteristics similar to vehicles powered by ICEs. Powered by lead-acid batteries, the Impact can accelerate from 0 to 96 km/hr (60 mph) in 8 seconds and has a top speed over 161 km/hr (100 mph). The maximum range is 193 km (120 mi) at constant highway speeds, but the practical range will probably be about 129 km (80 mi). General Motors had originally planned to mass produce the Impact by the mid 1990s, but recently announced a hold on these plans due to corporate losses and uncertainty in the EV market (J.E. Sinor, 1993b).

The Ford Ecostar is an electric version of the Ford Escort minivan, which is primarily sold in Europe. The Ecostar uses sodium-sulfur batteries that provide a range between 161 and 322 km (100 and 200 mi) at 40 km/hr (25 mph). The van will go from 0 to 80 km/hr (0 to 50 mph) in 12 seconds.

The Chrysler TEVan and the General Motors G-Van have a range of about 129 km (80 mi). Both vans have operated in electric utility company fleets, and the G-Van has also operated in several private company fleets. Neither van is mass produced at this time, a factor that has lead to very high prices (1993 prices are $120,000 for the TEVan and $50,000 for the G-Van.).

There are several small companies that have developed battery-powered electric buses and shuttles. The buses are generally under 9 m (30 ft) in length, have a range of 97-121 km (60-75 mi), and are able to reach speeds of around 64 km/hr (40 mph). These buses are available for immediate purchase and use, and several transit agencies already have them in their fleet services. A detailed discussion of the buses and shuttles available at this time is presented in Chapter 3.

HYBRID ELECTRIC VEHICLES

Hybrid vehicles are a step in the evolution from the ICEV to the battery-powered EV, using an ICE and a battery-powered electric motor. In most cases, a very small ICE using a "clean fuel", such as natural gas, provides the primary driving force for the vehicle. In order to compensate for the small ICE, a battery-powered electric motor provides additional power for peak performance periods, such as climbing steep grades or initial acceleration. The electric motor can also serve as the primary driving motor during the first few minutes of vehicle operation. During this period, the batteries heat the catalytic converter as well as supply power to the electric motor, eliminating the very high cold-start emissions associated with ICEs. This can significantly reduce emissions since catalytic converters only work when heated. When the electric motor is not needed during driving, the batteries can be recharged by the ICE.

Hybrid vehicles offer the advantages of increased range and quick refueling compared to a battery-powered EV. However, there are several disadvantages. Because the hybrid's ICE relies on a fuel source such as gasoline or natural gas to operate, it does not offer zero tailpipe emissions. An EV can be produced without a transmission, but the introduction of an ICE into the power train necessitates the use of a transmission. Finally, the vehicle must be designed to function using two different power sources, requiring maintenance personnel to be familiar with both ICEs and electric motors.

General Motors, Volkswagen, Audi, and Fiat have all developed hybrid automobiles at this time. The Volkswagen Chico, for example, uses a 2-cylinder gasoline engine with an operating range of 403 km (250 mi). The Chico can achieve a top speed of 130 km/hr (81 mph) using both its ICE and electric motor (Siuru, 1991). While the range is more than double that of most battery-powered EVs, it should be noted that the increase is primarily due to the use of an ICE, which does produce tailpipe emissions, albeit at a lower rate.

Ontario Bus Industries of Mississauga, Ontario, is one of the companies currently developing hybrid electric buses. Ontario Bus Industries is developing an 8 m (25 ft), 24-passenger hybrid bus that will use natural gas and electricity as fuel sources. The bus will have a top speed of 60 km/hr (37 mph) using only the ICE before power from the storage batteries is needed. Energy efficiency for the proposed model was rated for several different driving cycles. On level ground, at a constant speed of 80 km/hr (50 mph), the hybrid vehicle had a 26 percent fuel savings over a diesel-powered bus. However, in typical central business district (CBD) driving the estimated fuel savings was only 6 percent. Considering that transit buses seldom operate at constant speed (with the exception of express buses), the energy savings for a hybrid bus will be closer to the 6 percent value (J.E. Sinor, 1991).

FUEL CELL-POWERED ELECTRIC VEHICLES

A fuel cell combines a fuel (such as hydrogen), with oxygen (found in the air), and converts the chemical energy from the combination directly into electricity. The process is highly efficient, the cell can be quickly refueled, and there are almost zero fuel-cycle emissions. Fuel cells have been in use for many years but have only recently been developed to the point where they can supply enough electricity to power an EV.

Hydrogen used in fuel cells can be produced from several sources, including methanol, ethanol, and natural gas. The hydrocarbons in these fuels are converted into hydrogen and carbon dioxide through a thermal chemical process in a fuel reformer. For practical use, fuel cells still require the development of an inexpensive and compact fuel reformer, which can be carried aboard the vehicle, to convert their fuel source into hydrogen (Royer, 1992).

DOE has been developing a fuel cell/battery propulsion system for use in an urban transit bus. Compared to a diesel bus, DOE expects the fuel cell bus to have a 50 percent higher fuel economy, a 99 percent lower emissions rate, and to operate 10 to 20 decibels quieter. A transit bus was selected because it is large enough to carry the fuel cell design, the fixed route permits controlled testing, the longer service life of a transit bus helps justify the cost, and the use of a transit bus in an urban area will take advantage of the environmental benefits associated with a zero emission vehicle. The bus uses a phosphoric acid fuel cell with methanol as a fuel source to supply energy to the electric motors. Conventional batteries are also used to provide the motor with additional energy for accelerations and to reduce the size of the fuel cell needed. At the present time, one 8.2 m (27 ft) bus is operational and two additional 8.7 m (27 ft) buses are being constructed. The second bus is scheduled for delivery in September 1994, and delivery of the third bus is scheduled for January 1995. Controlled testing will begin with the operational bus on a fixed route at Georgetown University in the fall of 1994, and DOE expects to start field testing a small fleet of fuel cell buses by 1995 (Kost, 1994).

Fuel cells have been available for many years, but their use in transportation has only recently been investigated. They are an extremely efficient means to produce energy, and while not commercially available at this time, there may be widespread use in future years. If the DOE study proves successful, transit agencies may be able to attain fuel cell-powered electric buses in as little as 2-3 years.

ROADWAY ELECTRIFICATION SYSTEMS

A roadway electrification system delivers electricity to vehicles through inductive coils buried in the roadway. The coils are placed in segments along a highway and eliminate the need for long-range batteries. A maximum air gap of 5 to 10 cm (2.0-3.9 in.) between the vehicle and the highway is required. As a vehicle passes over a segment, the power in that segment is switched on and electricity is used for both powering the EV and recharging batteries. The advantage of this system is that EVs would no longer be limited in range, as a direct source of electricity would constantly be available. The high capital costs, approximately $1.25 million/lane-km ($.78 million/lane-mi) of implementing such a system can be reduced if the system is placed only on freeways. This would require vehicles to use battery power during trips on local roads, but allow them to use the roadway electrification system and recharge their batteries during longer trips on the freeway (Ross, 1992).

A roadway-powered EV system has been underway in Southern California for the past 10 years. The eventual goal is to provide roadway electrification to about 3 percent of the highway network. The first phase of the project, completed in 1991, included building prototypes of vehicles, segments of the roadway, and a power supply for the electrification system. Phase II involves construction of 300 and 450 m (984 and 1476 ft) test facilities, a range of 5 vehicle types including a full size electric transit bus, additional power supplies, and economic feasibility studies. Phase II should be complete by the end of 1994 (Ross, 1992).

For transit services, coils could be placed under the lanes on transit routes. This system would eliminate the need for buses to carry large amounts of batteries, yet still provide an unlimited source of power to the electric motor. While much of the technology needed for this type of system is available, a major roadway power electrification project has yet to be completed. Roadway electrification may be a strong possibility for the future, but until further research and development occurs, it appears that the system is not feasible for the short term.

ENERGY USE

A recent study (Swan, 1990), estimated the energy use of a conventional ICE vehicle, a battery-powered EV, a roadway-powered EV, and a fuel cell-powered EV. The energy consumption estimates for a conventional ICE vehicle are based on a conversion efficiency of crude oil to gasoline of 90 percent, and a vehicle with a 32.2 km/liter (20 mi/gal) fuel consumption rating. Energy consumption estimates for a battery-powered EV and a roadway-powered EV are based on electric utility energy consumption of 9,500 BTU per kWh produced, and a transmission efficiency of 95 percent. The conversion of natural gas to hydrogen for the fuel cell is estimated to be 65 percent efficient, and the fuel cell net energy efficiency is estimated at 45 percent. The energy consumption estimates of each technology are presented in Table 2-2.

The study did not consider a hybrid EV. It is important to note the difficulty in quantifying the energy consumption of a hybrid. At any given time, a hybrid EV may operate using power exclusively from an ICE, power exclusively from an electric motor, or power from both. The use of these power sources depends on trip length, trip route, and driving characteristics. The ICE and the electric motor have different rates of energy consumption, and unless the percentage use of each power source can be identified, accurate quantification of the energy consumption of a hybrid EV is not possible.

Table 2-2 Comparison of Energy Use*

Conventional ICE Vehicle	Battery-Powered EV	Roadway-Powered EV	Fuel Cell-Powered EV
4,725 Btu/km (7,602 Btu/mi) 100%	4,027 Btu/km (6,479 Btu/mi) 85%	3,128 Btu/km (5,033 Btu/mi) 66%	2,189 Btu/km 3,522 Btu/mi 46%

*Energy consumption based on a 1991 Chrysler Caravan (8.5 km/l / 20 mpg) operating in city traffic.
Source: Swan, 1990.

Using the per kilometer (per mi) energy consumption of the conventional ICE vehicle as a base, the battery-powered EV uses 85 percent of the energy required of an ICE vehicle, the roadway-powered EV uses 66 percent, and the fuel cell-powered EV uses 46 percent. Although more energy efficient than battery-powered EVs, roadway-powered electric buses and fuel cell-powered electric buses are not commercially available at this time. Battery-powered electric buses are currently available and have been proven to be a reliable technology by several transit agencies. Until other electric technologies are further developed and proven reliable, battery-powered EVs will remain the most feasible zero emission technology available.

CHAPTER 3. AVAILABILITY AND USE OF ELECTRIC BUSES

The purpose of this chapter is to discuss the availability, performance, and use of battery-powered electric buses. The first section identifies U.S. manufacturers of electric buses. Performance characteristics and vehicle specifications for several manufacturer's buses are presented in the second section. The third section identifies public agencies operating electric buses in the U.S. and discusses their experiences. Finally, the sources of funding available to public agencies to assist with the capital and operating costs of electric buses are discussed.

ELECTRIC BUS MANUFACTURERS

Table 3-1 presents companies involved with the development and manufacturing of electric buses in 1993. It is interesting to note that 6 of the 7 companies are located in California. California currently has the strictest air quality laws of any state as well as the largest U.S. vehicle market, and several Californian transit agencies have purchased electric buses.

Table 3-1 1993 Electric Bus Companies

Company	Location	Activity
Advanced Vehicle Systems, Inc.	Chattanooga, TN	Manufacture/develop electric buses
APS Systems	Oxnard, CA	Develop electric buses Retrofit buses for electrification
Bus Manufacturing U.S.A., Inc.	Goleta, CA	Manufacture custom buses
Electric Vehicle Marketing Corp.	Palm Desert, CA	Market electric buses for Specialty Vehicle Manufacturing Corporation Research and development
Futura Propulsion Systems	Mission Viejo, CA	Develop electric buses
NEVCOR	Stanford, CA	Manufacture/develop electric buses
Nordskog Industries, Inc.	Redlands, CA	Manufacture/develop electric buses
Specialty Vehicle Manufacturing Corporation	Downey, CA	Manufacture/develop electric buses

Specialty Vehicle Manufacturing Corporation is the largest manufacturer of dedicated electric buses. The Chattanooga Area Regional Transportation Authority (CARTA), the City of Monterey, California, and the Georgia Power Corporation are all operating 6.7 m (22 ft), 22-passenger electric buses manufactured by this company. In addition to the 6.7 m (22 ft) bus, Specialty Vehicle Manufacturing Corporation offers a 6.7 m (22 ft), 21-passenger trolley, a 6.7 m

(22 ft), 22-passenger shuttle, a 28.8 m (9 ft), 28-passenger bus, and a 9.4 m (31 ft), 28-passenger bus.

Advanced Vehicle Systems, Inc. was formed in Chattanooga, Tennessee as a sister company of Specialty Vehicle Manufacturing Corporation to meet the growing electric bus demand of CARTA for electric buses. In 1993, CARTA operated four 6.7 m (22 ft) Advanced Vehicle Systems buses. Advanced Vehicle Systems offers the same vehicle models as Specialty Vehicle Manufacturing Corporation and is designated as the eastern U.S. supplier of Specialty Vehicle Manufacturing Corporation's line of electric buses.

Marketing of the vehicles produced by both Specialty Vehicle Manufacturing Corporation and Advanced Vehicle Systems is provided by the Electric Vehicle Marketing Corporation, based in Palm Desert, California.

Bus Manufacturing U.S.A., Inc. built eight 6.7 m (22 ft) open air shuttles for the Santa Barbara Metropolitan Transit District (MTD). The shuttle accommodates 22 seated passengers and 7 standing passengers.

Nordskog Industries, Inc. built three electric shuttles for the Sacramento Municipal Utility District (SMUD). Nordskog Industries has been building electric vehicles for applications in airports and industry for over 40 years. They are currently producing a 14-passenger and a 20-passenger electric shuttle.

APS Systems, Futura Propulsion Systems, and NEVCOR are each developing electric buses, but have not produced an electric bus that is currently in use.

PERFORMANCE CHARACTERISTICS

Table 3-2 identifies cost, performance, and specifications of several models of battery-powered electric transit vehicles manufactured by Advanced Vehicle Systems, Inc. and Specialty Vehicle Manufacturing Corporation.

The base price of an electric bus is high relative to that of a diesel-powered bus. For example, the purchase price of the 9.1 m (30 ft), 29-passenger Gillig Phantom bus operated by the Capital Metropolitan Transportation Authority (Capital Metro) is $174,000. Purchase price of the 9.4 m (31 ft), 25-passenger Advanced Vehicle System battery-powered electric bus operated by CARTA was $225,000; $51,000 higher than the comparable diesel-powered bus.

Table 3-2 Electric Bus Cost, Performance, and Specifications

Performance Measure	Advanced Vehicle Systems Inc./ Specialty Vehicle Manufacturing Corporation		
	Trolley (3122T)	6.7 m (22') Bus (3122B)	49.9 m (31') Bus (5131)
Base Price	$140,000	$175,000	$215,000
Maximum Speed (km/hr) / (mph)	48 / 30	56 / 35	72 / 45
Range per charge	75-100 / 121-161	75-100 / 121-161	50-75 / 80-121
Length (m/ft)	7 / 22	7 / 22	50 / 31
Height (cm/in)	262 / 103	262 / 99	239 / 94
Width (cm/in)	206 / 81	234 / 92	244 / 96
Seating Capacity (passengers)	21	22	25
Gross Vehicle Weight (kg/lbs)	5,443 / 12,000	7,258 / 16,000	8,709 / 19,200
Regenerative Braking	Yes	Yes	Yes
Battery Type	Lead Acid	Lead Acid	Lead Acid

Sources: Electric Vehicle Marketing Corporation, 1992; Electric Transit Vehicle Institute, 1993.

The maximum speed of each bus, while low relative to internal combustion engine buses, should be adequate for most shuttle and bus routes located in downtown areas. The range per charge for the buses limits daily operation to approximately 10 hours depending on the type of route the bus is operated. Experience by agencies operating the 7 m (22 ft) bus manufactured by Advanced Vehicle Systems, Inc. and Specialty Vehicle Manufacturing Corporation reveals an actual range of 105 to 121 km (65 - 75 mi) per charge (Kist, 1993; Litchtanski, 1993).

Electric buses are not yet available in sizes comparable to large diesel and natural gas buses. However, large transit buses are rarely filled to capacity, and in many cases smaller shuttles and buses can be substituted for large buses. All of the electric buses use conventional lead acid batteries, but as battery technology improves, larger electric buses with greater ranges may be developed.

The use of regenerative braking on these buses extends their operating range. The Santa Barbara MTD estimated that the use of regenerative braking provides about 1.5 more hours of service per charge for their shuttles (Gleason, 1992).

AGENCIES OPERATING ELECTRIC BUSES

Table 3-3 lists the agencies operating electric buses in 1993. The experiences of these agencies are summarized in the following sections.

Table 3-3 1993 Agencies Operating Electric Buses

Agency	Location	Manufacturer	Number of Vehicles Operated
Chattanooga Area Regional Transportation Authority (CARTA)	Chattanooga, TN	Specialty Vehicle Manufacturing Corporation Advanced Vehicle Systems, Inc.	2 6.7 m (22') Electric buses 4 6.7 m (22') Electric buses
Santa Barbara Metropolitan Transit District (MTD)	Santa Barbara, CA	Bus Manufacturing, U.S.A., Inc. Specialty Vehicle Manufacturing Corporation	2 6.7 m (22') Open air shuttles 6 6.7 m (22') Open air shuttles
Sacramento Municipal Utility District (SMUD)	Sacramento, CA	Nordskog Industries, Inc.	3 6.7 m (22') Shuttle buses
Georgia Power Corporation	Atlanta, GA	Specialty Vehicle Manufacturing Corporation	2 6.7 m (22') Electric buses
City of Monterey	Monterey, CA	Specialty Vehicle Manufacturing Corporation	1 6.7 m (22') Electric bus

Chattanooga Area Regional Transportation Authority (CARTA)

The Chattanooga experience with battery-powered electric buses began with the revitalization of their central downtown area. CARTA opted for a shuttle circulator system to provide transportation for visitors along the 3 km (2 mi) long, 4 to 6 block wide revitalized central downtown area. A unique and innovative shuttle to match the downtown area was desired. Given the city's recent commitment to environmental issues, an environmental friendly shuttle was also desired. The electric bus met these objectives and was chosen to operate on the downtown shuttle route.

CARTA operated 2 Specialty Vehicle Manufacturing Corporation and 4 Advanced Vehicle Systems, Inc. battery-powered electric buses on their downtown shuttle route in 1993. Eight additional buses were ordered from Advanced Vehicle systems, Inc. in 1993 including one 9.4 m (31 ft), 28-passenger electric bus. Funding has been approved for the purchase of another 10 electric buses in 1994; bringing CARTA's total electric bus fleet to 24 buses. Initial costs of the Specialty Vehicle Manufacturing Corporation 6.7 m (22 ft) buses were approximately $140,000 per bus. The 9.4 m (31 ft) bus Advanced Vehicle Systems, Inc. will manufacture has a purchase per bus. The 9.4 m (31 ft) bus Advanced Vehicle Systems, Inc. will manufacture has a purchase price of $215,000. Fuel costs for the electric buses have been in the range of 2.8-3.5 ¢/km (4.5-5.7 ¢/mi) and maintenance costs have been estimated at 21.8 ¢/km (35 ¢/mi). For a comparable diesel bus, fuel costs are about 11.2 ¢/km (18 ¢/mi) and maintenance costs are about 43.5 ¢/km (70 ¢/mi). The electric buses range have been approximately 105 km (65 mi) and are operated 7-8 hours on their shuttle route.

In response to requests for information regarding their electric bus program, CARTA formed the Electric Transit Vehicle Institute. The purpose of this Institute is to promote the design, production, and utilization of electric transit vehicles powered by non-stationary means of storage or production of energy. Described as a "Living Laboratory" for the research, design, development, and demonstration of electric transit vehicles, the Electric Transit Vehicle Institute is comprised of CARTA, Advanced Vehicle Systems, Inc., and Electrotek, an electric vehicle test facility (Hartman, 1993).

Santa Barbara Metropolitan Transit District (MTD)

Similar to CARTA, MTD procured a fleet of electric shuttles to operate on a downtown route. The downtown-waterfront shuttle serves Santa Barbara's commercial district and waterfront.

The first electric shuttle bus, manufactured by Bus Manufacturing, U.S.A., Inc., began operation in January 1991. Manufacturing of additional buses was subcontracted to Specialty Vehicle Manufacturing Corporation. In 1993, MTD operated eight 6.7 m (22 ft) electric shuttle buses on their downtown-waterfront shuttle route. The shuttles are scheduled for at least 10 hours of service per day, and some have operated for as long as 12 hours in a single day. Their range has been approximately 137 km (85 mi) on a single charge. Recharging occurs overnight to take advantage of off-peak electric utility rates. Fuel costs for the MTD electric shuttle buses are estimated at 1.8 ¢/km (2.9 ¢/mi), while fuels costs for the diesel buses operated in Santa Barbara are estimated at 10 ¢/km (16 ¢/mi). The range of the electric shuttle buses was found to be highly sensitive to the operating characteristics of the bus drivers. Slow rates of acceleration and thoughtful deceleration that make the best use of regenerative braking systems can increase the range of the electric shuttle buses.

MTD has expressed a great deal of satisfaction with their electric shuttle buses. Between 1991, when electric shuttle buses first began replacing diesel buses, and 1992, ridership on the route has increased 800 percent to nearly 1 million passengers per year (Gleason, 1992). MTD attributed a great deal of this increase to the use of electric buses and have had many requests to introduce or extend the electric shuttle bus service to other parts of the city.

Sacramento Municipal Transit District (SMUD)

SMUD purchased three 6.7 m (22 ft), 16-passenger buses from Nordskog Industries, Inc. One bus is operated by SMUD, a second is operated by the Sacramento airport, and the third is operated by McCullough Air Force Base. The buses, equipped with heating and air conditioning, cost approximately $179,000 each. Although little data was available on the performance of these buses, SMUD expects cost/benefits of the electric buses to be comparable to a diesel bus when the benefits of zero emissions are considered (MacDougal, 1993).

Georgia Power Corporation

The Georgia Power Corporation operated two 6.7 m (22 ft), 22-passenger battery-powered electric buses in 1993. The buses, manufactured by Specialty Vehicle Manufacturing Corporation, are operated on a shuttle route for employees. The performance of the electric buses has generally matched the performance specifications given for the 6.7 m (22 ft) Specialty Vehicle Manufacturing Corporation bus listed in Table 3-2. The decision on future purchases is pending, based on the test results of the first two electric buses. The Georgia Power Corporation is also operating several types of battery-powered electric vans, including 10 Chrysler TEVans, two Griffin Electric vans, and two General Motors G-Vans. (Kist, 1993).

City of Monterey

Monterey, California operated one 6.7 m (22 ft), 22-passenger Specialty Vehicle Manufacturing Corporation battery-powered electric passenger bus in 1993. The bus, purchased by Pacific Gas and Electric, is leased to the City of Monterey. Monterey has been achieving a range of 116-121 km (72-75 mi) per day, however, this is not enough to run the bus a full service day of 12-14 hours. Modifications were required on the torque output of the bus to compensate for major inclines on the route, which also reduced the maximum speed to 43-45 km/hr (27-28 mph). While the base price of the bus was $140,000, an additional $100,000 was necessary to obtain the bus options the City wanted as well as to provide needed modifications to a recharging station. The initial ride quality of the bus was rated poor by several passengers, but most of the problems related to ride quality have since been resolved. Several drivers, however, have indicated that they are unhappy with the handling characteristics of the bus. Although the City of Monterey noted the value of a zero emission electric bus, they did not feel that widespread

FUNDING

There are several programs available through the federal Government and the State of Texas to encourage the use of battery-powered electric vehicles. This funding can help alleviate the high capital costs associated with purchasing electric buses, making them more cost competitive with diesel and natural gas buses. Below is a summary of the current programs available.

Federal Assistance

The Energy Policy Act of 1992 (EPACT) authorizes a 5-year, $40 million government/private industry program to research, develop, and demonstrate EV infrastructure. Projects may receive up to $4 million dollars in funding, which can be used for such activities as servicing of EVs, installation of charging facilities, and information dissemination efforts. The funding can help a transit agency lower construction costs of the initial infrastructure that will be needed to support electric buses.

EPACT also authorizes $50 million dollars over the next ten years for projects that will accelerate development and evaluate operational performance and infrastructure needs of EVs. The programs must be in urban areas and involve at least 50 vehicles. Financial assistance of up to $10,000 per vehicle will be available to decrease the cost of EVs. This program would be ideal for a transit agency considering a wide-scale electric bus or electric vanpool service initiative.

A $50 million, 5-year federal assistance program will provide assistance to states for the development of state alternative fuel and alternative fueled vehicle incentive plans. To be eligible for funding, a state's plan must examine such ideas as exempting alternative fuel vehicles from state taxes and providing infrastructure for refueling. If a state's plan is approved by the United States Department of Energy (DOE), federal assistance may provide as much as 80 percent of implementation costs of the program. Incentives to transit agencies may be included in the state's plan.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) includes a $6 billion, 6-year Congestion Mitigation and Air Quality Improvement Program that will allow cities in non-attainment areas to utilize funds from the Federal Highway Trust Fund for transportation related projects. Project funding selection is the responsibility of Metropolitan Planning Organizations (MPOs) in non-attainment areas. A variety of programs that will aid a city in attaining national ambient air quality standards (NAAQS) can be funded. Mass transit is one way to ease pollution and, therefore, is eligible for funding.

Federal Tax Incentives

Several federal tax incentives are available which apply to electric vehicles. Although public transit agencies are tax exempt, they may contract operation of some of their services to private industry. For example, the Capital Metropolitan Transportation Authority's (Capital Metro) UT shuttle service is operated by DAVE Transportation, a private firm which is not tax exempt.

A 10 percent tax credit (up to $4,000 per vehicle) based on the purchase price of a qualifying electric vehicle is available for electric vehicles purchased after June 30, 1993. The tax credit will be phased out between 2002 and December 31, 2004, when the credit is terminated.

A $100,000 tax deduction is available for investments made in clean fuel vehicle refueling property. This deduction is available for refueling property placed into service between June 30, 1993 and December 31, 2004.

State of Texas Assistance

In 1991, the Texas legislature adopted Senate Bill 740 (SB740) requiring transit authorities to begin converting their fleets to alternative fuel vehicles (which include EVs). By September 1, 1994, transit fleets must consist of 30 percent or more alternative fuel vehicles. This percentage increases to 50 percent by September 1, 1996, and to 90 percent by September 1, 1998.

In order to assist in funding these fleet conversions, the 1993 Texas legislative session enacted Senate Bill 737 (SB 737), which establishes an Alternative Fuels Council and an Alternative Fuels Conversion Fund. This fund consists of approved allocations from oil overcharge funds, gifts and grants for financing alternative fuel activities, interest earned on the fund, and any other government approved monies. The Alternative Fuels Council administers the fund's loan program to aid with alternative fuel fleet conversion. Senate Bill 737 also authorizes the Texas Public Finance Authority to issue bonds for alternative fuel fleet conversion. Transit authorities in Texas are eligible for funding from both the Alternative Fuels Conversion Fund and the Texas Public Finance Authority issued bonds.

As the momentum towards alternative fuels continues to grow, additional funding may become available.

CHAPTER 4. APPLICATIONS FOR ELECTRIC BUSES

The purpose of this chapter is to discuss possible applications for battery-powered electric buses within the existing services of the Capital Metropolitan Transportation Authority (Capital Metro), the transit authority of Austin, Texas. An overview of the route services offered by Capital Metro and the criteria used for route selection are discussed. Finally, Capital Metro routes that are most feasible for electric bus operations are identified .

CAPITAL METRO ROUTE SERVICES

The creation of Capital Metro was approved in January 1985 by voters in Austin and surrounding areas. Originally funded by a 1 percent sales tax, the board of directors voluntarily lowered the sales tax to 3/4 percent beginning in April 1989. Capital Metro currently provides service throughout a 1,219.9 square km (471 square mil) area which encompasses the cities of Austin, Cedar Park, Leander, Lago Vista, Jonestown, Pflugerville, Manor, and San Leanna. Capital Metro's service area also includes the unincorporated area of Precinct Two in Travis County and the Anderson Mill area in Williamson County.

Capital Metro offers a variety of route services to the public, including metro routes, flyer routes, 'Dillo routes, express/park & ride routes, and the University of Texas shuttle routes. Appendix A lists all routes currently served by Capital Metro.

Metro Routes

Capital Metro offers 40 metro routes, which provide local service throughout the Austin area. Most metro routes run north-south and pass through the downtown area, although several crosstown and feeder routes do exist. Service on all routes begins by 6:30 AM on weekdays and continues until as late as midnight. Weekend service is also provided on most routes. The one-way fare for adults is 50 cents.

Flyer Routes

Flyer routes combine local service within various neighborhoods with express service to downtown Austin. There are currently seven flyer routes, which are operated only on weekdays during morning and late afternoon periods. A one-way adult fare of 50 cents is charged.

Express/Park & Ride Routes

Four express/park and ride routes provide express service from free park and ride lots to downtown Austin. The IRS/VA Express, North East Express, and the Pflugerville Express routes are operated only on weekdays during morning and late afternoon periods. The Leander Express is operated continuously throughout the day on weekdays and Saturdays. A one-way fare of $1.00 is charged for adults.

'Dillo Routes

Dillo service is provided on three routes and acts as a circulator service in downtown Austin, the Capitol Complex, the University of Texas campus, and the Austin Convention Center. 'Dillo buses operate using diesel engines but resemble older versions of electric trolleys. The Convention Center/UT 'Dillo offers service during weekdays and Saturdays, while the Congress Capitol 'Dillo and the ACC/Lavaca 'Dillo offer service on weekdays only. 'Dillo service is free, and a free park and ride lot located near Palmer Auditorium is serviced by each of the 'Dillo routes.

University of Texas Shuttle Routes

Twelve shuttle routes provide service to the University of Texas campus when classes are in session. Shuttle routes operate full weekday schedules and most provide limited service on weekends. Students pay a fee each semester for unlimited use of the shuttle buses, as well as metro route buses, during the semester. The adult one-way fare for non-students is 50 cents.

CRITERIA FOR ROUTE SELECTION

The selection of Capital Metro routes most feasible for electric bus use is based primarily on route service area and route characteristics.

Route Service Area

One of the most important considerations for route selection is based on the area serviced. In order to provide the benefits of zero tailpipe emissions to the greatest number of people, electric buses should be operated in densely developed areas such as central business districts (CBDs). This allows transit agencies to operate buses in urban areas (where air pollution is generally a problem) without adversely affecting air quality.

Routes that place buses in highly visible areas should also be considered. The absence of exhaust fumes and the quiet operation of an electric bus distinguishes it from a standard transit bus. Many people realize the importance of clean air and are more likely to appreciate the efforts of a transit company to reduce air pollution within a city.

The decisions to utilize electric buses on routes in Santa Barbara and Chattanooga were due in large part to the clean image of electric vehicles. Both Santa Barbara and Chattanooga operate their electric buses in dense areas of the city popular with local residents and tourists. The Santa Barbara and Chattanooga transit agencies found that not only did the public appreciate their efforts to improve air quality, but the novelty of an electric bus increased ridership along the routes serviced by the electric buses.

Route Characteristics

Several route characteristics also influence the feasibility of electric bus implementation. These characteristics include:

- Maximum speed required along the route
- Number of stops along the route
- Service hours for the route
- Terrain along the route
- Ridership on the route.

The highest operating speed of an electric bus is approximately 64 km/hr (40 mph). This relatively low maximum speed does not allow operation of an electric bus on a freeway, but it is generally adequate for operation in downtown urban areas and has not presented a problem in either Chattanooga or Santa Barbara. A careful evaluation of any route on which an electric bus will be operated should be performed to determine if the maximum speed of the bus is adequate.

The number of stops along the route contribute to the effectiveness of a battery-powered electric bus compared to a diesel-powered or CNG-powered bus. During each stop for boarding and deboarding passengers, internal combustion engine buses emit pollutants and use energy. The use of an electric bus on routes with frequent stops eliminates pollutants resulting from periods of idling. Overall energy consumption is also reduced since the electric bus consumes no energy for stops due to boarding and deboarding of passengers, due to traffic control signals, or due to highway congestion.

The maximum range of 113 to 121 kilometers (70 to 75 mi) per charge limits the daily operation time of the bus. A bus that operates with an average speed of 16.1 km/hr (10 mph) will be limited to approximately 7 to 7.5 hours of service per day, depending on the driving characteristics of the driver and the terrain on which the bus is operated. Quick accelerations and steep grades will reduce the range, while gentle accelerations, level terrain, and thoughtful use of the regenerative braking systems will increase the range.

Finally, ridership on the route must be considered to assure that an electric bus, which generally seats less than half the passengers of a standard full-size diesel-powered bus, can accommodate demand.

RECOMMENDED ROUTES

An evaluation of all metro routes, flyer routes, express routes, 'Dillo routes, and UT shuttle routes was made to determine which routes are most feasible for electric bus use. This section presents the methodology used to identify routes with characteristics not amenable to current electric bus technology. The following section presents the routes selected for further evaluation and the criteria used for final route selection. Finally, the third section presents the Capital Metro route determined most feasible for operation of electric buses.

Unfeasible Routes

An initial evaluation of all routes serviced by Capital Metro was made to determine which routes were not feasible for electric bus use. Routes were eliminated from consideration based on two criteria: 1) maximum speed required on the route and 2) area serviced by the route.

Routes that required buses to operate on freeways were eliminated from consideration. Most models of electric buses have a maximum speed rating of 56 to 72 km/hr (35 to 45 mph) and, therefore, are unable to operate safely on freeways.

Routes that serviced areas outside the CBD were also eliminated from consideration. In this report, the CBD is defined as the area in downtown Austin bordered by Interstate 35 on the east, Lamar Boulevard on the west, the University of Texas campus to 26th Street on the north, and Riverside Drive and Barton Springs Road on the south.

A route matrix was developed to indicate which routes operated on freeways and which routes operated outside the CBD. The matrix also indicates which routes are served exclusively by large transit buses (buses at least 9.1 m (30 ft) long). Routes which are served by smaller buses under 9.1 m (30 ft) are preferred because electric buses, which are also under 9.1 m (30 ft) would be adequately suited to accommodate ridership on those routes. However, service of a route by a smaller bus is not a requirement for effective use of an electric bus. Headways can be shortened so that smaller buses can service routes where large buses currently operate. Also, ridership on a particular route may be low enough that smaller buses can accommodate demand.

The route matrix was applied to each type of route service offered by Capital Metro. The completed matrix for each type of route service is presented in Tables 4-1 through 4-5.
Routes that met either criteria of operation on freeway or operation outside of the defined CBD were eliminated from consideration. A majority of metro routes operate primarily outside the CBD, providing service from less dense urban and suburban areas to the CBD. Due to their operation outside of the CBD, all metro routes were eliminated from consideration.

Table 4-1 Route Matrix-Metro Routes

Route#	Route Name	Operation on Freeway	Operation Outside the CBD	Served by Large Buses Only
1	North Lamar		•	•
1	Rosewood		•	•
1	Burnet		•	•
1	Montopolis		•	•
1	Woodrow		•	•
1	East 12th		•	•
1	Duval		•	•
1	Govalle			•
1	Enfield			•
11	South First		•	•
12	Manchaca		•	•
13	South Congress		•	•
14	Travis Heights		•	
15	Red River		•	•
16	South Fifth/Westgate		•	•
17	Johnston		•	•
18	Martin Luther King		•	•
19	Bull Creek		•	•
20	Manor Rd/LBJ H.S.		•	•
21	Exposition		•	
22	Chicon		•	
25	Ohlen		•	•

Table 4-1 Route Matrix-Metro Routes (cont'd)

Route#	Route Name	Operation on Freeway	Operation Outside the CBD	Served by Large Buses Only
26	Riverside		•	•
27	Dove Spring		•	•
28	Ben White		•	•
29	Barton Hills		•	•
30	Barton Creek Square		•	•
31	Oltorf		•	
32	Airport Blvd.		•	
33	William Cannon		•	
37	Colony Pk./Windsor Pk.		•	•
38	South Lamar/Westgate		•	•
39	Walnut Creek/Koenig		•	•
40	Parkfield		•	
LVF	Lago Vista Feeder		•	
42	Quail Valley/Metric		•	
43	South Oaks		•	
44	Balcones Northwest		•	
45	Copperfield		•	
46	Bergstrom		•	

Table 4-2 Route Matrix-Flyer Routes

Route#	Route Name	Operation on Freeway	Operation Outside the CBD	Served byLarge Buses Only
61	Dove Spring Flyer	•	•	•
62	Metric Flyer	•	•	•
63	Oak Hill Flyer	•	•	
64	South Central Flyer		•	•
65	Manchaca Flyer		•	•
66	North Central Flyer	•	•	•
67	Cameron Road Flyer	•	•	

Table 4-3 Route Matrix-Express/Park & Ride Routes

Route#	Route Name	Operation on Freeway	Operation Outside the CBD	Served byLarge Buses Only
IRS	IRS/VA Express	•	•	•
NEX	North East Express	•	•	
PX	Pflugerville Express	•	•	•
LX	Leander Express	•	•	•

Table 4-4 Route Matrix-'Dillo Routes

Route#	Route Name	Operation on Freeway	Operation Outside the CBD	Served byLarge Buses Only
85	Convention Center/UT 'Dillo(Red Line)			•
86	Congress Capitol 'Dillo (Blue Line)			•
87	ACC/Lavaca 'Dillo (Green Line)			•

Table 4-5 Route Matrix-UT Shuttle Routes

Route#	Route Name	Operation on Freeway	Operation Outside the CBD	Served by Large Buses Only
48	Red River		•	•
49	South Riverside	•	•	•
50	West Campus			•
51	Cameron Road	•	•	•
53	Enfield Road		•	•
54	Forty Acres			•
55	Far West	•	•	•
56	Intramural Fields		•	•
57	Lake Austin		•	•
58	North Riverside	•	•	•
59	Pleasant Valley	•	•	•
60	East Campus		•	•

All express/park & ride routes and most flyer routes were eliminated because of their freeway routing which require speeds of up to 88.5 km/hr (55 mph). Those flyer routes not operating on freeways require buses to travel fairly long distances without stopping for passengers and operate outside the CBD. These flyer routes were also eliminated from consideration.

Finally, most UT shuttle routes operate outside the CBD and several operate on freeways. UT shuttle routes meeting either of these criteria were eliminated from consideration.

Selected Routes

Based on the initial evaluation criteria presented in the route matrix, three 'Dillo routes and two UT shuttle routes were selected for possible electric bus implementation. 'Dillo routes include the Convention Center/UT 'Dillo, Congress Capitol 'Dillo, and ACC/Lavaca 'Dillo; UT shuttle routes include the Forty Acres and West Campus routes.

These routes were initially selected because of their continuous service in high density areas, which provides exposure for the electric buses and maximizes the zero tailpipe emissions benefits. Detailed maps of the Convention Center/UT 'Dillo, Congress Capitol 'Dillo, ACC/Lavaca 'Dillo, Forty Acres shuttle route, and West Campus shuttle route, including the location of all bus stops, are provided in Figures 4-1 through 4-5 found at the end of this chapter.

The three 'Dillo routes and two UT shuttle routes are all located in areas which make electric bus utilization a feasible alternative. Selection of the best route was based on three additional criteria:

- Number of bus stops per km (mil) along the route
- Average speed of the bus on the route
- Daily ridership.

An evaluation of the above criteria is presented in Table 4-6.

Table 4-6 Routes Considered for Implementation

Route	Route Length (km/mi)	Number of Bus Stops	Cycle Time (minutes)	Bus Stops per km/mi Along Route	Average Route Speed (km/hr)/ (mph)	Weekday Ridership[a]
Congress Capitol 'Dillo	6.3/3.9	24	32	3.9/6.2	11.7/7.3	725
Convention Center/UT 'Dillo (With UT extension)	13.0/8.1	40	51	3.0/4.9	15.3/9.5	496[b]
Convention Center/UT 'Dillo (Without UT extension)	9.2/5.7	29	36	3.2/5.1	15.3/9.5	496[b]
ACC/Lavaca 'Dillo	9.0/5.6	38	40	3.1/5	13.5/8.4	2087
40 Acres	3.9/2.4	6	14	1.6/2.5	16.7/10.3	4989
West Campus	4.5/2.8	13	20	2.9/4.6	13.5/8.4	5579

[a]Based on Capital Metro ridership survey, November 1992.
[b]Ridership is given for the entire day and not divided between ridership with and without UT extension.

The number of bus stops per kme (mi) indicates the frequency of stops the buses make during service of the route. As explained above, the greater the frequency of stops, the more beneficial electric buses are relative to ICE buses. The Congress Capitol 'Dillo had the greatest number of bus stops per kilometer with 24 stops on a route of 6.3 km (3.9 mi), equivalent to 3.9 stops per km (6.2 stops per mile).

Low average speeds on routes allow electric buses to service the route for a longer period of time throughout the day, which is crucial due to the current range limitations of electric buses. The Congress Capitol 'Dillo also had the lowest average speed of any selected route, completing a 6.3 km (3.9 mi) route in 32 minutes, which is an average speed of 11.7 km/hr (7.3 mph).

Finally, weekday ridership surveys were obtained from Capital Metro to assure the smaller electric vehicles had the capacity to handle ridership demand on selected routes. In the case of replacement of 'Dillo service with electric buses, ridership is not a major consideration since the electric buses seat approximately the same number of riders as the 'Dillo buses. Based on the ridership data for the 'Dillo routes, currently manufactured electric buses with seating capacities of 22 passengers are adequate to accommodate ridership demand on the 'Dillo routes. However, the high weekday ridership of the Forty Acres and West Campus UT shuttle routes may prove troublesome for the smaller electric buses. Most likely, current headways of buses on these routes during peak demand times would need to be reduced by using additional buses in order to meet ridership demand.

Final Route Recommendations

Of the four selected routes, the Congress Capitol 'Dillo route offers the most feasible route for electric buses. The operation of this route in a high density urban area takes full advantage of the benefits of a zero emission vehicle. Operation of the Congress Capitol 'Dillo along Congress Avenue from Town Lake to the Capitol will provide a great deal of exposure for the electric buses to both Austin residents and out of town tourists. The high frequency of bus stops along the route and low average speed will help to minimize the negative effects of the 113-121 km (70-75 mi) range. The current average operating speed of the Congress Capitol 'Dillo of 12.1 km/hr (7.5 mph) allows electric buses to operate continuously for approximately 10 hours before requiring a recharge.

The selection of routes on which to operate electric buses is crucial to their success. Selected routes should take maximum advantage of the benefits of an electric bus while minimizing the disadvantages, such as short range and low maximum speeds. Based on the selection criteria presented in this chapter, and the current status of electric bus technology, it is believed that the Congress Capitol 'Dillo route is best suited for use of electric buses.

Figure 4-1 Congress Capitol 'Dillo

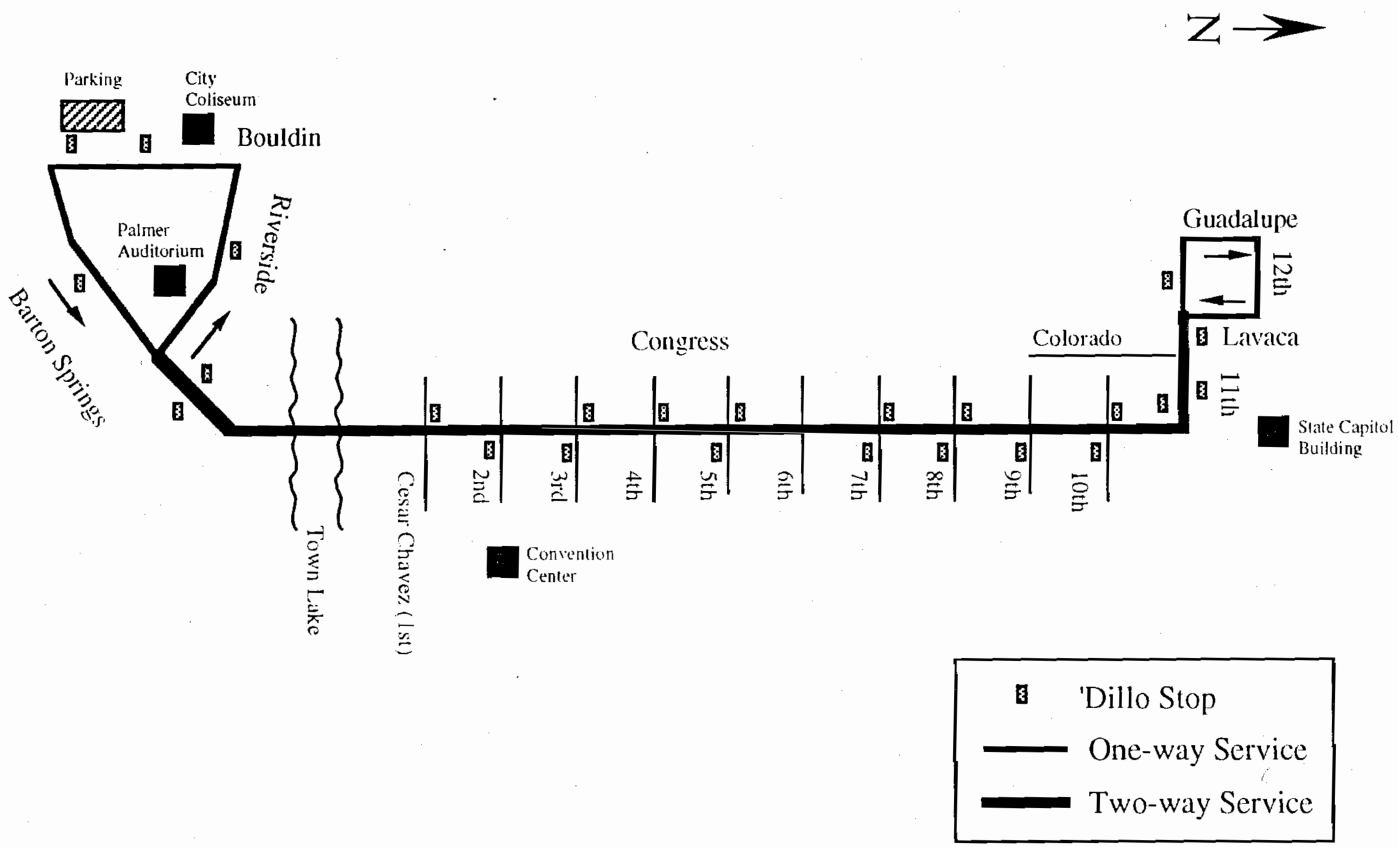


Figure 4-2 Convention Center/UT 'Dillo

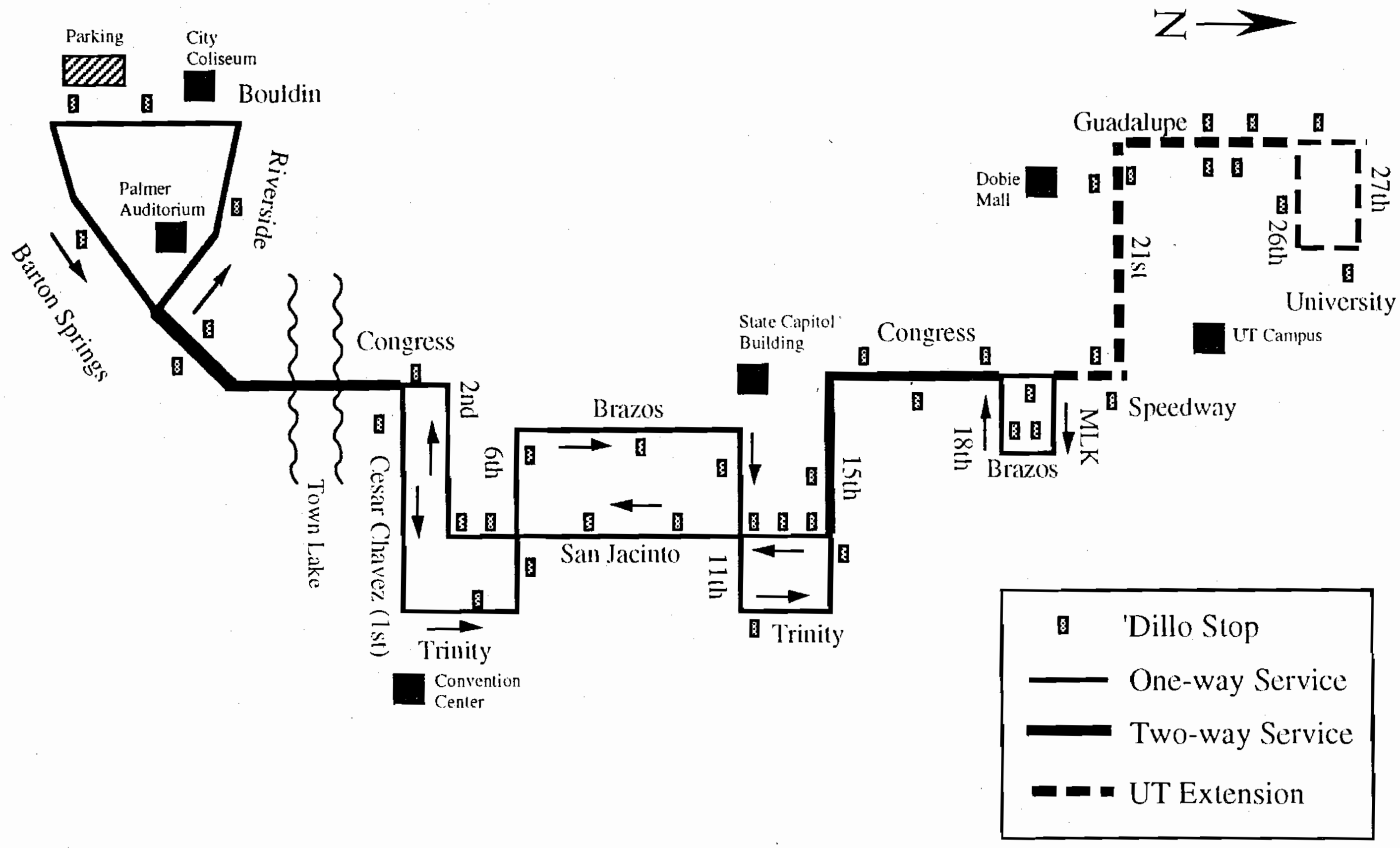


Figure 4-3 ACC/Lavaca 'Dillo

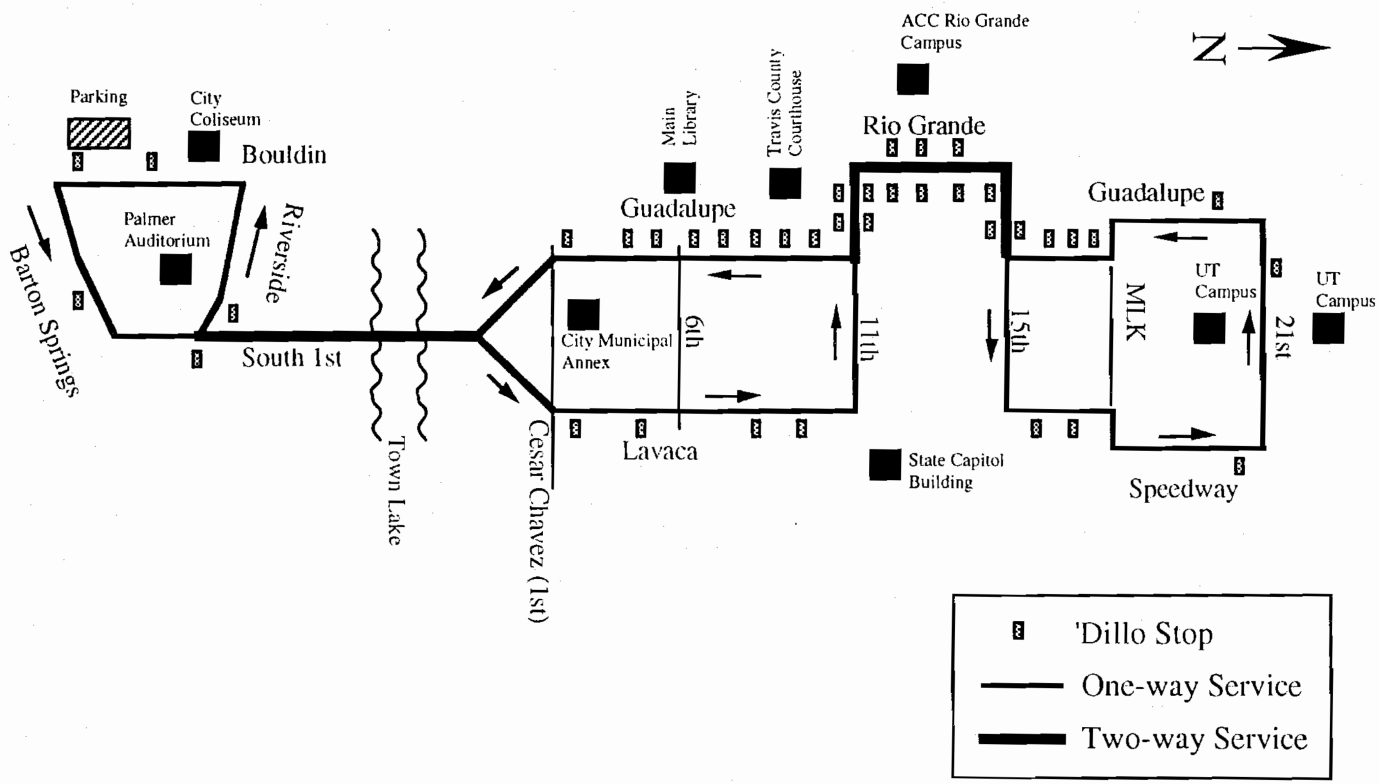


Figure 4-4 Forty Acres Shuttle Route

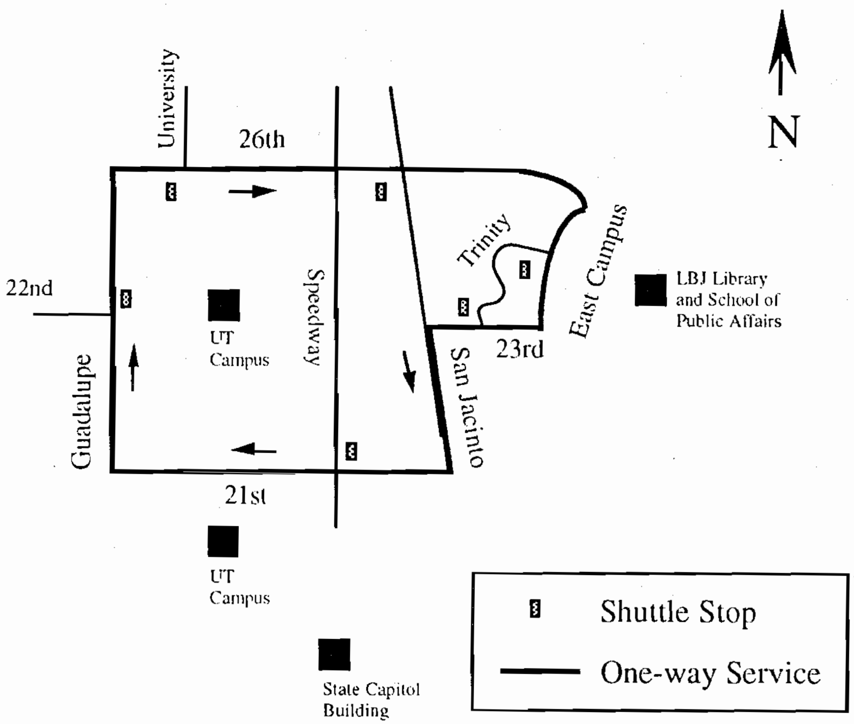
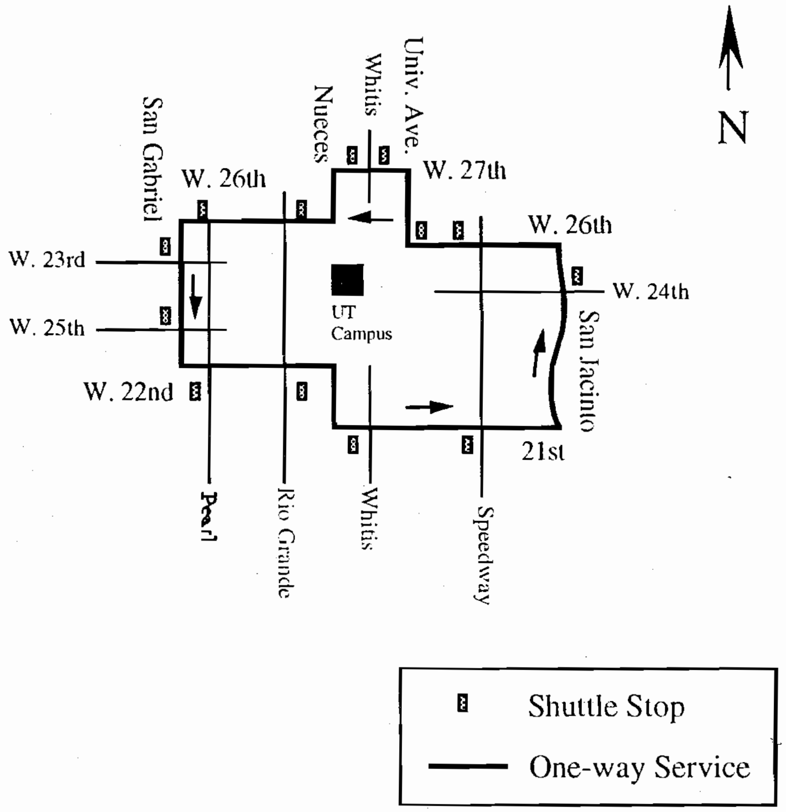


Figure 4-5 West Campus Shuttle Route



CHAPTER 5. COSTS AND BENEFITS OF ELECTRIC BUSES

This chapter attempts to measure the quantifiable costs and benefits of electric buses compared to diesel and compressed natural gas (CNG) buses. Quantifiable costs include capital costs, fuel costs, and maintenance costs. The emissions from the three types of buses are also considered, and damage costs of pollutants due to emissions are estimated.

CAPITAL COSTS

The costs of several models of diesel, natural gas, and electric buses are included in Table 5-1. Costs for the diesel and natural gas buses represent the total cost of each bus, including such features as wheelchair lifts and air conditioning. Electric bus costs represent the total bus cost and also include the cost of a separate battery charger unit.

Table 5-1 Capital Costs of Buses

Transit Agency	Bus Year, Manufacturer, and Model	Fuel Type	Length	Seating Capacity	Cost	Cost per Passenger Seat
Capital Metro	1993 TMC RTS	CNG	12.2 m (40')	41	$247,000	$6,024
Capital Metro	1993 Chance Trolley ('Dillo)	CNG	8.8 m (28.8')	28	$209,000[a]	$7,464
Capital Metro	1989 Gillig Phantom	Diesel	10.7 m (35')	39	$187,000	$4,795
Capital Metro	1989 Gillig Phantom	Diesel	9.1 m (30')	29	$174,000	$6,000
CARTA	1994 Advanced Vehicle Systems 31' Bus	Electric	9.4 m (31')	25	$225,000[b]	$9,000
CARTA	1993 Advanced Vehicle Systems 22' Bus	Electric	6.7 m (22')	22	$145,000[b]	$6,591
MTD	1992 Bus Manufacturing U.S.A, Inc. 22' Open Air Shuttle	Electric	6.7 m (22')	22	$125,000[b]	$5,682

[a]Estimated cost (Capital Metro, 1994).
[b]Includes $5,000 cost of battery charger.

Data from Capital Metro, the Chattanooga Area Regional Transportation Authority (CARTA), and the Santa Barbara Metropolitan Transit District (MTD) are used in Table 5-1 and throughout this chapter. CARTA and MTD have both been operating electric buses for several years, and have the most extensive electric bus data available.

Capital Metro buses listed in Table 5-1 represent all buses purchased in the last five years and include their 1993 TMC RTS's, 1993 Chance Trolley, and 1989 Gillig Phantoms.

The 40 ft (12.2 m) TMC RTS bus is fueled by CNG. Capital Metro acquired 30 of these buses in 1993 for use on metro routes.

The Chance Trolley is also fueled by CNG and is currently leased from Chance to provide service on the 'Dillo routes. The Chance Trolley is an experimental vehicle, and a purchase price has not been set (Capital Metro estimates that the cost for this trolley will be approximately $209,000). The 1985 diesel fuel Spartan trolleys, which provide primary service on 'Dillo routes, are not included in this study because Capital Metro will replace them in 1995. Capital Metro plans to write specifications for the new 'Dillo trolleys based on the CNG Chance trolley model and a competitive bidding process will be used to select the manufacturer (Young, 1994).

Both the 9.1 m (30 ft) and 10.7 m (35 ft) Gillig Phantom buses included in Table 5-1 are diesel fueled and operate on Capital Metro fixed routes including UT shuttle routes.

The two models of CARTA's electric buses currently in operation are included in Table 5-1. These buses include the 9.4 m (31 ft) Advanced Vehicle Systems electric bus and the 6.7 m (22 ft) Advanced Vehicle Systems electric buses. These buses are not equipped with air conditioning or heating units from the manufacturer. CARTA has installed propane fueled heaters on several buses but has not equipped any buses with air conditioning.

Finally, MTD's 22 ft (6.7 m) open air shuttle is included in Table 5-1. MTD's first two open air shuttles were manufactured by Bus Manufacturing U.S.A., Inc., and an additional six open air shuttles were manufactured by Specialty Vehicle Manufacturing Corporation. The specifications and costs of all eight shuttles are the same. These open air shuttles have an overhead roof but do not include doors or passenger windows.

In addition to the cost per bus, Table 5-1 also lists the cost per passenger seat. This was calculated by dividing the cost of the bus by the seating capacity to determine the cost of a bus to provide service to one passenger. The least expensive units based on cost per passenger seat are the diesel fueled Gillig Phantoms. MTD's open air electric shuttle also had a low cost relative to the other buses, but it is not suited for service in cold or inclement weather. The TMC CNG buses were in the mid-price range based on cost per seat. CARTA's electric buses and the CNG fueled trolley were on the high side of the cost per passenger seat estimates.

FUEL COSTS

Fuel costs, measured on a cents per kilometer (mil) basis, are provided in Table 5-2. These costs are given for Capital Metro's TMC 12.2 m (40 ft) CNG buses, Capital Metro's diesel fleet, CARTA's 6.7 m (22 ft) electric bus, and MTD's 6.7 m (22 ft) electric shuttle. Information on specific diesel bus models was not available from Capital Metro. The fuel costs per passenger seat per kilometer are also provided in Table 5-2.

The fuel costs per kilometer (mi) of the electric buses are well below those of diesel and CNG buses. CARTA's electric buses consume .93 to 1.2 kWh/km (1.5 to 1.9 kWh/m) of travel, and unlike diesel and CNG buses which idle and continue to consume fuel when stopped, electric buses do not consume any electricity when stopped. CARTA's estimate of 2.8-3.5 ¢/km (4.5 to 5.7 ¢/mi) (Hartman, 1993) are below the fuel costs of the diesel and CNG buses, even when measured by fuel costs per passenger seat per kilometer (mi). MTD's estimate of 4.4 ¢/km (7 ¢/mi) (Doerschlag, 1994) is also below the fuel costs of diesel and CNG buses. When measured based on fuel costs per passenger seat per kilometer, fuel costs of the MTD electric shuttle are equivalent to the fuel costs for CNG buses and below the fuel costs for diesel buses.

Table 5-2 Fuel Costs

Bus Model	Fuel Cost per km (mi)	Fuel Cost per Passenger Seat per km (mi)
Capital Metro TMC CNG[a]	8.1¢ (13¢)	20¢ (.32¢ (.)
Capital Metro Diesel[b]	12.4¢ (20¢)	.36¢ (.59¢)
CARTA 22' Electric Bus[c]	2.8-3.5¢ (4.5-5.7¢)	.13-.16¢ (.20-.26¢)
MTD 22' Electric Shuttle[c]	4.4¢ (7¢)	.20¢ (.32¢)

[a]Based on average Capital Metro CNG fleet fuel efficiency rating of 4.8 km/g (3 mpg), CNG fuel cost of 39¢/gallon equivalent, and CNG bus fleet passenger seating capacity of 41.
[b]Based on average Capital Metro diesel fleet fuel efficiency rating of 5.6 km/g (3.5 mpg), diesel fuel cost of 70¢/gallon, and average diesel bus fleet passenger seating capacity of 34.
[c]Based on battery recharging during off peak electricity rates. The electric buses have a seating capacity of 22.

MAINTENANCE COSTS

Maintenance costs of Capital Metro's diesel and CNG buses, and CARTA's electric bus, are given in Table 5-3. Capital Metro's estimates for diesel and CNG maintenance costs are the same. (Insufficient data is available to evaluate any differences in costs between the two vehicle types.)

Table 5-3 Maintenance Costs

Bus	Maintenance Cost per km (mi)	Total Maintenance Cost per km (mi)	Total Maintenance Cost per Passenger Seat per km (mi)
Capital Metro Diesel and CNG[a]	11.6¢ (18.7¢) Parts 19.2¢ (30.9¢) Labor	30.8¢ (49.6¢)	.9¢ (1.5¢) Diesel[c] .8¢ (1.2¢) CNG[d]
CARTA 22' Electric Bus	21.8¢ (35.0¢) Maintenance 7.1¢ (11.4¢) Battery[b]	28.9¢ (6.4¢)	1.3¢ (2.1¢)[e]

[a]Maintenance cost based on Capital Metro 1994 fleet maintenance budget.
[b]Battery replacement cost based on a battery pack with a life of 1,500 recharge cycles and cost of $12,000.
[c]Based on average Capital Metro diesel bus fleet passenger seating capacity of 34.
[d]Based on CNG bus fleet passenger seating capacity of 41.
[e]Based on electric bus passenger seating capacity of 22.

Maintenance costs for CARTA's 6.7 m (22 ft) electric buses also include the cost for battery replacement. It is estimated that battery life is consumed at 1,500 recharge cycles. (Capell, 1994). CARTA's buses have only experienced approximately 500 cycles at this time, and CARTA expects to pay $12,000 per battery pack for replacement (Capell, 1994).

Specific maintenance data was not available from MTD, but their initial estimates for battery cycle life and replacement costs match those of CARTA (Doerschlag, 1994).

Total maintenance costs, including battery replacement costs, are lower for electric buses compared to diesel and CNG buses. However, if compared on a cost per passenger seat basis, the maintenance costs of the electric buses are actually higher than diesel and CNG buses.

The reduced maintenance costs of electric buses (due to their lack of transmissions, cooling systems, and tune-ups) are partially offset by the costs for battery maintenance and replacement. Maintenance costs will remain close if a larger electric bus is compared with a diesel and CNG bus because bus size does not have a significant impact on maintenance costs. (It would, however, increase the fuel costs because of the larger battery pack required for bigger buses.) Unfortunately, CARTA did not have estimates on maintenance costs for their 9.4 m (31 ft), 25-passenger bus, which only recently began route service. The maintenance costs for this bus should be similar to the maintenance costs for the 6.7 m (22 ft), 22-passenger electric bus. If this is true, maintenance costs per passenger seat on the 9.4 m (31 ft) electric bus would be

1.2¢/km (1.9 ¢/mile), still higher than the diesel and CNG costs per passenger seat but lower than the maintenance costs per passenger seat for the 6.7 m (22 ft) electric bus.

EMISSIONS

The primary benefit of electric buses is that they have zero tailpipe emissions. There are, however, emissions associated with electricity generation which must be accounted for, but total fuel-cycle emissions of electric buses are still less than those of diesel and natural gas buses. A pollutant cost index is developed in this section to determine the damage cost of individual pollutants. These pollutant costs are then applied to the emissions levels of each bus to estimate the pollutant damage costs for operating each bus.

Effects of Emissions

The five emissions associated with the National Ambient Air Quality Standards (NAAQS) were selected for evaluation: carbon monoxide (CO), hydrocarbons (HC)[1], nitrogen oxides (NO_X), sulfur oxides (SO_X), and particulates.

Carbon monoxide is a colorless, odorless, tasteless gas, produced by incomplete combustion in motor vehicles, industrial processes, gas and wood stoves, and cigarette smoking. Nationally, 63 percent of the outdoor carbon monoxide pollution is emitted by motor vehicles (EPA, 1993). Carbon monoxide is absorbed into the blood and displaces oxygen in red blood cells, reducing the amount of oxygen available to cells throughout the body. Exposure to high levels of carbon monoxide can place additional strain on cardiac and respiratory systems (Hyndman, 1992), and adversely affect mental processes (Halvorsen, 1981).

Hydrocarbons are the volatile portion of unburned fuel emitted from motor vehicle engines. Sources of hydrocarbons include exhaust gases and evaporative loss due to refueling engines. Hydrocarbons may cause skin irritations and has been linked to an increase in the number of leukemia cases (Hyndman, 1992).

Nitrogen oxides include nitric oxide, an odorless, colorless gas, and nitrogen dioxide, a yellow-brown gas with a sweet, pungent odor. Nitric and nitrogen dioxide are produced by motor vehicles and other combustion sources such as coal-or oil-fueled power plants. Nitrogen oxides can interfere with the defense mechanisms of the lung (thereby increasing susceptibility to lung infections), decrease pulmonary function, and adversely affect vegetation (Faiz, 1990).

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[1]The NAAQS do not include HC as a criteria pollutant. Ground level ozone, the primary constituent of smog, is the principal concern. HC, however, is a major contributor, along with NO_X, to the development of tropospheric ozone. Regulations for tailpipe emissions, etc. are for hydrocarbons.

Hydrocarbons and nitrogen oxides react with sunlight to form ozone, a major constituent of smog. Exposure to elevated levels of ozone can cause irritations in the eyes and chest, headaches, respiratory illness, increased asthma attacks, and reduced pulmonary functions. Ozone can also inflict damage on vegetation, reduce crop yield, and accelerate the deterioration process of plastics and rubber (Faiz, 1990).

Sulfur dioxide combines with water to form sulfurous acid. Major sources of sulfur dioxide include power plants, primary metals industries, and industrial boilers. Sulfur dioxide can adversely affect the respiratory system, and is a primary contributor to acid raid. Extensive damage to lakes, streams, and the wildlife inside of them has been associated with sulfur dioxide. Acid rain also causes damage to vegetation, stone, structural steel, and oil-based paint (Halvorsen, 1981).

Combustion sources often emit fine particulates under 10 micrometers (PM10). PM10 can reduce local visibility, cause human respiratory problems, and cause soiling when deposited on buildings and other materials. Further, fine particulates will tend to remain airborne until brought down by precipitation (Chernick, 1989).

Pollutant Costs

There are three methods that can be used to measure the social costs of pollutants (Federal Highway Administration, 1984). The damage cost method evaluates damage in the form of medical injuries, death, lost earnings, and physical damage to property and agriculture. External social costs reflect the actual expenditures used to compensate for these damages.

The revealed preference method measures how much people would be willing to pay to avoid a particular externality. Real estate property values are often used as a measure of the price a person will pay to avoid an externality such as noise or air pollution.

Finally, the optimal control costs method measures the cost of reducing an externality to some defined limit, for example, the U.S. Environmental Protection Agency (EPA) ambient air standards. The social cost of a particular pollutant is then the cost to reduce the level of that pollutant to the EPA standards.

A literature review revealed four studies that attempt to estimate pollutant costs on a cost per unit weight basis: Small (1977), Haugaard (1981), Massachusetts Department of Public Utilities (1989), and Ottinger, et. al. (1989). All of the studies use the damage cost method for estimating pollutant costs. Table 5-4 presents pollutant cost estimates for each study on a per gram basis.

Small bases his pollutant costs estimates on damages caused by air pollution to health and materials. The costs due to mortality are based on lost earnings as a result of death. An attempt to arrive at a value of human life estimate is not included. The costs associated with morbidity include medical costs and lost earnings due to absence from work. Small determines that the best lower bound estimate of U.S. cost due to air pollution is five percent of the total U.S. cost due to mortality and morbidity in 1963. Allocation of the total cost to various pollutants is based on the emissions and severity of each pollutant.

The costs due to materials damage and the need to use more expensive materials (such as aluminum for galvanized steel) to combat the effects of pollution are also considered.

Small also omits the pollutant costs for damage to agriculture. He reasons that the estimates of agriculture damage costs are so small that including them is not warranted. Other categories such as aesthetic loss, damage to wildlife, and possible long term ecological damage are not included because of the difficulty of quantitative estimates.

Haugaard's estimates of pollutant costs are based on damage to human heath, materials, and vegetation. Damage costs to human health are based on medical bills and lost earnings as a result of mortality and morbidity. Damage costs to materials are based on 32 kinds of materials affected by pollution. Damage costs to vegetation are based on 77 crops, as well as shade trees and other ornamental trees and shrubbery.

The purpose of Ottinger's study was to develop a pollutant cost index that could be used for electric utilities to estimate the social costs of producing electricity. Pollutant damages were estimated individually for each pollutant. This differs from the approach used by Small and Haugaard, who first evaluate the social cost of all air pollution and then attempt to disaggregate by specific pollutants.

Cost estimates of NO_X emissions in Ottinger's study are based on impacts to health, materials, vegetation, and visibility. A value of human life estimate of $4 million is used to determine mortality costs. Estimation of vegetation damage is based only on damage to crops, with the categories of damage to forests and ornamental plants excluded.

Pollutant costs of SO_X emissions are based on impacts to health, materials, and visibility. Health costs accounted for nearly all of the total SO_X pollutant cost.

Particulate pollutant cost estimates are based on impacts to health and visibility. Visibility accounted for approximately 70 percent of the total particulate pollutant cost.

Table 5-4 Pollutant Costs Estimates By Study (¢/Gram)

Study	CO	HC	NO_X	SO_X	Part.
Small 1977 Health costs per urban emission, 1974 (¢/gram)	0.00068	0.00683	0.0164	0.0144	0.0206
Materials costs per urban emission, 1974 (¢/gram)	0.0	0.00375	0.0185	0.0289	0.0
Total cost per urban emission, 1974 (¢/gram)	0.00068	0.0106	0.0350	0.0432	0.0206
Haugaard 1981 Health costs per emission, 1981 (¢/gram)	0.00158	0.0158	0.0380	0.0332	0.0475
Materials costs per emission, 1981 (¢/gram)	0.00025	0.00765	0.0396	0.0627	0.0405
Vegetation costs per emission, 1981 (¢/gram)	*	0.00076	0.00091	0.00007	*
Total cost per urban emission, 1981 (¢/gram)	0.00183	0.0238	0.0779	0.0960	0.0880
Ottinger 1989 Health costs per emission, 1989 (¢/gram)	*	*	0.139	0.390	0.079
Materials costs per emission, 1989 (¢/gram)	*	*	0.002	0.026	0.0
Vegetation costs per emission, 1989 (¢/gram)	*	*	0.002	0.0	0.0
Visibility costs per emission, 1989 (¢/gram)	*	*	0.037	0.031	0.183
Total cost per urban emission, 1989 (¢/gram)	*	*	0.180	0.448	0.262
Massachusetts Department of Public Utilities 1989 Total cost per urban emission, 1989 (¢/gram)	0.0959	*	0.716	0.165	0.441

* Values not given

In August 1990, the Massachusetts Department of Public Utilities issued a regulation requiring electric utilities to consider pollutant costs when calculating the social costs of resource options. Similar to Ottinger's study, the Massachusetts Department of Public Utilities study estimates the damage cost of each pollutant separately. Eight pollutants were evaluated, including CO, NO_X, and SO_X. Hydrocarbon damage costs were not included in the study.

The results presented in the previous tables have been recalculated to January 1993 dollars. This was done using the January 1993 implicit price deflator value for personal consumption expenditures (U.S. Department of Commerce, 1993). Table 5-5 summarizes the results of each study in January 1993 dollars.

Table 5-5 Pollutant Costs (¢/gram), January 1993 Dollars

Study	CO	HC	NO_X	SO_X	Part.
Small	0.0019	0.0294	0.097	0.120	0.057
Haugaard	0.0029	0.0384	0.122	0.155	0.142
Ottinger	*	*	0.180	0.448	0.262
Massachusetts Department of Public Utilities	0.096	*	0.822	0.189	0.506

* Values not given

Total Fuel-Cycle Emissions

Total fuel-cycle emissions are determined for the CNG, diesel, and electric buses. Total fuel-cycle emissions include emissions due to feedstock extraction, feedstock transportation, conversion of feedstock into end-use fuel or electricity, transportation of end-use fuel, and tailpipe emissions of vehicles. Estimates for total fuel-cycle emissions are given in Table 5-6. Emissions for the CNG and diesel buses are divided into two categories, fuel-cycle and tailpipe emissions. Fuel-cycle emissions are defined in this study as all emissions associated with the total fuel-cycle other than tailpipe emissions.

Full fuel-cycle emissions estimates for CNG buses include emissions from extraction, transportation, and compression of the fuel; and emissions from the tailpipe. Values given in Table 5-6 for fuel cycle emissions are based on a study by Darrow (1994) prepared for the Gas Research Institute. The study uses a small van as a base vehicle for calculations of grams per mile equivalent emissions. The estimates for CNG bus emissions in Table 5-6 are adjusted to reflect the lower fuel efficiency, and therefore higher emissions, of the CNG buses.

Table 5-6 Bus Emissions In Grams Per Mile (G/Km)

Bus	CO	HC	NO_X	SO_X	Part.
Capital Metro CNG[a]					
Fuel Cycle	0.40 (0.25)	0.62 (0.39)	3.26 (2.03)	1.96 (1.22)	0.04 (0.02)
Tailpipe	3.38 (2.10)	1.25 (0.78)	10.68 (6.64)	*	0.13 (0.08)
Total	**3.78 (2.35)**	**1.87 (1.16)**	**13.94 (8.66)**	**1.96 (1.22)**	**0.17 (0.11)**
Capital Metro Diesel[a]					
Fuel Cycle	0.50 (0.31)	1.58 (0.98)	1.41 (0.88)	0.27 (0.17)	0.08 (0.05)
Tailpipe	26.8 (16.66)	1.4 (0.87)	27.6 (17.15)	*	3.1 (1.93)
Total	**27.30 (16.97)**	**2.98 (1.85)**	**29.01 (18.03)**	**0.27 (0.17)**	**3.18 (1.98)**
CARTA 22' Electric Bus[b]					
Feedstock Extraction	0.06 (0.04)	0.08 (0.05)	0.23 (0.14)	0.03 (0.02)	0.01 (0.006)
Power Plant	0.12 (0.07)	0.04 (0.02)	4.38 (2.72)	7.87 (4.89)	0.01 (0.006)
Tailpipe	0.0	0.0	0.0	0.0	0.0
Total	**0.18 (0.11)**	**0.12 (0.07)**	**4.61 (2.87)**	**7.90 (4.91)**	**0.02 (0.012)**
MTD 22' Electric Bus[c]					
Feedstock Extraction	0.04 (0.02)	0.06 (0.04)	0.16 (0.10)	0.02 (0.01)	0.01 (0.006)
Power Plant	0.07 (0.04)	0.02 (0.01)	2.77 (1.72)	5.56 (3.46)	0.01 (0.006)
Tailpipe	0.0	0.0	0.0	0.0	0.0
Total	**0.11 (0.07)**	**0.08 (0.05)**	**2.93 (1.82)**	**5.58 (3.47)**	**0.02 (0.012)**

*Values not given

[a]Based on Cummins L10 Engine (Kitchen and Damico, 1992).

[b]Electric bus energy consumption estimated to be 1.9 kWh/mile (1.18 kWh/km) (Hartman, 1993), emissions data based on data from SCEVC (1992) and Hamilton (1992).

[c]Electric bus energy consumption estimated to be 1.2 kWh/mile (.75 kWh/km) (Gleason, 1992), emissions data based on data from SCEVC (1992) and Hamilton (1992).

Tailpipe emissions for the CNG buses are based on the engine manufacturer's estimates in grams per brake-horsepower-hour (Turner, 1994). Using a conversion factor determined by Kitchen and Damico (1992), grams per brake-horsepower-hour are converted to grams per kilometer (mi) for a vehicle operating in the central business district (CBD) driving cycle. The CBD driving cycle attempts to simulate driving in a dense urban environment with the vehicle operating at an average speed of 19.9 km/hr (12.4 mph).

Diesel bus fuel cycle emissions are based on Darrow's emission estimates for a gasoline-powered vehicle. (Darrow did not include a diesel-powered vehicle in his study.) Estimates for diesel bus emissions are adjusted to reflect the fuel economy differences of the diesel buses compared to the gasoline van used in Darrow's study.

Tailpipe emissions for the diesel buses are based on Kitchen and Damico's study. In their study, emissions per kilometer (mi) are determined for a diesel bus operating with an engine comparable to those in Capital Metro's diesel buses. The emissions are estimated using the CBD driving cycle.

Electric vehicle emissions are based on emissions associated with feedstock extraction and electricity generation. There are zero tailpipe emissions associated with electric buses.

Feedstock extraction emissions include emissions from mining and drilling, and emissions from the transport of feedstock fuel. These estimates are based on Darrow's study. Darrow's study estimates the emissions in grams per mile based on an electric van with an electricity consumption rate of 0.30 kWh/km (0.48 kWh/mi). Darrow's estimates of emissions on a per mile basis are increased for use in this study to appropriately reflect the greater electricity consumption of the electric buses.

Emissions from electricity generation vary depending on the fuel used to produce electricity. In Austin, approximately half of the electricity is produced by the Holly and Decker natural gas power plants. The other half is usually produced by the Fayette plant, which is coal-fueled, or purchased from other Texas utilities. Austin is also a partner in the South Texas Project, a nuclear power plant which has not been in operation since February 1993. Although the plant has recently been brought back on line, the percentage of power that it will supply to Austin is currently unknown. For this study, half of the electricity is assumed to be produced from natural gas-powered plants and half is assumed to be produced from coal-powered plants. Estimates of emissions from these power plants are used to determine the electric bus emissions per kilometer (mi) due to electricity generation.

Damage Costs Due to Emissions

Table 5-5 presented pollutant cost damage estimates. The Massachusetts Department of Public Utility estimates are significantly different than the estimates of the other three studies. It was not possible within the scope of this study to determine the cause of these differences. Therefore, an average cost based on the studies by Small, Haugaard, and Ottinger is used for each pollutant. Pollutant damage values calculated are 0.0024 ¢/gram for carbon monoxide, 0.0339 ¢/gram for hydrocarbons, 0.133 ¢/gram for nitrogen oxides, 0.241 ¢/gram for sulfur oxides, and 0.154 ¢/gram for particulates.

Based on the previous values and the values given in Table 5-6, the damage costs of pollutants are calculated per distance of operation for the buses. These damage costs are based only on emissions from the tailpipe of the vehicles and from the generation of electricity. Table 5-7 presents the pollutant damage per kilometer (mi) estimates.

Table 5-7 Pollutant Damage Costs per km (mi) of Operation

Bus	CO costs per km (mi)	HC costs per km (mi)	NO_x costs per km (mi)	SO_x costs per km (mi)	Part. costs per km (mi)	Total Damage Costs per km (mi)
Capital Metro CNG	0.0057¢ (0.0091¢)	0.0394¢ (0.0634¢)	1.1520¢ (1.8540¢)	0.2936¢ (0.4724¢)	0.0158¢ (0.0255¢)	1.5068¢ (2.4244¢)
Capital Metro Diesel	0.0407¢ (0.0655¢)	0.0628¢ (0.1010¢)	2.3980¢ (3.8583¢)	0.0405¢ (0.0651¢)	0.2965¢ (0.4770¢)	2.8383¢ (4.5669¢)
CARTA 22' Electric[a]	0.0002¢ (0.0004¢)	0.0025¢ (0.0041¢)	0.3810¢ (0.6131¢)	1.1833¢ (1.9039¢)	0.0020¢ (0.0032¢)	1.5691¢ (2.5247¢)
MTD 22' Electric[b]	0.0002¢ (0.0003¢)	0.0017¢ (0.0027¢)	0.2422¢ (0.3897¢)	0.8358¢ (1.3448¢)	0.0019¢ (0.0031¢)	1.0817¢ (1.7406¢)

[a]Electric bus energy consumption estimated to be 1.18 kWh/km (1.9 kWh/mi) (Hartman, 1993).
[b]Electric bus energy consumption estimated to be .75 kWh/km (1.2 kWh/mi) (Gleason, 1992).

ANALYSIS

The Federal Transit Agency (FTA) requires that buses purchased with their assistance operate a minimum of 804,500 km (500,000 mi) or 12 years. For the purpose of this analysis, it is assumed that all buses analyzed are operated for 804,500 km (500,000 mi), at which time they are retired and retain no value.

Two cost scenarios are considered. The first evaluates the total cost to purchase and operate buses based on capital costs, fuels costs, and maintenance costs presented in Tables 5-1 through 5-3. The second scenario evaluates total costs based on the previous three factors as well as damage due to pollutants.

Refueling infrastructure and operating costs are not considered in either scenario, although it is important to note that these costs can have a significant impact on the cost of bus operations. Construction costs for Capital Metro's CNG refueling station were approximately 2.7 million dollars, and operating costs for the station are approximately 2.6¢/liter (10¢/gal) equivalent of fuel distributed.

Total Costs Based on Capital, Fuel, and Maintenance Costs

The first scenario evaluates the costs for Capital Metro's 12.2 m (40 ft) TMC CNG bus, 10.7 m (35 ft) diesel-power Gillig Phantoms, and 10.7 m (30 ft) diesel-power Gillig Phantoms; CARTA's 9.4 m (31 ft) and 6.7 m (22 ft) electric buses; and MTD's 6.7 m (22 ft) open air shuttle.

The purchase costs of the buses are added to the fuel costs and maintenance costs of operating each bus for 804,500 kilometer (500,000 mi). (Capital Metro's 1993 Chance Trolley is not included in either scenario because an actual purchase price is unknown and maintenance costs for the trolley are not available.)

Table 5-8 presents the results. Total cost of purchase and operation is lowest for the three electric bus models. Over a lifetime of 804,500 km (500,000 mi), electric buses generate a fuel cost savings of $65,000 compared to diesel buses and $30,000 compared to CNG buses. Maintenance cost savings for the electric buses compared to diesel and CNG buses are approximately $16,000.

On a cost per passenger seat basis, electric buses compare less favorably with diesel and CNG buses. The 12.2 m (40 ft) CNG bus and the 10.7 m (35 ft) diesel bus had the lowest costs per passenger seat. Costs per passenger seat for the electric buses are comparable to those for the CNG trolley and the 10.7 m (30 ft) diesel bus.

It should be noted that bus ridership rarely reaches the maximum seating capacity of the bus. In many cases, larger diesel and CNG buses can be replaced with electric buses. In these cases, electric buses offer a costs savings, based on purchase, maintenance, and fuel costs, compared to diesel and CNG buses. Moreover, infrastructure costs are not included for CNG or diesel.

Total Costs Including Pollutant Costs

The second scenario includes all of the costs from the first scenario as well as the pollutant damage costs. Table 5-9 presents the results of adding the pollutant damage costs into the total cost of operating the CNG, diesel, and electric buses. Pollutant damage costs that were computed for CARTA's 6.7 m (22 ft) electric bus were also applied to CARTA's 9.4 m (31 ft) electric bus. Although the exact number of kilowatts per mile required by the 9.4 m (31 ft) bus was not known, CARTA estimated that it should be close to that of the 6.7 m (22 ft) electric bus.

Pollutant damage costs had greatest adverse affect on the operating costs of the diesel buses. Pollutant damage costs for CARTA's electric buses are nearly equivalent to those of the CNG bus, and MTD's electric shuttle's pollutant damage costs are the lowest of all buses evaluated.

The use of the pollutant damage cost estimates must be done with some caution. Values placed on the damage of pollutants is very subjective. While approximate values may be attempted, it's rare that two studies of pollutant damages yield very similar results.

The operating costs over a 804,500 kilometer (500,000 mi) life of all three electric bus models presented in table 5-9 are substantially lower than those of the CNG and diesel buses on a total cost basis. Transit agencies that find a 22-passenger bus will suit the needs of a particular route served by a 29-passenger diesel bus may find their total yearly savings compared to the diesel to be from $129,750 to $144,150 if the value of pollution reduction is considered.

The costs per passenger seat for the electric buses are still high relative to the cost per passenger seat for the CNG and diesel buses, even with the savings in pollutant costs. The 9.4 m (31 ft) and 6.7 m (22 ft) electric buses still represent the highest costs per passenger seat at $19,804 and $18,868 per passenger seat respectively. The TMC RTS 12.2 m (40 ft) CNG bus has the lowest cost per passenger seat at $13,954. Importantly, this latter figure does not include the cost of fueling or maintaining CNG refueling infrastructure. Including the CNG station development and operating costs, estimated to be about $0.30 per gallon equivalent (DOE, 1988), increases the total cost of the CNG bus to $621,428, or $15,157 per passenger seat.

Table 5-8 Total Cost Based on Capital, Fuel, and Maintenance Costs

Bus Year, Manufacturer, and Model	Purchase Cost	Fuel Cost per km (mi)	Maintenance Cost per km (mi)	Total Cost Based on 804,500 km (500,000 mi) Life of Vehicle	Cost per Passenger Seat Based on 804,500 km (500,000 mi) Life of Vehicle
12.2 m (40') CNG Bus	$247,000	8.1¢ (13¢[a])	30.8¢ (49.6¢[e])	$560,000	$13,658
10.7 m (35') Diesel Bus	$187,000	12.4¢ (20¢[b])	30.8¢ (49.6¢[e])	$535,000	$13,718
9.1 m (30') Diesel Bus	$174,000	12.4¢ (20¢[b])	30.8¢ (49.6¢[e])	$522,000	$18,000
9.4 m (31') Electric Bus	$225,000	3.2¢ (5.1¢[c])	28.9¢ (46.4¢[f])	$482,500	$19,680
6.7 m (22') Electric Bus	$145,000	3.2¢ (5.1¢[c])	28.9¢ (46.4¢[f])	$402,500	$18,727
6.7 m (22') Electric Shuttle	$125,000	4.4¢ (7¢[d])	28.9¢ (46.4¢[f])	$392,000	$17,818

[a]Based on average Capital Metro CNG fleet fuel costs.
[b]Based on average Capital Metro diesel fleet fuel costs.
[c]Average value of CARTA's high and low end fuel costs estimate.
[d]MTD estimate.
[e]Maintenance costs are based on Capital Metro's 1994 fleet maintenance budget.
[f]Maintenance costs are based on CARTA's 6.7 m (22 ft) and are assumed to be the same for the Advanced Vehicle Systems 9.4 m (31 ft) bus and the Bus Manufacturing, U.S.A. Inc. 6.7 m (22 ft) shuttle.

Table 5-9 Total Cost Including Pollutant Damage Costs

Bus Year, Manufacturer, and Model	Purchase Cost	Fuel Cost per km (mi)	Maintenance Cost per km (mi)	Total Pollutant Damage Costs per km (mi)	Total Cost Based on 804,500 km (500,000 mi) Life of Vehicle	Cost per Passenger Seat Based on 804,500 km (500,000 mi) Life of Vehicle
12.2 m (40') CNG	$247,000	8.1¢ (13¢[a])	30.8¢ (49.6¢[e])	1.51¢ (2.42¢)	$572,100	$13,954
10.7 m (35') Diesel	$187,000	12.4¢ (20¢[b])	30.8¢ (49.6¢[e])	2.84¢ (4.57¢)	$557,850	$14,304
9.1 m (30') Diesel	$174,000	12.4¢ (20¢[b])	30.8¢ (49.6¢[e])	2.84¢ (4.57¢)	$544,850	$18,788
9.4 m (31') Electric Bus	$225,000	5.1¢[c] (3.2¢)	28.9¢ (46.4¢[f])	1.57¢ (2.52¢)	$495,100	$19,804
6.7 m (22') Electric Bus	$145,000	3.2¢ (5.1¢[c])	28.9¢ (46.4¢[f])	1.57¢ (2.52¢)	$415,100	$18,868
6.7 m (22') Electric Shuttle	$125,000	4.4¢ (7¢[d])	28.9¢ (46.4¢[f])	1.08¢ (1.74¢)	$400,700	$18,214

[a]Based on average Capital Metro CNG fleet fuel costs.
[b]Based on average Capital Metro diesel fleet fuel costs.
[c]Average value of CARTA's high and low end fuel costs estimate.
[d]MTD estimate.
[e]Maintenance costs are based on Capital Metro's 1994 fleet maintenance budget.
[f]Maintenance costs are based on CARTA's 6.7 m (22 ft) and are assumed to be the same for the Advanced Vehicle Systems 9.4 m (31 ft) bus and the Bus Manufacturing, U.S.A. Inc. 6.7 m (22 ft) shuttle.

CHAPTER 6. CONCLUSION

SUMMARY

The goals of this study are to determine the technical and economic feasibility of electric bus operations. Technical feasibility can be measured through objective criteria such as range, maximum speed, and size of an electric bus. Determining economic feasibility presents a great deal more difficulty. Valuing the monetary benefit from emissions reductions is very inaccurate as displayed by the disparity in results of the pollutant costs studies discussed in this chapter. Several economic factors which contribute to the feasibility of electric bus operations were not considered in this study. Benefits of a reduction in dependence on foreign oil resulting from the use of electric vehicles, energy conservation, and decreases in noise pollution are all valuable attributes of battery-powered electric buses which are extremely difficult, if not impossible, to accurately assign monetary values.

Based on the review of current technology and use of electric buses in Chapters 2 and 3, this study concludes that electric buses are technically feasible for operation in transit services. As discussed in Chapter 3, electric buses provide adequate range, speed, and size to service a variety of routes. Transit officials must be fully aware of the limitations of the buses, however, and be sure to select routes suitable for electric bus operations. One such decision process for route selection is presented in Chapter 4.

Based on the analysis in Chapter 5, operation of electric buses can prove to be economically feasible if their smaller passenger seating capacity is adequate to serve present demand. The fuel and maintenance costs of electric buses are below those of diesel and natural gas buses, and over their expected service life the fuel and maintenance savings can make electric buses an attractive alternative fuel option. However, there are many additional costs that are associated with implementing new technologies that need to be considered before a determination can be made regarding the economic feasibility of electric buses.

RECOMMENDATIONS

Although this study concludes that electric bus operations are technically feasible at this time, the economic feasibility of electric buses is less certain. There are several costs which this study did not attempt to quantify. Transit agencies operating electric buses expressed concern over the number of hours that management has devoted to the implementation of the electric buses. Costs for familiarizing drivers and mechanics with the buses are higher than if an agency were to convert to CNG or other alternative fuel which utilizes an internal combustion engine similar to a diesel engine. Schedulers and planners must be cognizant of electric bus limitations, such as range and maximum speed, and take these into account when determining a route and its service schedule. Although electric buses may prove to be feasible, the management of a transit agency will have to be fully committed to the idea of implementing electric buses, if only on a small scale, for the buses to be successful. A high initial investment in capital and training will need to be made, but over time, as technology develops and transit personnel gain experience, electric buses may not only reduce pollution but transit expenses as well.

APPENDIX A

CAPITAL METROPOLITAN TRANSPORTATION AUTHORITY SERVICE ROUTES

Table A-1 Metro Routes

Route#	Route Name	Type of Bus	Days Service Offered	Weekday Service Begins	Weekday Service Ends
1	North Lamar	Large	Everyday	5:40 am	12:25 am
2	Rosewood	Large	Everyday	5:34 am	11:39 pm
3	Burnet	Large	Everyday	5:10 am	12:39 am
4	Montopolis	Large	Everyday	4:57 am	11:43 pm
5	Woodrow	Large	Everyday	5:40 am	11:50 pm
6	East 12th	Large	Everyday	5:28 am	11:58 pm
7	Duval	Large	Everyday	5:16 am	11:32 pm
8	Govalle	Large	Everyday	5:05 am	12:12 am
9	Enfield	Large	Everyday	6:04 am	10:44 pm
10	South First	Large	Everyday	5:28 am	11:21 pm
12	Manchaca	Large	Everyday	5:30 am	12:26 am
13	South Congress	Large	Everyday	5:30 am	12:12 am
14	Travis Heights	Large/ Small	Weekdays/ Saturday	6:07 am	10:32 pm
15	Red River	Large	Everyday	5:40 am	12:19 am
16	South Fifth/ Westgate	Large	Everyday	5:40 am	12:01 am
17	Johnston	Large	Everyday	5:20 am	12:57 am
18	Martin Luther King	Large	Everyday	5:17 am	12:13 am
19	Bull Creek	Large	Weekdays/ Saturday	5:25 am	10:26 pm
20	Manor Rd/ LBJ H.S.	Large	Everyday	5:04 am	12:27 am
21	Exposition	Large/ Shuttle	Everyday	5:08 am	10:34 pm
22	Chicon	Large/ Shuttle	Everyday	5:16 am	10:18 pm
25	Ohlen	Large	Everyday	6:03 am	10:31 pm

Table A-1 Metro Routes (cont'd)

Route#	Route Name	Type of Bus	Days Service Offered	Weekday Service Begins	Weekday Service Ends
26	Riverside	Large	Everyday	6:03 am	11:21 pm
27	Dove Spring	Large	Everyday	5:30 am	12:01 am
28	Ben White	Large	Everyday	6:05 am	11:29 pm
29	Barton Hills	Large	Weekdays/ Saturday	5:50 am	9:44 pm
30	Barton Creek Square	Large	Everyday	6:00 am	9:55 pm
31	Oltorf	Small	Weekdays/ Saturday	5:50 am	9:18 pm
32	Airport Blvd.	Large/ Small	Weekdays/ Saturday	6:00 am	10:17 pm
33	William Cannon	Large/ Shuttle	Everyday	5:39 am	9:43 pm
37	Colony Pk./ Windsor Pk.	Large	Everyday	5:23 am	12:01 am
38	South Lamar/ Westgate	Large	Everyday	5:39 am	12:30 am
39	Walnut Creek/ Koenig	Large	Weekdays/ Saturday	6:04 am	10:09 pm
40	Parkfield	Shuttle	Weekdays	5:38 am	7:13 pm
LVF	Lago Vista Feeder	Shuttle	Weekdays	5:55 am	8:38 pm
42	Quail Valley/ Metric	Large/ Small	Everyday	6:24 am	10:25 pm
43	South Oaks	Small	Weekdays/ Saturday	5:11 am	9:23 pm
44	Balcones Northwest	Small	Weekdays	6:30 am	7:07 pm

Table A-1 Metro Routes (cont'd)

Route #	Route Name	Type of Bus	Days Service Offered	Weekday Service Begins	Weekday Service Ends
45	Copperfield	Small	Weekdays/ Saturday	6:11 am	9:11 pm
46	Bergstrom	Small	Everyday	5:31 am	11:14 pm

Source: Capital Metro Schedule Booklet, January 1994.

Table A-2 Flyer Routes

Route #	Route Name	Type of Bus	Days Service Offered	Weekday Service Begins	Weekday Service Ends
61	Dove Spring Flyer	Large	Weekdays	6:37 am	5:45 pm
62	Metric Flyer	Large	Weekdays	6:05 am	7:09 pm
63	Oak Hill Flyer	Shuttle	Weekdays	6:39 am	5:58 pm
64	South Central Flyer	Large	Weekdays	6:47 am	`5:59 pm
65	Manchaca Flyer	Large	Weekdays	6:44 am	5:49 pm
66	North Central Flyer	Large	Weekdays	6:28 am	6:03 pm
67	Cameron Road Flyer	Large/Small	Weekdays	6:39 am	5:51 pm

Source: Capital Metro Schedule Booklet, January 1994.

Table A-3 Express/Park & Ride Routes

Route #	Route Name	Type of Bus	Days Service Offered	Weekday Service Begins	Weekday Service Ends
IRS	IRS/VA Express	Large	Weekdays	5:55 am	4:30 pm
NEX	North East Express	Shuttle	Weekdays	6:00 am	6:23 pm
PX	Pflugerville Express	Large	Weekdays	6:09 am	6:25 pm
LX	Leander Express	Large	Weekdays/ Saturdays	5:38 am	9:17 pm

Source: Capital Metro Schedule Booklet, January 1994.

Table A-4 'Dillo Routes

Route #	Route Name	Type of Bus	Days Service Offered	Weekday Service Begins	Weekday Service Ends
85	Convention Center/ UT 'Dillo (Red Line)	'Dillo	Weekdays/ Saturday	6:30 am	7:11 pm
86	Congress Capitol 'Dillo (Blue Line)	'Dillo	Weekdays	6:30 am	7:13 pm
87	ACC/Lavaca 'Dillo (Green Line)	'Dillo	Weekdays	6:44 am	9:37 pm

Source: Capital Metro Schedule Booklet, January 1994.

Table A-5 UT Shuttle Routes

Route#	Route Name	Type of Bus	Days Service Offered	Weekday Service Begins	Weekday Service Ends
48	Red River	Large	Weekdays/ Sunday	7:15 am	11:05 pm
49	South Riverside	Large	Weekdays/ Sunday	6:45 am	11:05 pm
50	West Campus	Large	Weekdays/ Sundays	7:15 am	11:00 pm
51	Cameron Road	Large	Weekdays/ Sunday	7:15 am	11:05 pm
53	Enfield Road	Large	Weekdays/ Sundays	7:15 am	11:00 pm
54	Forty Acres	Large	Weekdays	7:30 am	5:45 pm
55	Far West	Large	Weekdays/ Sunday	6:45 am	11:05 pm
56	Intramural Fields	Large	Weekdays/ Sunday	6:45 am	11:00 pm
57	Lake Austin	Large	Weekdays/ Sundays	7:15 am	11:00 pm
58	North Riverside	Large	Weekdays	7:15 am	11:00 pm
59	Pleasant Valley	Large	Weekdays/ Sundays	6:45 am	11:00 pm
60	East Campus	Large	Weekdays/ Sundays	7:15 am	11:05 pm

Source: Capital Metro Schedule Booklet, January 1994.

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