Southwest Region University Transportation Center

Electric Vehicle Applications for Urban Travelers: Technology, Cost, and the Market

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16. Abstract

This report examines the viability of the electric vehicle (EV) as a partial solution to Texas' air quality problems. According to the 1990 Federal Clean Air Act, mobile source pollution is the primary contributor to poor air quality in the United States. Texas is among the top 10 emitting states for several air pollutants. In Texas, approximately 71 percent of the total local travel occurs in the Texas cities with populations over 200,000. Such urban areas are clearly most in need of air quality improvement. The technology of the EV makes it most suitable for urban travel. This report investigates whether this apparent match between need and technology is viable in market terms. Chapter One describes the air quality, energy security, and global warming issues that have prompted research into alternative fuels such as the EV, and describes the legislative initiatives that have provided funding for this research. Chapter Two examines the current state of EV technology. Chapter Three provides a life-cycle cost analysis of the EV. In particular, this chapter assesses the economic costs of such externalities as air pollution, and compares the cost of gas vehicles and EVs if such externalities are taken into account. Chapter Four analyzes the potential market for EVs. This chapter surveys current research on the market for EVs, and then introduces the Center for Transportation Research Interactive Web Survey, designed by the author. This survey combines some of the most promising features of previous EV market research--especially research that serves to educate the public and air quality as well as gathering information about vehicle use--in a low-cost, widely-distributable format. The report concludes by examining the data from this survey in light of EV technology, cost and potential marketability.

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ELECTRIC VEHICLE APPLICATIONS FOR URBAN TRAVELLERS: TECHNOLOGY, COST, AND THE MARKET

by

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Research Report SWUTC/96/465530-1

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EXECUTIVE SUMMARY

The air quality in many urban areas in Texas continues to worsen and increasing personal travel adds to this problem. The battery-powered electric vehicle (EV) is a viable alternative to the gasoline-powered vehicle for many of these areas. This report contains a life-cycle cost analysis as well as an analysis of the market potential of the EV. Based on life- cycle costs, including the social costs of pollutants, the EV compares favorably with the gasoline-powered vehicle. As battery technology improves, and production of batteries increases, the EV will become even more attractive using the cost criterion. In addition, the market potential of EV appears favorable. Respondents to a survey administered over the Internet as part of this project show that there is a significant portion of the population which can accommodate the limited range of the EV in their household travel. In addition, participants in the survey showed that the more information they had about both technical attributes and social benefits of the EV, the more likely they were to consider acquiring an EV. These findings suggest that both technological development and consumer education are necessary for the market success of the EV as a partial solution to Texas' air quality problems.

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ABSTRACT

This report examines the viability of the electric vehicle (EV) as a partial solution to Texas' air quality problems. According to the 1990 Federal Clean Air Act, mobile source pollution is the primary contributor to poor air quality in the United States. Texas is among the top 10 emitting states for several air pollutants. In Texas, approximately 71 per cent of the total local travel occurs in the Texas cities with populations over 200,000. Such urban areas are clearly most in need of air quality improvement. The technology of the EV makes it most suitable for urban travel. This report investigates whether this apparent match between need and technology is viable in market terms.

Chapter One describes the air quality, energy security, and global warming issues that have prompted research into alternative fuels such as the EV, and describes the legislative initiatives that have provided funding for this research. Chapter Two examines the current state of EV technology. Chapter Three provides a life-cycle cost analysis of the EV. In particular, this chapter assesses the economic costs of such externalities as air pollution, and compares the cost of gas vehicles and EVs if such externalities are taken into account. Chapter Four analyzes the potential market for EVs. This chapter surveys current research on the market for EVs, and then introduces the Center for Transportation Research Interactive Web Survey, designed by the author. This survey combines some of the most promising features of previous EV market research--especially research that serves to educate the public about air quality as well as gathering information about vehicle use--in a low-cost, widely-distributable format. The report concludes by examining the data from this survey in light of EV technology, cost, and potential marketability.

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CHAPTER 1. INTRODUCTION

PROBLEM DEFINITION

At the end of 1987, 68 metropolitan areas were exceeding ambient air quality standards for ozone and 59 were exceeding carbon monoxide standards. A total of 107 areas, including the 24 largest metropolitan regions, containing 135 million people, were violating one or both standards" (Greene 1988: 227). The transportation sector in the U.S. is the single largest consumer of oil in this country. The use of this fuel contributes significantly to the following pollutants: carbon monoxide, nitrous oxides, volatile organic compounds, sulfur dioxide, lead, and particulate matter. Measures such as the Corporate Average Fuel Economy (CAFE) standards, while helpful, have not been able to solve these problems.

The 1990 Amendments to the Federal Clean Air Act (CAAA) recognizes mobile source pollution as a primary contributor to poor air quality in the United States. The Act has taken measures such as further tightening emission standards and requiring the use of reformulated gasoline, beginning in 1995, in nine urban areas with the worst ozone problems. However, in some cases such as California, New York, and Massachusetts, it is the states which are taking the lead and mandating emissions standards even more stringent than the federal regulations. In addition, under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), air quality has emerged as a legislative priority. Perhaps more emphatically than any other piece of transportation legislation, ISTEA addresses the air quality problem. ISTEA directly ties itself to the 1990 CAAA and in so doing indirectly gives priority to air quality as the most urgent transportation planning goal of this country. Under ISTEA legislation, transportation projects considered for funding will have to conform with air quality goals. Although other stated goals of ISTEA are backed by funding and regulations, they have nothing comparable to the conciseness and power of the CAAA to back them up. Due to the link between ISTEA and CAAA, air quality has moved from being just one of many criteria for transportation projects to being a priority for transportation planning.

Many lawmakers and researchers have turned to alternative fueled vehicles (AFVs) to address these air quality problems and the legal and regulatory pressures they have spawned. Concern over air quality in the late sixties led to solutions that reduced new vehicle emissions levels by an order of magnitude (USDOE 1992: 37). AFVs also offer economic and political benefits. Energy supply and price shocks, such as those seen in the 1970's, can be ameliorated by reducing dependence on imported petroleum through the use of other fuel sources. AFVs are not the panacea to the crises the transportation sector of this country is presently facing, but they do provide the possibility of mitigating some of these problems.

Strategies for decreasing air pollution in non-attainment areas contain aggressive plans for AFVs. For example, the California Air Resources Board (CARB) has announced that two percent of all cars sold in California by 1998 must be zero emitters, and the number increases to ten percent by 2003. Also, since 1991 in Texas, new vehicle purchases by Texas public agencies have been required to be capable of operation on an alternative fuel. Although these goals may be ambitious, the need to curtail tail pipe emissions is clear. This report will address the pivotal and challenging role the transportation planner plays in evaluating and implementing one of the most promising of alternative fuels policies, the promotion of the electric vehicle (EV).

The EV is particularly well suited to metropolitan areas. Metropolitan population grew from 56 percent of the total population in 1950 to 77 percent of the total population in 1990 (USDOT 1994: 51). Metropolitan travel accounts for an increasingly large proportion of all personal vehicle travel each year. In fact, in Texas approximately 71 percent of the total local travel occurs in the Texas cities with populations over 200,000 people (Euritt et al.: 2). Clearly such urban areas are most in need of air quality improvement. Furthermore, residents in urban areas on average travel distances well within present day EV range. This report focuses on the Texas urban traveler.

This report describes the debate surrounding the EV and attempts to analyze critically the arguments of proponents as well as critics. The EV is often cited as the solution to the air quality problem because it produces no tail pipe emissions. Another well-known benefit of the EV is that it allows for flexibility between fuel sources. This factor can allow the EV to be potentially beneficial to air quality (if the right fuel mix is used for producing electricity) as well as potentially allowing the transportation sector to decrease its dependence on foreign fuel sources. Other added advantages such as lower maintenance costs and reduced noise pollution are often cited. On the other hand, critics of the electric vehicle allege that the EV cannot compete in the marketplace with conventional gasoline powered vehicles. First, the power source technology of EVs does not produce ranges and speeds that automobile consumers will accept. Second, the cost of an electric vehicle is prohibitively high. And finally, there is debate as to whether or not the emissions of the electric power plants offset the benefits of zero tail pipe emissions.

In addressing these various issues, this report begins with an overview of the EV, including reasons for researching and developing AFVs and the specific legislative and regulatory measures that have been implemented to address those concerns. Next, this report includes a description of EV technology, including battery as well as fuel cell technology, existing hybrid vehicle technology, and roadway electrification technology. The third chapter will address how EVs compare to gasoline-powered vehicles in terms of cost. The primary focus in this chapter is estimates of vehicle owning and operating costs and of costs of emissions. The fourth chapter describes current research on the market penetration of EVs. Then the chapter describes an original survey designed by the Alternative Transportation Fuels Program of the Center for Transportation Research, commenting on its relationship to previous research. The chapter concludes by describing the results of the survey.

This report set out to explore the following questions: if consumers were aware of the social costs of operating conventional gas-powered vehicles (GVs), would they be willing to consider purchasing an EV instead? Would consumers trade off the low purchase price, engine power, and convenience of a GV for the clean-air benefits of the EV? These questions, however, must be viewed in the context of the relative unavailability of EVs to consumers. No matter how a survey participant responds to the question, "Would you be willing to purchase an EV for urban use?" he or she cannot then go out and purchase one. Thus, the research this report brings together must be considered a preliminary step in the marketing of EVs or any AFV.

Air Quality

Concern about the impact of mobile source emissions on air quality has prompted much of the federal and state legislation and regulation of alternative transportation fuels. This section of the report will provide background information on the air quality problem of the United States and the degree to which highway transportation contributes to this problem. The primary air pollutants that are emitted directly into the atmosphere and are of concern are carbon monoxide (CO), hydrocarbons (HC) and other volatile organic compounds (VOCs), sulfur dioxide (SO_2), oxides of nitrogen (NO_X), particulate matter (PM), and compounds of lead (Pb). The emission levels for these pollutants for the years 1986 through 1992 are illustrated in Appendix A.

In 1993, the Environmental Protection Agency (EPA) reported that since 1970, highway vehicles have been the largest single contributing source of CO emissions (EPA 1993). Although vehicle emission controls have drastically reduced CO emissions, the trend of increasing vehicle miles traveled (VMT) makes these improvements less significant than they might otherwise be. From 1980 to 1992, emissions control devices and the retirement of older vehicles without such devices helped reduce CO emissions a total of 37 percent, but at the same time VMT increased 49 percent (EPA 1993: 3-3).

In 1990, 1991, and 1992 NO_X emissions by highway vehicles were 7816, 7715, and 7477 thousand short tons, respectively. These small but steady decreases are viewed as benefits of the implementation of the Federal Motor Vehicle Control Program (FMVCP) and the replacement of older vehicles by newer, more efficient automobiles (EPA 1993: A-10). However, in 1992, NO_X emissions from highway vehicles still accounted for 32.3 percent of the total national NO_X emissions (EPA 1993:

2-37).

Reactive VOC and NO_x emissions are the principal components in the chemical and physical atmospheric reactions that form ozone and other photochemical oxidants. Despite increases in VMT, FMVCP initiatives combined with the retirement of older vehicles, are credited for the 50 percent decrease in VOC emissions from gasoline and diesel-powered vehicles from 1970 to 1992. In 1992, however, highway vehicles were nonetheless responsible for 26.8 percent of total national VOC emissions (EPA 1993: 2-43).

Sulfur dioxide emissions have been identified as precursors of acidic precipitation and deposition. SO_2 emissions from highway vehicles have been steadily increasing for over 20 years. In 1992, highway vehicles emitted 785 thousand short tons of sulfur dioxide, accounting for 3.5 percent of the national SO_2 emissions (EPA 1993: A-27, 2-49).

Total national Pb emissions have been decreasing since 1970. In 1970, Pb emissions form highway vehicles were 171,961 short tons. In 1992, Pb emissions from highway vehicles were only 1,383 short tons, which did account, however, for 26.7 percent of the total national Pb emissions (EPA 1993: 2-55, 3-17). The decreases in Pb emissions are attributed to the FMVCP and the EPA requirement that petroleum refiners lower the Pb content of leaded gasoline to 0.5 grams per gallon in 1985 and 0.1 grams per gallon in 1986. Previously, the Pb content of gasoline had been at 1.1 grams per gallon or more (EPA 1993: 3-9).

The EPA presents data on fine particulate matter less than ten microns (PM-10). Emissions of PM-10 shows it greatest decrease in the 1970's. In 1992, the EPA reports a preliminary figure of 1,558 thousand short tons of PM-10 emissions from highway vehicles (EPA 1993: 3-17). This figure comprises approximately 3 percent of the total national PM-10 emissions in 1992 of 51,427 thousand short tons (EPA 1993: 3-17).

Texas is on the list for top 10 emitting states for several of the pollutants. Texas is responsible for 8 percent of national CO emissions (EPA 1993: 2-32), 12 percent of NO_x emissions (EPA 1993: 2-38), 13 percent of VOC emissions (EPA 1993: 2-44), and five percent of SO_2 emissions (EPA 1993: 2-50). Although these figures include sources other than highway source emissions, they do serve as indicators to the severity of the air quality problem in Texas.

In summary, legislative initiatives have done much to decrease the rate of environmental deterioration. However, emissions may still far exceed the level that the earth's ecosystem can bear. Increasing vehicle miles traveled, along with increasing numbers of vehicles driven, are difficult factors to offset. The EPA predicts that between 2000 and 2010 CO and NO_x emissions will begin to increase again (EPA 1993: 6-1).

Energy Security

Alternative vehicle fuels offer a very strong potential to aid in the reduction of U.S. dependence on foreign oil supplies. It is predicted that, without new policy initiatives, U.S. oil consumption will increase by 20 percent over the next 20 years, reaching 20.3 million barrels per day in 2010 (Riley: 13). The economic, environmental, and energy security implications of this increase are significant, given that the Persian Gulf region contains 65 percent of the world's proven reserves and an increasingly large share of world oil production (Riley: 9). Because the transportation sector accounts for two-thirds of U.S. oil consumption, and personal transportation vehicles consume over half of this oil (Riley:12), serious attention should be given to options that might cost-effectively reduce the use of petroleum-based motor fuels.

Some economists are concerned that increasing oil imports will make it difficult to reduce the trade deficit. In addition, the Gulf War in the early 1990's and the increasing oil imports have renewed interest in U.S. economic security. The possibility of soaring gasoline prices had Saudi oil supplies been interrupted is a significant factor in renewed interest in non-petroleum fueled vehicles.

Global Warming

Over the last one hundred years, the increased use of fossil fuels has caused a significant rise in the concentration of carbon dioxide, CO_2, in the atmosphere. Carbon dioxide is the most important greenhouse gas contributing to global warming, but motor vehicle emissions have also played a part in increasing concentrations of other anthropogenic greenhouse gases, including nitrous oxide (NO_x), chlorofluorocarbons (CFCs), and methane. Energy from the sun reaches the earth in the form of light. Since neither CO_2 nor H_2O vapor absorbs the visible light in sunlight, they do not prevent this energy from reaching the surface of the earth. However, the energy that the earth itself gives off in the form of heat (lower-energy infrared radiation) is readily absorbed by both CO_2 and H_2O. Thus, some of the heat the earth must lose to maintain thermal equilibrium becomes trapped in the atmosphere, which can cause the temperature to rise. This is the greenhouse effect. The greenhouse effect is predicted to cause a 2 degree Celsius rise in average global temperatures by the year 2030 (Green et al. 1993: 5). Indeed, eight of the ten warmest years ever recorded in the Northern Hemisphere occurred between 1980 and 1989. Substituting electric vehicles for conventional internal combustion engine vehicles could increase or decrease greenhouse gas emissions depending on the fuels used for generation of electricity. This report will review some of the recent studies that address this question.

ALTERNATIVE FUELS INITIATIVES

Legislative and Regulatory

Recent legislative and regulatory measures have played an important role in attempting to reduce petroleum consumption in the transportation sector. These measures, which have been introduced at both the national and state levels, generally fall under one of two labels: air quality or energy consumption. Most often these measures do not mention electricity specifically as an alternative transportation fuel; however, the EV can be an important contributor in meeting the requirements of these measures by decreasing air pollution and petroleum consumption. The following sections describes the major legislative and regulatory measures now in existence.

National. The measure that most directly solicits alternative fuel development is the Alternative Motor Fuels Act of 1988 (AMFA), which was signed into law on October 14, 1988, as Public Law 100-494. AMFA's stated purpose is to 1) encourage the development and widespread consumer use of methanol, ethanol, and natural gas as transportation fuels; and 2) encourage the production of methanol-, ethanol-, and natural-gas-powered motor vehicles. This act directs the U.S. Department of Energy (DOE) to work with other Federal agencies in order to take a number of actions. The Federal agencies the DOE is encouraged to work with are the General Services Administration (GSA), the Department of Transportation (DOT), and the EPA. The major programs established by DOE (all began in FY 1990) are as follows: 1) the Alternative-Fuel Federal Light-Duty-Vehicle Program; 2) the Truck Commercial Application Program; and 3) the Alternative-Fuels Bus Testing Program (USDOE 1992).

Although it does not specifically address the subject of alternative transportation fuels at the national level, the most far-reaching piece of legislation may be ISTEA. ISTEA directly ties itself to the CAAA and asserts air quality as a primary goal of transportation policy and projects. Thus, ISTEA pertains to projects and programs at state and local levels, particularly in clean air non-attainment areas. In Texas, these non-attainment areas are Beaumont-Port Arthur, El Paso, Dallas-Fort Worth, and the Houston region. The Dallas-Fort Worth and Houston-Galveston regions are already proposing substantial alternative fuel investments using ISTEA funding.

The most likely source of alternative-fuels funding at the present time is the Congestion Mitigation and Air Quality Improvement Program (CMAQ). A Title 1 program funded at $6 billion over 6 years with an 80 percent federal share, CMAQ can fund projects and programs that contribute to attainment of air quality standards, such as transportation control measures or transit projects.

An additional measure promoting alternative transportation fuels is the Energy Policy Act (EPACT), which was signed into law in late 1992 as Public Law 102-486. The underlying philosophy of the EPACT is to reduce U.S. dependence on foreign oil and to increase energy efficiency. The act intends to reduce total motor fuel consumption by 10 percent by the year 2000 and by 30 percent by 2010. The use of alternative fuels in the transportation sector is one way in which EPACT addresses its goals. The Act requires certain vehicle fleets in larger metropolitan areas to begin using alternative fuels, including federal, state, and municipal government fleets, as well as large private fleets such as those belonging to fuel providers. In addition to fleet mandates, EPACT provides tax incentives for the use of AFVs, including a tax credit of up to $4,000 for purchasers of EVs. Because it focuses more on alternatives to petroleum products than on increasing the efficiency of existing petroleum products, EPACT in many ways goes beyond the CAAA (discussed in next paragraph, below) in its encouragement of alternative fuels. EPACT sets earlier deadlines for fleet purchases than the CAAA and also excludes reformulated gasoline and "clean" diesel. In addition, EPACT applies to more fleets because it includes in its purview all metropolitan areas with 250,000 population or more, not just cities with major air quality problems (USDOE 1992: 1-6).

CAAA authorizes the EPA to set and enforce National Ambient Air Quality Standards (NAAQS) to address air pollution, specifically CO and ozone levels. Ozone non-attainment areas are classified as extreme, severe, serious, moderate, and marginal. Carbon monoxide non-attainment areas are classified as serious or moderate. In the state of Texas, non-attainment status for ozone is as follows: Houston-Galveston-Brazoria (severe), Beaumont-Port Arthur and El Paso (serious), and Dallas-Fort Worth (moderate). El Paso is classified as moderate for CO non-attainment.

To enable States to meet the standards for ozone, CO, and other pollutants, the CAAA contains requirements designed to reduce the amount of mobile-source pollutants from traditional transportation fuels. Strategies include fuels and vehicle operating characteristics, alternative transportation programs (i.e. ridesharing, use of commuter transit, etc.), and increasingly stringent tailpipe emission and inspection standards.

In addition, the CAAA includes requirements for the use of reformulated gasoline as well as incentives for the use of cleaner fuels other than reformulated gasoline. The pertinent provisions include the reformulated and oxygenated gasoline requirements (Section 219 of the Amendments), the clean-fuel centrally fueled fleet program (section 229), the California Pilot Test Program (section 229), the low polluting fuel requirement for urban buses (section 227), and Phase II of the emissions standards for conventional vehicles (section 203) (USDOE 1992: 29). All of these provisions other than the reformulated gasoline provision have possible implications for the use of the EV.

Furthermore, the CAAA requires each state to develop a State Implementation Plan (SIP). These plans commit states to develop a broad range of specific air pollution control programs and to estimate the emission reduction benefits of each program. In nonattainment areas, the state plan describes how the area will achieve compliance.

State of California. California has led the nation in devising state-sponsored measures for promoting clean air. In fact, the CAAA allow states to adopt and enforce California's Low Emissions Vehicle (LEV) program rather than the federal vehicle emission standards. The LEV program establishes four categories of vehicles; Transitional Low Emission Vehicle (TLEV), LEV, Ultra-Low Emission Vehicle (ULEV), and Zero Emission Vehicle (ZEV). The program allows auto manufacturers to earn credits that can be banked, traded or sold, which provides some flexibility if vehicle sales for particular models are poor. It is expected that the California LEV program will increase the use of AFVs. Certainly, this measure has heightened interest in the EV, possibly the only vehicle that ultimately qualifies as a ZEV.

State of Texas. Texas, another large state with a growing air quality problem, has also authored some significant state measures. The Texas Legislature enacted two bills in 1989 (Senate Bills 740 and 769) that encourage the use of alternative fuels. Senate bill 740 relates to the purchase, lease, or conversion of motor vehicles by certain state agencies, school districts, and local transit authorities and districts to assure use of natural gas or other alternative fuels. The bill requires affected entities to purchase AFVs and to increase over time the percentage of their fleet that uses alternative fuels. By 1998, 90 percent or more of the fleet vehicles may be required to be capable of using alternative fuels. The following entities must comply with SB 740: all school districts with over 50 buses to transport children, state agencies with over 15 vehicles (excluding law enforcement and emergency vehicles), and all metropolitan transit departments (no fleet size specified). SB 740 set the following deadlines for affected entities: By September 1, 1994 the fleet had to consist of 30 percent or more AFVs; By September 1, 1996 the percentage increases to 50 percent; and by September 1, 1998 the percentage increases to 90 percent.

Senate Bill 769 amends the Texas Clean Air Act and addresses air quality in the four Texas non-attainment regions: Houston, Dallas-Fort Worth, Beaumont-Port Arthur and El Paso. SB 769 applies to the fleets of metropolitan and regional transit/transportation authorities, city transportation departments, local governments with 16 or more vehicles (excluding law enforcement and emergency vehicles), and private vehicle fleets with 26 or more vehicles (also excluding law enforcement and emergency vehicles). SB 769 states that public transportation organization fleets had to consist of 30 percent or more AFVs by September 1, 1994. By September 1, 1996 the percentage increases to 50 percent and by September 1, 1998 the percentage increases to 90 percent. The schedule is different for local government and private fleets. If the Texas Air Quality Control Board finds the alternative fuel program effective by December 31, 1996 local governments with fleets of more than 15 vehicles and private fleets with more than 25 vehicles will be required to add or convert AFVs into their fleet. By September 1, 1998 these fleets must consist of 30 percent or more AFVs. The percentage increases to 50 percent by September 1, 2000 and to 90 percent by September 1, 2002.

More recently, Senate Bill 7 amends SB 740 and revises the schedules for school districts to begin converting their fleets. In addition, some portions of the act regarding waivers and reporting requirements have been amended. Effectively, SB 7 allows for a more gradual implementation of the alternative fuels program in affected school districts. The deadlines for acquiring alternative fuel school buses are from 1 to 3 years behind the deadlines stipulated in SB 740. SB 7 states that after September 1, 1993 affected school districts must acquire only school buses capable of using an alternative fuel. By September 1, 1997 50 percent of a district's fleet must be capable of using an alternative fuel. And by September 1, 2001 the percentage increases to 90 percent. SB 7 waives the 30 percent AFVs in 1993 that SB 740 previously required.

Utilities

Utility Companies are in a unique position in the discussion of alternative fuels. Not only could the use of EVs increase overall electricity usage, but overnight charging of EVs could increase energy consumption during off-peak hours potentially raising revenues for these companies without the need for increased capacity. Because the majority of electricity is consumed during the day, electric utilities could greatly benefit from the non-peak overnight consumption of electricity that EVs offer. Thus, many utility companies are leading the way in research and development of electric vehicles.

Other Corporations

Presently, General Motors, Ford, and Chrysler all manufacture EVs, albeit on a limited scale. GM has recently developed the Impact and has plans to produce 50 of these vehicles for a program to develop the EV market and infrastructure (J.E. Sinor September 1993: 151). This vehicle body is lightweight and was especially designed for EV use. It is not simply a conventional body fitted with an electric motor. Chrysler has built the TEVan and, as of September of 1993, sold 50 of these vehicles to electric utilities (J.E. Sinor September 1993: 150). In addition, Ford Motor Company currently has 26 Ecostars (minivans) on the road participating in an electric vehicle test fleet. By the end of 1994, Ford plans to increase this number to 105. Presently, participants in the test fleet do not purchase these vehicles, but lease them and agree to participate in a performance study (J.E. Sinor April 1994: 159). An evaluation of prices is somewhat premature given that EVs are not presently being mass produced. At present, the cost to Ford Motor Company of the Ecostar's sodium-sulfur battery alone is approximately $50,000 (Hanten 1994). Although other battery technologies are not as expensive as that of the sodium-sulfur, the approximate prices that the big three American car manufacturers currently cite are high; but this is clearly due to research and development costs and limited production. The Electric Vehicle Development Corporation reports that the price of a G-Van EV would be $57,000 when 100 vehicles have been manufactured, but would fall to $18,100 when a cumulative volume of 50,000 vans had been produced (J.E. Sinor September 1993: 159). Optimistically, EVs could be more feasible in the near future in terms of price.

Small, innovative technology firms have produced some of the most promising AFVs currently available. In December 1990, the G-Van became available. Although a limited production vehicle, this van, priced at $50,000 and produced by Conceptor Industries, was the first ground-up EV available to meet U.S. Federal Motor Vehicle Safety Standards (Science Applications International Corporation 1992: 34). Other small EV manufacturers are trying to enter the market but are faced with some obstacles. Most significantly, these manufacturers are finding it difficult to offer competitive prices. In general, they retrofit existing internal combustion engine (ICE) vehicles which carries a high initial investment. For example, Solectria of Arlington, Mass. produces the Force EV which is based on the Geo Metro subcompact model. After purchasing the Geo Metro, this company removes the engine, the exhaust system, and other parts of the car that are not needed and installs the electric engine, battery pack, regenerative braking system, etc. Obviously, in this case many original parts have been purchased that are not needed. In addition, the retrofitted vehicle is not as efficient as a ground-up vehicle could be, since the basic design of the car is intended for an entirely different engine (Kirk, phone interview). However, this same company is planning to use a $1.1 million grant funded in part from the U.S. Defense Department's Advanced Research Projects Agency defense conversion grant to develop a ground-up, composite EV called the Flash (Green Car Media 1993: 137). Because of the significant cost of research and labor, the cost is initially estimated at approximately $20,000, the same as their current retrofit vehicle. If a nickel-cadmium battery is used instead of a lead-acid battery in either the retrofit or ground-up vehicle, the cost increases approximately $20,000 to $40,000. On a similar note, Battery Automated Transportation (BAT) has introduced a converted Geo Metro for $15,900 and a converted Ford Ranger pickup truck for approximately $25,000 (J.E. Sinor November 1993: 165). Despite such high initial costs, it is apparent that if increasing numbers of original manufacturers are able to penetrate the EV market, prices are likely to decrease in the future.

CHAPTER 2. ELECTRIC VEHICLE TECHNOLOGY

BATTERIES

At present, the power source used by the majority of electric vehicles (EVs) is the battery. In the past, the most significant problem cited by critics of the EV was that the battery's limited range characteristics would decrease the vehicle's feasibility for the average urban household. But battery technology is improving, and new data indicates that the average commute for most urban drivers is less than 60 miles per day. In light of these facts, the most popular arguments against aggressively pursuing EV production may be misapplied. Because batteries represent a crucial issue for EV development, this chapter will begin with an overview of battery technology.

United States Advanced Battery Consortium

The United States Advanced Battery Consortium (USABC) was formed in January of 1991 in recognition of the need for a major advancement in battery technology in order for EVs to penetrate the market. The USABC is a business partnership between Chrysler, Ford, and General Motors (GM). In July of 1991, participation by the Electric Power Research Institute and some of its member utilities was formalized. Also, the USABC and the United States Department of Energy (DOE) signed a Cooperative Agreement in October of 1991, which initiated funding from the DOE to match that of industry in this effort. The purpose of the consortium is to work with battery developers, universities, the National Laboratories, and other companies that will conduct research and development on battery technologies in order to increase the driving range, improve the performance, and reduce the cost of EVs. The USABC has defined both mid-term and long-term objectives. The mid-term goals for battery improvement include doubled vehicle range, a power-to-weight ratio of 150 to 200 watts per kilogram, an energy-to-weight ratio of 80 to 100 watt hours per kilogram and a battery life of five years at a cost of less than $150 per kilowatt hour. The long-term goal, targeted for the early 21st century, is a battery with a power-to-weight ratio of 400 watts per kilogram, an energy-to-weight ratio of 200 watt hours per kilogram and a battery life of 10 years at a cost of less than $100 per kilowatt hour. The primary criteria for both mid-term and long-term battery technologies are summarized in Table 2.1.

TABLE 2.1 USABC PRIMARY CRITERIA		
Criterion	Mid-Term	Long-Term
Specific Energy (Wh/kg)	80	200
Energy Density (Wh/L)	135	300
Specific Power (W/kg)	150	400
Power Density (W/L)	250	600
Life (years)	5	10
Life (cycles at 80% DoD)	600	1000
Ultimate Cost ($/kWh)	< 150	< 100
Operating Environment (degrees Celsius)	-30 to 65	-40 to 85
Recharge Time (hours)	< 6	3-6/ fast recharge for emergency
Continuous Discharge in one hour (no failure)	75% of rated energy capacity	75% of rated energy capacity
Power and Capacity Degradation	20 % of rated specification	20 % of rated specification

Source: OECD 1992: 349

Battery Technologies

Presently, several types of batteries are in public use, or being researched for expected use in the near future. These include lead-acid, advanced lead-acid, nickel-cadmium, and sodium-sulfur batteries.

Lead-Acid Battery. Currently, lead-acid batteries are the most popular. In fact, a study from 100 EV owners in California found that every EV owner in this study group used a lead-acid battery, although the total battery packs were of varying voltages (Kurani 1994: 11). The primary reason for the popularity of the lead-acid battery is its relatively low cost and accessible technology, especially for those who build or convert their own EVs. In addition, lead-acid batteries can be more easily recycled than other batteries. The major drawbacks of this battery are its heavy weight and low energy density. In other words, the lead-acid battery cannot provide a great deal of range before needing to be recharged.

On the other hand, advanced lead-acid batteries are relatively new, and are likely to offer improved performance as the technology develops. In fact, Electrosource, Inc. of Austin, Texas, has recently developed the Horizon EV Battery. This advanced lead-acid battery can be recharged to 50 percent of its power in 8 minutes, and to 99 percent of its power in 30 minutes. In addition, Electrosource estimates their battery will yield an approximate range of 85 miles when installed in a mid-size van. They project that their battery will last more than 600 cycles in on-road EVs (Electrosource 1995).

Nickel Cadmium. A number of the EVs manufactured by the major U.S. automobile companies have recently begun employing other battery technologies. The 1994 Chrysler Minivan uses a 180 volt nickel-cadmium or nickel-iron battery pack, and advertises an 80-mile range (without running air conditioning or heating), a top speed of 65 mph, and an acceleration from 0-40 mph in 11.0 seconds (Chrysler 1994). Advantages of the nickel-cadmium battery include higher energy and power densities, and an anticipated longer life cycle (J.E. Sinor September 1993: 155). In short, nickel-cadmium batteries have longer ranges between charges, can reach higher top speeds, and will last longer than the typical lead-acid battery. The primary drawback of this battery is its increased cost due to the high cost of both nickel and cadmium. Solectria, an electric vehicle manufacturer in Arlington, Mass, states that using a nickel-cadmium battery as opposed to a lead-acid battery increases the cost of their EVs by approximately $20,000 (phone interview).

Sodium Sulfur. Like the nickel-cadmium battery, the sodium-sulfur battery provides vehicle speed advantages. In fact, the sodium-sulfur battery is often cited as the highest performance battery. The Ford Ecostar, which is powered by a sodium-sulfur battery, is reported to have a range of 100 miles, a top speed of 75 mph, and an estimated 0-60 mph acceleration of 16.5 seconds (*Green Car Journal* 1993: 135). The main drawback of the sodium-sulfur battery is that it must operate at a temperature of 270-410 degrees Centigrade, and the hot liquids in the battery are corrosive. Thus, manufacturers can incur high costs when trying to reduce failure probabilities of individual cells and connections (Bevilacqua-Knight, Inc. 1992: 2-3).

FUEL CELLS

Fuel cells are another important technology for the EV, although they have been used for many years for other purposes such as powering spacecraft. DeLuchi and Swan go so far as to say that a fuel-cell vehicle is the only zero emission vehicle (ZEV) that could possibly accelerate as fast, drive as far, and be refueled as quickly as today's gasoline cars (DeLuchi and Swan 1993: 14).

How Fuel Cells Work

Instead of storing electricity taken from a wall socket, the fuel cell converts the chemical energy in a liquid or gaseous fuel to electrical energy. The fuel cells can use hydrogen directly, or accepts fuel that has been converted to hydrogen from another source. Hydrogen fuel can be produced from a variety of sources including methanol, coal, natural gas, or solar energy to hydrolyze water. If a fuel is used that needs to be converted to hydrogen, an on-board converter is necessary. A fuel cell consists of a positive anode, a negative anode and an electrolyte between the two anodes. Usually hydrogen diffuses through the typically platinum-coated anode and strips off electrons, creating electricity. The protons continue through the electrolyte to the cathode, where the protons, electrons and oxygen combine to form water (Bevilacqua-Knight, Inc. 1992: 7). A hydrogen-powered fuel cell vehicle is considered a ZEV since it emits only water vapor. Methanol fuel cell vehicles produce small amounts of nitrogen oxides (NO_x) and carbon monoxide (CO) from the methanol reformer, and small amounts of evaporated methanol from the fuel supply and storage systems (DeLuchi and Swan 1993: 19).

Classification of Fuel Cells

Fuel cells are most often classified according to which type of electrolyte they employ. Some of the most popular ones are alkaline, solid oxide, and alkaline proton exchange membrane (PEM). Alkaline fuel cells perform very well, and have been projected to have a low materials cost, but the electrolyte is so intolerant of carbon dioxide (CO_2) that the system must be supplied with either bottled oxygen or air scrubbed of CO_2 a costly and space-consuming requirement. Solid-oxide fuel cells are projected to have good performance, but if started cold, they require a relatively long warm-up period to reach their operating temperature. Projected costs of the solid oxide fuel cell vary. Generally, they are considered costly, but according to some researchers they may be less expensive than PEM fuel cells in the future. Currently, PEM fuel cells appear to be the most promising. Their most important advantage is good performance. In addition, PEM fuel cells provide considerable power at ambient temperatures without corrosive fluids and are relatively simple in construction. Because of these qualities, they have the potential to be inexpensive to manufacture. Not surprisingly, most fuel-cell related vehicle research, development, and demonstration programs are currently using PEM fuel cells, or anticipate doing so. Although PEM fuel cells will not be commercially available for a few years, they are perhaps the most promising technology for use in highway vehicles in the short term (OECD: 82).

Comparison of Fuel Cells with Batteries

Compared to batteries, fuel cells offer some advantages and some disadvantages. First of all, fuel cells are more complex and expensive. Another disadvantage is that some CO and CO_2 emissions are currently associated with its use. Also, because fuel cells tend to be large and heavy, they present some of the same problems associated with batteries. Furthermore, it may be difficult to convince the public and policy makers that the use of hydrogen as a transportation fuel is no more dangerous than gasoline even though officials at the U.S. National Bureau of Standards at Stanford Research International have come to this conclusion. Despite these disadvantages, there are a limited number of fuel cell projects currently underway in the U.S.. Energy Partners of Florida is building a fuel cell vehicle than will use a PEM fuel cell powered by hydrogen. In addition, the U.S. Department of Energy is sponsoring the Georgetown Bus Project and a project with General Motors (DeLuchi and Swan 1993: 20). In summary, "commercial success certainly is not guaranteed, and at best is many years off." (DeLuchi and Swan 1993: 20-21).

HYBRID VEHICLES

Vehicles that use EV technology in combination with other vehicle technologies, such as gasoline or natural gas, are considered an alternative to the "all electric" vehicle. With this technology, the power and range limitations of the dedicated EV can be reduced if not entirely overcome. The term "hybrid" can imply any vehicle that employs more than one energy source such as fuel cells, ultra capacitors, and flywheels to supplement batteries, but generally, and for this discussion, the term refers only to vehicles with on-board carbon-fuel-burning engines. Hybrids are designed to operate as EVs in urban areas where air pollution is a problem. Operating on batteries alone, they typically have a range of 50-100 miles. These vehicles could well operate solely as EVs for more than 90 percent of the time, and reserve their engines for longer trips.

Hybrids have several advantages over either gasoline-powered vehicles or battery-powered EVs. Hybrid engines are designed for average loads, not peak loads. The engines can be relatively small and run at a constant speed while charging the EV battery. Hybrids can be twice as efficient and much less polluting than comparable internal combustion engine vehicles. Typically equipped with batteries and regenerative brakes, hybrids can capture much of the energy normally lost in braking, which further increases overall fuel efficiency. An on-board engine makes the vehicle's range far greater than that of a battery-powered EV, increasing consumer acceptance.

Hybrid vehicles do suffer from a significant disadvantage: they do emit air pollutants unless the on-board energy source is hydrogen. Vehicles that possess an additional hydrogen energy source are of course more complex and expensive to design and build. For this reason, the California

Air Resource Board does not currently qualify hybrids as ZEVs. Hybrids are therefore often considered transitional vehicles whose best use is in filling the gap in technology until more efficient batteries or other power storage devices can be made marketable.

Nonetheless, the Department of Energy has awarded GM and Ford money to develop prototype hybrid vehicles. GM received a $138 million cost-shared contract in September 1993 and in December of the same year Ford's research group received $122 million.

The goal of these awards is to encourage the emergence of vastly more fuel-efficient vehicles that can meet emission standards yet still maintain comparable cost and performance to conventional vehicles. Production of these vehicles is slated to begin sometime after 2001. In addition, overseas auto makers are developing their own hybrid vehicles (MacKenzie 1994: 54).

ROADWAY ELECTRIFICATION

Roadway Electrification is another technology that has been proposed to address the growing problem of poor air quality. Although this technology differs considerably from the battery-powered EV approach which is the focus of this report, roadway electrification is addressed briefly here since these two technologies do share some common attributes. Theoretically, roadway electrification can provide the range, payload, acceleration and the life-cycle costs of the gasoline-powered vehicle with the zero tailpipe emission advantages of the EV. With an electrified roadway, an external energy source provides additional fuel to that offered by the battery, making roadway electrification effective for long trips. For this reason, roadway electrification would be used in freeways where most long trips occur, so that this external energy could be made available to EVs during the trip. The external energy source makes possible a significant reduction in onboard battery size, thus making the vehicle quicker to accelerate and faster, as well as less expensive at least in terms of battery cost (Bresnock: 3)

The primary drawback of roadway electrification is cost. Estimates are approximately $.78 million/lane-mile ($1.25 million/lane-km) of road (cited in Fowler 1994: 17). In the short term, this cost is prohibitively high. Other considerations are the following environmental and health issues: exposure to electromagnetic fields, hazardous waste associated with battery disposal, and acoustic noise levels in vehicles traveling on the powered roadway.

CHAPTER 3. DETERMINING ELECTRIC VEHICLE COSTS

One of the most important factors in evaluating the merits of the electric vehicle (EV) as a viable solution to the current transportation problems of air pollution, global warming, and growing oil imports, is the question of cost. How do EVs compare economically and environmentally to gasoline-powered vehicles (GVs) on a full cost basis? This chapter addresses the issues surrounding this question. First the chapter defines the market costs of owning and operating typical GVs and EVs. Then the external costs of both types of vehicles are defined and assessed. Next, both market and external costs of GVs and EVs are calculated. Finally, the impact of potential EVs on energy consumption is addressed.

DETERMINING MARKET VEHICLE COSTS

In 1993, U.S. consumers spent $455.3 billion on user-operated transportation (AAMA 1994: 60). On average in 1992, consumers spent 17.6 percent of their disposable income on transportation (AAMA 1994: 59) .

Operating a motor vehicle generates two kinds of costs, which have been defined as "market costs" and "external costs." Market costs are those consumers most often think of when they contemplate vehicle ownership: costs for which consumers must actually pay money, including the car's purchase, the purchase of fuel, paying taxes and fees to pay for road construction, repair, and parking space, and purchasing automobile insurance. These are the costs that are most easily and readily perceived by individual consumers.

The second type of costs do not show up directly in the consumer's economic transactions. These external costs, or "externalities," are hidden from the vehicle consumer because they are absorbed by all of society. Externalities include the social costs of illnesses resulting from the air pollution caused by vehicle operation, and the costs of foreign diplomacy, strategic reserves, and military action necessary for defense of the U.S. oil supply. They also include the economic risks of global warming caused by vehicle emissions. These are costs that clearly fall outside the scope of normal market prices. Yet because society experiences economic risk and loss due to such externalities, they too must be considered in determining what it costs not just for individual consumers, but for a whole society to operate motor vehicles. Total costs or full costs of motor vehicle operation can only be assessed when we determine both market and external costs.

Some current research indicates that the lifetime costs of operating an EV may well be lower than that of operating a conventional GV. In addition, even short-term costs may be significantly less for EVs: they will be cheaper to operate and have a longer vehicle life (Sperling 1995: 55). The most expensive aspect of the EV is the battery, however. Without a significant technological "battery breakthrough," the initial purchase price of an EV is likely to remain higher than that of a conventional GV. Thus, it is important in determining the EV market to calculate the total cost of ownership and operation.

In addition, it is important to examine both the market and external costs associated with GVs as well as EVs. Although the cost of a battery for the EV may be relatively high, this could potentially be offset by the benefit to air quality. While consumers generally consider only market costs when purchasing a vehicle, policy makers have the goal of encouraging consumers to consider external or non-market costs when purchasing a car. Presently, it is primarily the responsibility of public institutions to consider the external costs. Considering externalities as part of vehicle cost analysis will lead to more informed decisions when evaluating policies, initiatives or incentives to use alternative fuels.

Ownership and Operating Costs for GVs

While some costs occur whether or not the vehicle is driven (fixed costs), other costs vary with the amount a vehicle is driven (variable costs). The former category is generally referred to as ownership costs, and the latter as operating costs. Analysts often differ on the costs that should be included in each category. In this report, we define the two categories consistent with the Federal Highway Administration (FHWA).

Ownership costs include not only depreciation, finance charges, insurance, registration and titling fees, but also any taxes applied to these items. Even if a vehicle is rarely or never driven, the owner incurs most of these costs. Operating costs include scheduled and unscheduled maintenance, fuel, oil, tires, parking tolls, and the taxes applied to these items.

For the two scenarios of GVs we examine in this chapter (a compact vehicle and an intermediate-sized vehicle), these costs are based on the FHWA report, "Cost of Owning and Operating Automobiles, Vans, and Light Trucks 1991." While this report uses many of the values generated by the FHWA report, they are presented a little differently. The FHWA lists all costs year by year over the assumed 12 year life of the vehicle. The FHWA assumes the annual mileage decreases over the lifetime of the vehicle. This occurs because as a vehicle ages , it often becomes a second or third family vehicle or its ownership is transferred to a household that uses it less. (FHWA 1992: 4). As one might expect, many of the ownership and operating costs decrease over the life of the vehicle. However, for the purpose of this report, we present these FHWA values in terms of average annual cost, dollars/mile, and dollars/kilometer.

Only differences from the FHWA report in the definitions of each type of cost will be explained. Depreciation is the loss of value of the vehicle during its lifetime. Several factors contribute to depreciation, including passage of time, the vehicle's mechanical and physical condition, and the number of miles it is driven. While the FHWA reports that 25 to 45 percent of all depreciation occurs in the first year of ownership (FHWA 1992: 5), this report averages the depreciation over the life of the vehicle (since ultimately we are interested in the average cost per mile). This report calculates depreciation by subtracting the salvage value from the initial vehicle cost and then dividing the resulting value by the number of years of the vehicle life. Finance charges, for the purposes of this report, are based on a three-year financing term, an annual interest rate of 8.25 percent, and a 10 percent down payment. In Texas, the state registration fee varies with the age and value of the car. We used an average of $58.80 for all vehicles. The state vehicle excise tax is 6.25 percent of the initial purchase price of the car. In addition, a local fee of $11.50 per year and an inspection fee of $10.50 per year was applied in all scenarios.

For operating costs, differences from the FHWA report include the following. Fuel costs for GVs are based on a price of $0.816 per gallon excluding taxes. The state fuel tax rate is $0.20 per gallon, and the federal fuel tax rate is $0.184 per gallon. Maintenance, oil, and tire taxes are base on an 8 percent sales tax rate in the state of Texas.

Life-Cycle Cost Analysis Gasoline Vehicle

Below is a cost analysis in 1993 dollars which measures market prices and fees for owning and operating a GV. It is instructive to compare some key scenarios. Worksheets of the owning and operating costs of a compact and an intermediate-sized GV were formulated since these two vehicles are most comparable to EVs in terms of space, style, and performance. The detailed results of these two cases are presented in Appendix A, Tables A.1 and A.2.

The calculations are based on initial prices of $11,896 and $14,973 for the compact and intermediate-sized cars, respectively. These values are consistent with those presented in the FHWA report. Below in Table 3.1 is a more detailed description of the characteristics of the compact and intermediate-sized vehicles.

TABLE 3.1 CHARACTERISTICS OF THE GVs IN THE LIFE-CYCLE COST ANALYSIS

Characteristics	Compact GV (case 1)	Intermediate GV (case 2)
Vehicle price ($)	$11,895.86	$14,972.93
Payment plan (years)	3	3
Down payment -10% of purchase price ($)	$1,189.59	$1,497.29
Monthly payment ($)	$336.73	$423.83
Vehicle life (years)	12	12
Vehicle life (miles)	128,500	128,500
Average annual driving distance (miles/year)	10,708	10,708
Price of gasoline excluding taxes ($/gal)	$0.816	$0.816
Energy efficiency of vehicle (miles/gal)	22.86	19.87
Federal fuel tax rate ($/gal)	$.184	$.184
State fuel tax rate ($/gal)	$0.20	$0.20

Source: Assumptions for vehicle price, vehicle life (years and miles), annual driving distance and energy efficency from FHWA 1992: 14-17. Payment plan and fuel tax rates are added assumptions of this report.

Life-Cycle Cost Analysis Electric Vehicle

Below is a cost analysis which measures market prices and fees for owning and operating an EV. It is instructive to compare some key scenarios comparable to those of the GVs. The primary differences are the characteristics of the battery and the resulting cost of the battery. This cost is then added on to the cost of the gasoline-powered counterpart.

We analyze four EV cost cases. Case 1a is based on the compact GV. The characteristics and cost of the battery are consistent with those of the USABC's mid-term goals. Case 1b is also based on the compact GV; however, the characteristics and cost of the battery are consistent with the USABC's long-term goals.

Case 2a is based on the intermediate-sized GV. The characteristics and cost of the battery are consistent with those of the USABC's mid-term goals. Case 2b is also based on the intermediate-sized GV; however, the characteristics and cost of the battery are consistent with the USABC's long-term goals. The detailed results of cases 1a, 1b, 2a, and 2b are in Appendix A tables A.3 through A.6.

Calculations are based on initial prices of $11,896 plus the cost of the batteries and $14,973 plus the cost of the batteries for the compact and intermediate-sized cars respectively. The vehicle life in these scenarios is 12 years, the same as the GVs in this study. However, it is important to note that many researchers assume EVs will have longer lives than comparable GVs because an electric drive has fewer moving parts (Sperling 1994: 56 and IEA 1993: 160). In addition, the energy efficiency of the compact EV measured at the wall outlet is assumed to be 0.38 kWh/mile and the energy efficiency of the intermediate-sized EV measured at the wall outlet is assumed to be 0.44 kWh/mile. Below in Table 3.2 is a more detailed description of the characteristics of the compact and intermediate-sized EVs.

TABLE 3.2 CHARACTERISTICS OF EVs IN THE LIFE-CYCLE COST ANALYSIS

Characteristics of Vehicle	Com. EV (case 1a)	Com. EV (case 1b)	Int. EV (case 2a)	Int. EV (case 2b)
Characteristics of battery				
USABC criteria	mid-term	long-term	mid-term	long-term
Cycle life of battery to 80% discharge	600	1000	600	1000
Acceptable range (miles)	100	100	100	100
Energy efficiency of vehicle measured at the wall outlet (kWh/mile)	0.38	0.38	0.44	0.44
Cost of battery ($/kWh)	150	100	150	100
Life of a battery (miles)	60,000	100,000	60,000	100,000
Cost of a battery ($)	7,171	4,781	8,250	5,500
Number of batteries needed for life of a vehicle	2.14	1.28	2.14	1.28
Total cost of batteries for life of vehicle (using 6%discount rate)	13,058.45	5,587.51	15,098.52	6,427.79

TABLE 3.2 CHARACTERISTICS OF EVs IN THE LIFE-CYCLE COST ANALYSIS (CONTINUED)

Characteristics of Vehicle with Battery	Com. EV (case 1a)	Com. EV (case 1b)	Int. EV (case 2a)	Int. EV (case2b)
Vehicle price not including battery ($)	11,895.86	11,895.86	14,972.93	14,972.93
Vehicle price including battery ($)	24,954.31	17,483.36	30,071.45	21,400.73
Payment plan (years)	3	3	3	3
Down payment - 10% of purchase price ($)	2,495.43	1,748.34	3,007.15	2,140.07
Monthly payment ($)	706.37	494.90	851.22	605.78
Vehicle life (years)	12.0	12.0	12.0	12.0
Vehicle life (miles)	128,500	128,500	128,500	128,500
Annual driving distance (miles/year)	10,708	10,708	10,708	10,708
Price of electricity excluding taxes ($/kWh)	0.07	0.07	0.07	0.07
Federal fuel tax rate (% of fuel cost)	22.55	22.55	22.55	22.55
State fuel tax rate (% of fuel cost)	24.51	24.51	24.51	24.51

Comparison and Summary of GV and EV Life-Cycle Cost

Using USABC's mid-term battery goals, a compact EV costs $1,017 more per year to own and operate than a compact GV. If USABC's long-term battery goals of lower cost and longer life of batteries are accomplished, the difference is reduced to $285 more per year.

Using USABC's mid-term battery goals, an intermediate-sized EV costs $1,167 more per year to own and operate than an intermediate-sized GV. If USABC's long-term battery goals of lower cost and longer life of batteries are accomplished, the difference is reduced to $317 more per year. A summary of the ownership and operating costs for case 1 and case 2 of GVs are presented in table 3.3. A summary of the ownership and operating costs for cases 1a, 1b, 2a, and 2b of EVs are presented in table 3.4.

TABLE 3.3 SUMMARY OF OWNERSHIP AND OPERATING COSTS GVs

Scenario	Annual Cost	Cents/mile	Cents/km
Case 1	$3,238.80	30.25	18.80
Case 2	$3,690.44	34.46	21.42

TABLE 3.4 SUMMARY OF OWNERSHIP AND OPERATING COSTS OF EVs

Scenario	Annual Cost	Cents/mile	Cents/km
Case 1a	$4,256.18	40.69	25.29
Case 1b	$3,523.99	33.85	21.04
Case 2a	$4,857.44	46.41	28.85
Case 2b	$4,007.66	38.48	23.91

DETERMINING EXTERNAL COSTS

A life-cycle cost analysis such as this is helpful in determining the cost of an individual consumer's personal travel. However, recent research suggests that such conventional analyses fail to take into account many of the factors determining the impact of vehicle operation, not just on individual consumers, but on the communities in which they live. Operation and ownership costs do not cover many of the costs associated with oil production and use. The costs of a damaged environment and energy security are also important but less visible and difficult to calculate. Health and environmental costs include air pollution, greenhouse gas emissions, water pollution, the destruction of natural habitat, and the clean-up and habitat-loss costs of oil spills that are not directly paid by oil companies. In addition, multi-billion dollar expenditures are made to protect U.S. shipping and oil interests in the Middle East (Natural Resource Defense Council: 16). This section of the report will address these issues.

Air Pollution Emissions

In this section of the report we address emissions of the full-fuel cycle for both GVs and EVs. This analysis relies primarily on Light Duty Vehicle Full-Fuel Cycle Emissions Analysis prepared for the Gas Research Institute (GRI). For the petroleum fuel cycle, the GRI summarizes the emitting processes as follows: (1) engine driven pumps and compressors at the wellhead, (2) natural gas flared at the wellhead, (3) refinery combustion processes, (4) distribution combustion processes, and (5) leakage and vapor releases from all stages of the fuel cycle including, wellhead, refineries, tank storage, and retail gasoline distribution (GRI: 8).

For the electric power sector, the GRI summarizes the emissions associated with the electric power cycle as follows: (1) fossil fuel combustion associated with power production, (2) fugitive emissions from onsite fuel storage, (3) increased production necessary to meet demand as a result of resistance losses associated with power transmission and distribution, and (4) upstream fuel-cycle emissions for fossil fuel electric power feed stocks (GRI: 27). We will only consider emissions from coal, petroleum, and natural gas feed stocks. We will assume nuclear, hydro, and other feed stocks have no air emissions associated with them.

Below in Table 3.7 is a summary of the air emissions associated with GVs. We have adjusted the calculations to reflect the scenarios we presented in the life-cycle cost analysis of GV. Namely, the emissions reflect the efficiency of the vehicles we are considering: a compact vehicle that gets 22.86 miles per gallon, and an intermediate-sized vehicle that gets 19.87 miles per gallon.

Table 3.8 presents various scenarios for different fuel mixes. Obviously, emissions of electric vehicle power generation will depend primarily upon the feed stock mix. First, projected mixes for the

U.S. for 1995 and 2010 are presented. Then the marginal mix for the U.S. in 1990 is presented. The importance for evaluating marginal feed stock mixes cannot be overstated. If EVs gain a significant amount of the automobile market share, they will rely on additional electricity generation. This additional generation will characterize the emissions associated with the EV. In addition, a scenario is presented that reflects the feed stock mix of Texas and another that reflects the feed stock mix for the city of Houston. Tables 3.7 and 3.8 summarize the air emissions associated with compact and intermediate-sized EVs for the various electricity generation scenarios.

TABLE 3.5 FUEL CYCLE EMISSIONS FOR GVs

Pollutant (grams/mile)	VOC	CO	NO_X	SO_X	PM10	CO_2 equiv.
Scenario:						
Case 1	0.245	0.077	0.217	0.042	0.013	81.6
Case 2	0.281	0.089	0.250	0.049	0.014	93.9

Source: GRI 1994: 61. Revised for fuel efficiencies of 22.86 mpg for case 1 and 19.87 mpg for case 2.

TABLE 3.6 VEHICLE COMBUSTION AND EVAPORATIVE EMISSIONS FOR GVs

Pollutant (grams/mile)	VOC	CO	NO_X	SO_X	PM10	CO_2 equiv
Scenario:						
Case 1	.427	3.272	.385			369.3
Case 2	.492	3.764	.443			424.8

Source: GRI 1994: 61. Revised for fuel efficiencies of 22.86 mpg for case 1 and 19.87 mpg for case 2.

TABLE 3.7 FULL FUEL CYCLE EMISSIONS FOR GVs

Pollutant (grams/mile)	VOC	CO	NO_x	SO_x	PM10	CO_2 equiv
Scenario:						
Case 1	.672	3.349	.602	.042	.013	450.8
Case 2	.773	3.853	.693	.049	.014	518.6

Source: GRI 1994: 61. Revised for fuel efficiencies of 22.86 mpg for case 1 and 19.87 mpg for case 2.

TABLE 3.8 PERCENTAGE OF ELECTRICITY GENERATED BY DIFFERENT FUELS

Region	United States			Texas	Houston
Fuel mix	1995	2010	Marginal mix, 1990	1990	1990
Coal	54.3	60.4	50.0	50.67	31.4
Petroleum	5.9	3.5	15.0	.23	0.5
Natural Gas	12.3	14.1	30.0	41.53	56.4
Nuclear	17.7	14.0	2.0	6.75	11.7
Others	9.8	8.0	3.0	.82	0.0

Source: EIA 1990, EIA 1992, and Wang et al.

TABLE 3.9 ELECTRIC POWER EMISSIONS FOR COMPACT EVs

Pollutant (grams/mile)	VOC	CO	NO_X	SO_X	PM10	CO_2 equiv.
Scenario:						
U.S. 1995	0.026	0.050	0.942	2.032	0.032	267.592
U.S. 2010	0.024	0.053	1.026	2.200	0.034	287.620
U.S. marginal mix	0.054	0.077	1.161	2.058	0.037	325.679
Texas 1990	0.037	0.076	1.175	1.793	0.027	302.798
Houston,TX	0.046	0.082	1.079	1.119	0.018	262.503

Source: All values of emissions based on GRI 1994 emissions estimates for 1993 assuming a vehicle efficiency of 22.86 mpg and fuel mixes from Table 3.8.

TABLE 3.10 ELECTRIC POWER EMISSIONS FOR INTERMEDIATE-SIZED EVs

Pollutant (grams/mile)	VOC	CO	NO_X	SO_X	PM10	CO_2 equiv.
Scenario:						
U.S. 1995	0.030	0.058	1.091	2.352	0.037	309.843
U.S. 2010	0.028	0.061	1.188	2.547	0.039	333.034
U.S. marginal mix	0.063	0.089	1.345	2.383	0.043	377.102
Texas 1990	0.043	0.088	1.360	2.076	0.031	350.608
Houston,TX 1990	0.054	0.095	1.249	1.295	0.021	303.950

Source: All values of emissions based on GRI 1994 emissions estimates for 1993 assuming a vehicle efficiency of 19.87 mpg and fuel mixes from Table 3.8.

Monetary Values of Air Pollution Emissions

Studies have been conducted to estimate the monetary value of air pollutant emissions in some U.S. areas. Because of the differences in air quality states and population exposed among areas, emission values should differ considerably. Application of emission values estimated for one area to another area without any adjustment is inaccurate. Area specific emission values need to be estimated.

Two general methods have been used to estimate emission values--namely, the damage estimate method and the control cost estimate method. The damage estimate method attempts to estimate the value of the adverse impacts of the actual emissions. Obviously, determination of the monetary values that individuals place on adverse air pollution effects is the key element. These values can be related to medical expenses, loss of work, discomfort, and inconvenience that result from adverse health effects. Physical damage to property and agriculture are also valid. Often market dollar values of property and agricultural products are used as the opportunity cost of the loss due to air pollution. The control cost estimate method is based on the assumption that emission standards or air quality standards are established at a socially acceptable level, where marginal damage is equal to the marginal control cost. Supposedly, the control cost required to meet predetermined air quality standards imposed by legislators reveals the value that society places on the emissions being controlled (thus, the method is sometimes known as the revealed preference method). Therefore, the estimated marginal control cost to meet an emission standard represents the marginal damage value of air pollution when the standard is met.

The Center for Transportation Research (CTR) at The University of Texas at Austin in cooperation with the Tellus Institute of Boston, MA, has usefully established a set of air emission values appropriate to Texas (Euritt et al. 1995). The dollar values CTR presents lie within the range of values operative in various areas within the United States and are presented in Table 3.11.

Tables 3.12, 3.13, and 3.14 contain estimates of the urban air emissions associated with GVs and EVs on a cents per mile basis. In order to calculate these values, the amount of emissions in grams per mile (Tables 3.7, 3.9, 3.10) are multiplied by the monetary value of the emissions (Table 3.11).

TABLE 3.11 ESTIMATED EMISSIONS VALUES FOR TEXAS

	Pollutants, Emissions cost, 1993, $/ton					
Regions of Texas	VOC	CO	NO_X	SO_X	TSP	CO_2
Urban	$6,371	$992	$9,070	$300	$4,560	$25
Rural	$3,021	$992	$3,705	$300	$4,560	$25

Source: Euritt et al.: 101

TABLE 3.12 ESTIMATED URBAN EMISSIONS VALUES FOR TEXAS FOR GVs (CENTS/MILE)

Pollutant	VOC	CO	NO_X	SO_X	PM10	CO2	Total cost
Vehicle type:							
compact 22.86 mpg	0.472	0.366	0.602	0.001	0.007	1.242	2.690
int-size 19.87 mpg	0.543	0.421	0.693	0.002	0.007	1.429	3.095

TABLE 3.13 ESTIMATED URBAN EMISSION VALUES FOR TEXAS FOR COMPACT EVs (CENTS/MILE)

Pollutant	VOC	CO	NO_X	SO_X	PM10	CO_2	Total
Scenario:							
U.S. 1995	0.019	0.005	0.942	0.067	0.016	0.737	1.787
U.S. 2010	0.018	0.006	1.026	0.073	0.017	0.793	1.932
Mar. Mix 1990	0.040	0.008	1.161	0.068	0.019	0.897	2.194
Texas 1990	0.028	0.008	1.174	0.059	0.014	0.834	2.118
Houston, TX 1990	0.034	0.009	1.079	0.037	0.009	0.723	1.891

TABLE 3.14 ESTIMATED URBAN EMISSION VALUES FOR TEXAS FOR INTERMEDIATE EVs (CENTS/MILE)

Pollutant	VOC	CO	NO_X	SO_X	PM10	CO_2	Total
Scenario:							
U.S. 1995	0.022	0.006	1.090	0.078	0.019	0.854	2.070
U.S. 2010	0.021	0.007	1.188	0.084	0.020	0.918	2.237
Mar. Mix 1990	0.046	0.010	1.344	0.079	0.022	1.039	2.540
Texas 1990	0.032	0.010	1.360	0.069	0.016	0.966	2.452
Houston, TX 1990	0.040	0.010	1.249	0.043	0.010	0.838	2.190

Monetary Values of Energy Security

Determining the external costs of energy security not born by drivers associated with the use of petroleum is a difficult task. For the purposes of this report we base our calculations on figures cited in The Going Rate: What It Really Costs to Drive. These costs include potential impacts that increasing imports could have on the international price of oil, and potential costs incurred in the case of sudden interruptions of supply (i.e. inflation, unemployment, etc.). MacKenzie et al. estimate these security costs for the transportation sector at approximately $25.3 billion (MacKenzie et al. 1992: 15-17). We calculate this cost to be approximately $0.012 per mile by dividing $25.3 billion by total vehicle miles traveled (VMT). We use $0.012 per mile for both the compact and intermediate gasoline vehicle scenarios. We assume this cost will not be incurred in all four EV scenarios.

CONCLUSIONS

Market and External Costs

Tables 3.15 through 3.19 outline the estimated total costs for both GVs and EVs. These costs include ownership and operating costs, estimated emission costs, and estimated energy-security costs. It should be noted that no energy externality costs have been calculated for any of the electric vehicle cases. In this part of the report we have assumed that electric vehicles would not incur energy security costs. This assumption, although conventional in EV market research, overlooks the fact that in order to completely avoid our dependence on foreign oil, the market penetration of electric vehicles would need to be far greater than current research anticipates.

In addition, this analysis assumes the same vehicle life for both EVs and GVs. If EVs are able to attain longer vehicle lives as expected (DeLuchi et al. 1989: 263), they will be even more competitive with GVs in terms of cost. In addition, the EVs in this analysis are assumed to have very high initial costs due to the high cost of batteries. The ownership costs in this analysis are conservative because a reduced initial EV cost due to large production schedules associated with a more mature market are not assumed. Other life-cycle cost analyses (DeLuchi et al. 1989: 263; Euritt et al.: 138; Sperling 1995: 57) assume much lower initial price of EVs. These two factors cause the EVs in this analysis to have high ownership costs. In fact, this analysis assumes a type of "worst case" cost scenario. However, using the long-term battery goals, the cost per mile of EVs is very close to that of comparable GVs.

However, operating costs and the external costs associated with air quality and energy security are lower in all cases for EVs. This is an important point because as urban centers grow so will the values placed on air pollutants, making the EV even more attractive in terms of total cost.

In all scenarios, total costs for GVs are less than those of similar size EVs. However, total costs for compact as well as intermediate-sized EVs will be only slightly higher than the comparable GVs when the long-term battery goals are achieved. For example, the total cost for the compact GV is 34.140 cents per mile; while the total cost of the compact EV is estimated to range from 35.637 to 36.044 cents per mile. Similar cost differences are estimated for the intermediate-sized vehicles. See tables 3.15 through 3.19 for complete total cost analyses.

TABLE 3.15 ESTIMATED TOTAL COSTS FOR GVs

	Market (cents/mile)	Emissions (cents/mile)	Eng Security (cents/mile)	Total Cost (cents/mile)	Total Cost (cents/km)
Scenario:					
Case 1	30.25	2.690	1.2	34.140	21.201
Case 2	34.46	3.095	1.2	38.755	24.067

TABLE 3.16 ESTIMATED TOTAL COSTS FOR COMPACT EVs (CASE 1A)

	Market (cents/mile)	Emissions (cents/mile)	Eng Security (cents/mile)	Total Cost (cents/mile)	Total Cost (cents/km)
Scenario:					
U.S. 1995	40.69	1.787	0.0	42.477	26.378
U.S. 2010	40.69	1.932	0.0	42.622	26.468
Mar. Mix 1990	40.69	2.194	0.0	42.884	26.631
Texas 1990	40.69	2.118	0.0	42.808	26.584
Houston, TX 1990	40.69	1.891	0.0	42.581	26.443

TABLE 3.17 ESTIMATED TOTAL COSTS FOR COMPACT EVs (CASE 1B)

	Market (cents/mile)	Emissions (cents/mile)	Eng Security (cents/mile)	Total Cost (cents/mile)	Total Cost (cents/km)
Scenario:					
U.S. 1995	33.85	1.787	0.0	35.637	22.131
U.S. 2010	33.85	1.932	0.0	35.782	22.221
Mar. Mix 1990	33.85	2.194	0.0	36.044	22.383
Texas 1990	33.85	2.118	0.0	35.968	22.336
Houston, TX 1990	33.85	1.891	0.0	35.741	22.195

TABLE 3.18 ESTIMATED TOTAL COSTS FOR INTERMEDIATE EVs (CASE 2A)

	Market (cents/mile)	Emissions (cents/mile)	Eng Security (cents/mile)	Total Cost (cents/mile)	Total Cost (cents/km)
Scenario:					
U.S. 1995	46.41	2.070	0.0	48.480	30.106
U.S. 2010	46.41	2.237	0.0	48.647	30.210
Mar. Mix 1990	46.41	2.540	0.0	48.950	30.398
Texas 1990	46.41	2.452	0.0	48.862	30.343
Houston, TX 1990	46.41	2.190	0.0	48.600	30.181

TABLE 3.19 ESTIMATED TOTAL COSTS FOR INTERMEDIATE EVs (CASE 2B)

	Market (cents/mile)	Emissions (cents/mile)	Eng Security (cents/mile)	Total Cost (cents/mile)	Total Cost (cents/km)
Scenario:					
U.S. 1995	38.48	2.070	0.0	40.550	25.182
U.S. 2010	38.48	2.237	0.0	40.717	25.285
Mar. Mix 1990	38.48	2.540	0.0	41.020	25.473
Texas 1990	38.48	2.452	0.0	40.932	25.419
Houston, TX 1990	38.48	2.190	0.0	40.670	25.256

Break Even Prices

The cost per mile of compact and intermediate-sized EVs with the long-term battery goals will equal that of comparable GVs if the total price of gasoline (including all taxes) increases from $1.20 per gallon to $1.65 per gallon. Disregarding the factor of gasoline prices, the total cost per mile of a compact EV with the long-term battery goals will equal that of a compact GV if the cost of the EV battery decreases from $4781 to $3000. The total cost per mile of an intermediate-sized EV with the long-term battery goals will equal that of an intermediate-sized GV if the cost of the EV battery decreases from $5500 to $3600.

CHAPTER 4. MARKET PENETRATION OF ELECTRIC VEHICLES

PROBLEM STATEMENT

This final chapter analyzes the potential market for electric vehicles (EVs), summarizing current research on EV market penetration and then describing and analyzing the results of a new survey of potential EV consumers, the Center for Transportation Research Interactive Web Survey (CTRIWS). Because the CTRIWS is available on the Internet, participants share the demographic characteristics of Internet users: primarily male, well-educated and with higher-than-average incomes. As described below, this group merits the scrutiny of EV researchers because it is also the group most likely to purchase a new car of any kind, including the EV. The majority of respondents indicated interest in considering the purchase of an EV, especially once they had received information about the air quality and energy security issues surrounding EV research. But it is not the argument of this report that, in some simple way, consumers aware of these issues constitute a ready-made EV market. Rather, the research summarized in this report, as well as the results of the CTRIWS, suggest that the respondents identified by CTRIWS, because they are receptive to education about EVs and because they are favorably inclined toward EV purchase in the abstract, are a group that merits further study. At such time as EVs become available to consumers, it is this group and the techniques to which they respond--primarily education about new technology--that offer EV marketers an entree into the consumer market.

This chapter begins by addressing the problem of identifying an urban market for EVs using decision theory to comment on the methods of framing questions that may characterize current consumer research on the topic. Previous research has relied on four main approaches to estimate EV marketability: traditional travel surveys, attitude surveys, stated-preference surveys, and game-type surveys. Traditional travel surveys do not typically solicit information about EVs per se, but are used to identify household travel patterns that are most amenable to EV use. Attitude surveys and stated-preference surveys have the advantage of directly querying consumers about their perceptions of EVs, but they share problems common to new technology surveys as discussed later. Game-type surveys, like traditional travel surveys, allow researchers to gain information about household travel patterns and vehicle use; like stated-preference and attitude surveys, they have been used to solicit specific responses about EVs. Identifying the underlying assumptions and framing of questions in game-type EV surveys is especially important. The most extensive EV survey, Purchase Intentions and Range Estimation Games (PIREG), draws heavily on this approach. Finally, this report will analyze the CTRIWS which draws on PIREG and also on the technology of the Internet, exploring the way questions for CTRIWS are framed in light of the approaches of and information obtained from previous surveys about EVs. The report concludes with a discussion of the distinction between surveys and models as it affects the framing of questions in EV research.

Determining a market for EVs is a difficult task for several reasons. First, it is never easy to identify a market for a new technology product, particularly a product which benefits from continual and rapid technology advances. Second, the uncertainty in the market for EVs does not rest solely with the consumers; clean air initiatives and regulations as well as the responses of motor vehicle manufacturers to these policies will continue to shape the market for EVs. In addition, the EV market will depend on the relative success or failure of the markets for other alternative fueled vehicles (AFVs). Indeed, the market for all of these AFVs appears to be one and the same, because they all to a large degree are in response to clean air and energy security policies. In other words, the level of market penetration of EVs will depend largely on the market penetration of natural gas-powered vehicles, propane-powered vehicles, and other AFVs. Finally, it is difficult to determine the degree to which consumers will accept or reject the attributes of the EV. The underlying hypotheses in this report is that degree to which consumers are educated not only about the attributes associated with EV operation but about underlying issues of energy consumption and clean air will undoubtedly have a large effect on the market for EVs.

The attempt to determine the potential market for EVs is made even more complex by the different interests of various agencies and institutions seeking this information. For example, motor vehicle manufacturers want to know how many consumers might purchase an EV in order to establish current production schedules and to anticipate future revenues. As well, manufacturers faced with designing and marketing clean-fuel vehicles need to know whether costs can be reduced by high-volume sales, and must base their designs on the consumer uses of EVs. Another example would be government agencies charged with promoting clean-fuel vehicles, which are in need of methods to analyze proposed policies for stimulating the demand for clean-fuel vehicles.

CURRENT RESEARCH ON THE ELECTRIC VEHICLE MARKET

This section summarizes relevant market research pertinent to developing an EV market. First, travel behavior studies, attitude surveys, and stated-preference surveys are discussed. These non-game surveys are compared with the results of models based on game-type approaches. Several game-type approaches, while not necessarily developed to determine the EV market have influenced the methodology of EV research, are reviewed. The most important game-type EV model, the PIREG study from The University of California at Davis (U.C. Davis), is discussed in detail. Next, CTRIWS, which draws on many of PIREG's innovations while providing a more economical and accessible survey than PIREG, is described. Both PIREG and CTRIWS play an important role in educating potential EV consumers about their own travel patterns as well as about the air quality and energy issues promoting government and industry interest for AFVs and EVs in particular.

Traditional Approaches

One of the simplest methods for predicting EV market penetration is the use of information obtained by traditional travel surveys. Researchers examine this information looking for households whose travel patterns can accommodate the attributes of EVs, particularly that of limited range between charges. For example, researchers determine which types of households they believe will be able to accommodate a limited range EV. Often these households have two cars and a garage where recharging could potentially take place. Most often one of the vehicles in these households only travels 30 or 40 miles per day. Researchers reason that these households may be willing to replace one of their gasoline-powered vehicles (GVs) with an EV since this change will not significantly alter their present travel pattern.

According to one such study, 57 percent of households in the U.S. could accommodate a vehicle with a range of approximately 80 miles (Kiselwich and Hamilton 1982). Other studies estimate that 60 percent of U.S. households drive 96 miles or less 348 days per year (Deshpande 1984) and that 95 percent of the time, 50 percent of U.S. drivers take trips that total less than 100 miles per day (Greene 1985). Nesbitt et al. (1992) found that 28 percent of households have the basic requirements for EV operation: two or more vehicles, a garage or carport for recharging, and at least one vehicle that almost never travels more than 80 miles per day (All studies cited in IEA 1993: 29 and Kurani et al. 1994: 3). While travel surveys are useful in that they take into account the constraints of consumers' actual travel patterns and relate those to the attributes of EVs, their drawback is that they do not account for the actual preferences of consumers. This type of analysis is called a constraints-based attribute-matching approach. Actually, this approach is not a survey but a fairly simple demand forecasting model.

There are limitations to this type of analysis. First, this type of research only states what consumers might be willing to do. In other words, it defines an upper bound on the size of the market without behavior adjustments. It says nothing about what consumers are willing to do. In addition, this approach assumes the only attribute that needs to be considered is the range of the vehicle. In other types of EV research, range has been identified as an important attribute; however, it is not the only attribute consumers consider. The primary benefit of this type of analysis is that it is simple to conduct and analyze.

Attitude surveys have been developed to gauge consumer preferences. Attitude surveys must confront the problem that consumers know very little about EVs. The most common method developed to help consumers gain the information they need to respond sensibly to questions about EVs is an informal focus group in which facilitators lead approximately 10-person discussions exploring group members' likely future travel behavior.

The focus groups have benefits as well as limitations. They provide an excellent opportunity for a small group of people to learn about EVs as well as some other issues such as air pollution. In addition, the focus groups provide individuals with a forum to discuss and perhaps evaluate their driving behaviors. But because focus groups are not selected randomly, their results cannot be generalized. A further disadvantage is that participants in these groups have little or no experience operating an EV, and have certainly never experienced many of the attributes associated with EVs. In particular, such novelties as home recharging, shorter driving range, and very high reliability would be unfamiliar and thus hard to evaluate for most consumers (IEA 1993: 29). In addition, the focus group method is particularly sensitive to the influence of surveyor bias. A wide range of unintended responses can be promoted especially when there is a face to face interview process.

Stated-preference surveys, usually a mail or telephone survey, generally suggest hypothetical scenarios that explore consumers' willingness to pay, or accept compensation, for vehicle and fuel attributes. These attributes include creating less pollution and lower maintenance costs on the positive side, and on the negative side, shorter driving range and higher purchase price. Respondents to stated-preference surveys are asked to make hypothetical choices from sets of vehicle attributes. The results of these studies to date predict very small markets for EVs. According to these surveys, consumers would need unrealistically large compensation in order to accept the short driving ranges and long recharging times of the typical EV. To accept a range of 50 miles (80 kilometers) instead of 199 miles (320 kilometers), for instance, Bunch et al. (1992) found that consumers would need to be compensated $15,000 (all figures adjusted to 1991 U.S. dollars).

Independent research by auto motor vehicle manufacturers confirms the findings of stated-preference surveys about the unwillingness of consumers to accommodate EV attributes. The Ford Motor Company, for example, arrived at a 1 percent market penetration estimate, using focus groups and defining an EV as being 100 percent emission-free, a top speed of just over 75 mph (120 km/h), 50 percent less space, reduced range, and a $3,000 higher purchase price. (IEA 1993: 29).

Game-type Surveys

Because the traditional approaches to gathering travel information cannot take into account both consumers' existing travel patterns and their desires or preferences at the same time, many researchers have turned to game-type surveys to develop a more dynamic model for determining the

EV market.

Household Activity Transportation Studies. The game type survey originated in the late 1970's with Peter Jones of Oxford University, England as one of the leading figures. Jones formulated a data collection device of transportation mode choice called the Household Activity Transportation Studies (HATS). HATS studies household activity and travel patterns and the way in which households respond to various travel constraints. By using HATS, some logical discipline is imposed on previously unrationalized survey responses. HATS offers household members a set of colored blocks with which to construct a simple model of his or her activity schedule on a display board. Changes to the activity schedule are represented by rearranging the blocks. Thus, HATS offers a physical analog of the logic of the household's activity, and hypothetical reactions are rendered more realistic by the respondents' sense of the overall framework in which activity decisions are made. In his paper "Methodology for Assessing Transportation Policy Impacts," Jones concludes that "by its nature, HATS is primarily an exploratory device, to be used when policy impacts are uncertain or as an aid to policy generation. " In a research context, the technique has obvious value as an aid to theory and model development, and is particularly useful at eliciting the decision rules that should be built into behavioral models. Because students take on the role of household members and recreate the impact of new policies on the daily routine of the household, HATS serves an important educational purpose. Not only does it illustrate the role of travel in daily life, it allows students to experience the effects of alternative travel policies (Jones 1979: 57).

The impact of HATS on transportation research has been significant. Cabrera and Hartgen (1990) conclude "although other methods may be as effective as methods of information transfer, this approach offers a unique experience to both the players and the researcher in that it affords a light, informal atmosphere for the give-and-take of ideas. The approach enables all of those concerned to get actively involved in a potentially useful learning situation and quite possibly will reach segments of the population that will not be reached by other methods."

Purchase Intentions and Range Estimation Games. Kurani, Turrentine, and Sperling of U.C. Davis with the help of Lee-Gosselin of Laval University in Quebec City, Canada developed a survey to explore the demand for EVs.

PIREG is an important advance in EV market survey research for several reasons. Its designers and their institution, U.C. Davis, have been responsible for the majority of EV research in the U.S., both technical and economic. Their collaboration with Lee-Gosselin, who designed a critical gaming-approach survey of vehicle use, brought together significant and innovative research ideas on the EV problem. In PIREG, problems encountered in previous survey research were addressed. The authors felt that attitude surveys and focus group studies done by other researchers misrepresented the decision-making process of consumers. They suggest that consumers often answered attitude surveys in ways that indicated their interest in AFVs and particularly EVs, usually because of the technical innovation or environmental attractiveness of the EV. And in travel behavior surveys, many consumers revealed a pattern of vehicle use that would be compatible with replacing at least one household vehicle with an EV. Yet in stated preference surveys, consumers targeted by attitude and travel behavior surveys as ideal candidates for EV use indicated a surprising inflexibility when it came to accommodating the limited range and other limiting factors of EV use. In fact, one survey indicated that consumers would rather pay full price for a vehicle with a 200-mile range than receive a vehicle at no cost with only a 50-mile range (cited in Kurani et. al. 1994: 4). Rather than concluding that attitude and focus-group surveys had simply reflected consumers' "pie-in-the-sky" ideals and had no relation to their real patterns of vehicle purchase and use, the U.C. Davis team hypothesized that more detailed information was needed about consumers' decision-making processes.

PIREG employs interactive stated lifestyle-preference techniques. The authors state that this type of survey responds to inconsistencies and oversights in previous survey work in the EV market. This method begins by determining the actual decision-making behavior of the household. The researcher and participants use this information to design simulated decision-making contexts that use the household's actual activities as the basis for a series of hypothetical choices. The responses generated by PIREG, the researchers argue, are more valid than those of previous surveys because they are rooted in observations of the household's lifestyle decisions. These observations are gathered in two ways. First, household members themselves keep detailed one-week diaries recording all household motor vehicle travel. Researchers use householders' own records to construct a timeline that represents all trips taken that week, including trip purposes, origins, destinations, distances and end times. The second major source of information is a two-hour interview conducted by researchers with household members. In this interview, the timeline is used to construct "what if" scenarios in which household members consider whether and how they could accommodate EV use in a variety of routine and emergency travel situations.

As a result of this new approach, new decision variables were discovered: safety buffer, routine activity space, and critical destination. The safety buffer is the range to be left on the EV at all times. The routine activity space is the area that contains the locations of activities that the household accesses on a routine basis. The critical destination is the furthest destination which the household member using the EV feel they must be able to reach. In addition, PIREG discovered that consumers need more information about recharging. Recharging of EVs is an unfamiliar concept and the benefit of home recharging is not initially understood by the consumer. All of these factors, not just vehicle range, proved to be important to consumers. The results of PIREG thus suggest that future research must solicit information about potential constraints other than vehicle range.

The authors divided the 51 surveyed households into three categories: pre-adapted households, which would require no changes in their vehicle use pattern to accommodate EVs; easily adapted households, which might infrequently need to change vehicles between drivers to accommodate an EV; and non-adapted households, in which it would be difficult or impossible to accommodate an EV in their current traffic patterns. Of the 51 households surveyed, 29 were pre-adapted, 15 were easily-adapted, and 7 were non-adapted. These results clearly suggest that with information about their own patterns of vehicle use and education about EV technology such as the travel diaries and interviews made possible, there exists a significant potential market for EVs. But these two factors--a break-down of the decision-making process regarding vehicle use, and education about EVs and their potential--are crucial to consumers' willingness to consider using an EV. Overall, the primary finding of PIREG is that consumers' perceived driving range needs are substantially lower than previous hypothetical stated preference studies.

Disadvantages or problems with PIREG stem mostly from the limited size and type of audience this survey reached. In all, only 51 households were interviewed. In addition, the researchers only interviewed two or more vehicle households who are buying new motor vehicles in California. The great majority of the households owned their own homes and had incomes greater than $50,000.

SURVEYS AND MODELS

The distinction between surveys and models is an important one in EV research. Surveys of potential consumers do not in themselves identify a potential market. In order to identify a group of consumers that can be accurately called a market for EVs, survey data must be incorporated into an appropriate model. A model can take into account the importance not just of consumer preferences but also of proposed policies for stimulating the demand for clean-fuel vehicles. A model can also take into account the observation that the market for EVs is only a part of a larger more general market for all AFVs.

Presently, Brownstone, Bunch and Golob are engaged in a project to develop a demand forecasting model for clean-fuel vehicles in California. This project focuses on both households and commercial fleet operators. The transactions models are estimated using standard econometric techniques. The key inputs to the forecasting system are vehicle technology, fuel price, fuel infrastructure, and incentives. Vehicle technology includes all attributes of vehicles which will become available in the future, including fuel type, refueling or recharging range, price, operating costs, vehicle tailpipe emissions, payload, and performance. The number of vehicles demanded is determined by a model that starts from the current condition and forecasts vehicle transactions. The baseline year is 1994, and the vehicle stock for this year is based on current data from vehicle registrations, with some additional information from large scale surveys of household and fleet behavior. The goal of this model is to analyze proposed policies for stimulating the demand for clean-fuel vehicles. The authors state that the system can also be used by vehicle manufacturers to help gauge the demand for various types and configurations of clean-fuel vehicles (Brownstone et al. 1994: 3).

The personal vehicle sub-model is the most complicated part of their modeling system. Since the model is concerned with the demand for a new product that does not yet exist, the researchers must ask respondents to make choices among hypothetical vehicles. The researchers collected this data through a three-part personal vehicle survey in June and July, 1993. First, the sample was identified using pure random digit dialing and covered most of the urbanized area of California. Preliminary information about household structure and vehicle usage was obtained. This information was used to create an individualized follow-up survey that was distributed by mail. The purpose of this survey was to obtain more detailed information about the travel patterns and vehicle usage of individual household members. The mail-out questionnaire contained two stated preference experiments for each household. Members of the household were asked to choose a preferred vehicle from three hypothetical vehicles, including both clean-fuel and gasoline vehicles. Respondents were also asked about their attitudes towards clean-fuel vehicles. The households were then contacted by telephone and the responses to the mail-out questions were collected. Complete sets of all data were gathered from a total of 4,747 households.

The most significant results of this survey process are as follows. Eighty percent of the households had exactly one driver per vehicle. In two vehicle households, approximately one-third of the vehicles are driven 10,000 miles per year or less, a third are driven 10,000 - 15,000 miles per year, and almost one-third are driven more than 15,000 miles per year. Fifty-four percent of these vehicles are driven on trips of 100 miles or more six or fewer times per year. The survey collected information about how easily households could make technical accommodations to limited-range EVs. Sixteen percent of the households have access to a private garage or carport with electric service and commute less than 30 miles per day round trip. An additional 20 percent of all households have a private garage or carport with electric service and commute less than 60 miles per day round trip (Brownstone et al. 1994: 12-13).

Another demand forecasting model addresses many assumptions of choice modeling and notes that the assumptions of stable tastes, good consumer knowledge of the alternatives, and consumer choices independent of social choices are not supportable for the AFVs market (Turrentine and Sperling 1992) . The authors incorporate research in disciplines of economics, sociology, psychology and marketing to address the uniqueness of the AFV market. The uniqueness of this market stems primarily from new product attributes and social benefits. This demand model takes seriously the developing AFV market and the evolving conditions of social choice. However, because of this, the model does not make conclusive predictions of the AFV market in the near future but tries to more theoretically model mature decision processes.

The distinction between surveys and models needs to be highlighted in order to better understand the preliminary status of the data gathered by CTRIWS. CTRIWS is a survey, not a model. Thus, it does not in and of itself identify a potential market for EVs. Rather, CTRIWS provides new data about a group of potential EV consumers: most importantly, that some respondents who initially say they would not consider purchasing an EV will, at least hypothetically, change their minds after they have received information about air quality, energy security, and greenhouse gas issues, as well as information about their own travel patterns in relation to the capabilities of the EV. CTRIWS thus identifies a group of respondents that deserves further research in order to construct an adequate model forecasting EV demand.

The two influential demand-forecasting models described below, then, need to be understood as in some ways premature. The results of CTRIWS suggest that we need much more data about how consumers make decisions about EV purchase before we can accurately model demand. The authors of these models themselves acknowledge this limitation to their research. As Brownstone, Bunch, and Golob put it: "Although the key models in the system will be calibrated from new surveys, it will be necessary to undertake additional survey work to validate and extend these models. Our preliminary work suggests that consumer's responses to our hypothetical vehicle choice experiments are realistic, but the only proof of this assertion will come when clean-fuel vehicles similar to these hypothetical vehicles are actually offered in the marketplace" (14).

THE CENTER FOR TRANSPORTATION RESEARCH INTERACTIVE WEB SURVEY

Relation to Previous Research

While this survey shares with the PIREG survey an emphasis on the roles of information, education, and consideration in the consumer's decision-making process, it also differs in important ways. The PIREG study focuses mostly on range, asking whether a household can adapt to shorter trips in their weekly schedule. The present survey, however, questions whether range is the only deterrent to consumer adoption of EVs. It is natural for researchers to assume that range might be the most important limitation in consumer perception because it is well known that range is one of the primary technological limitations facing EV research and development. This survey tries to begin from the point of view of the consumer, necessarily less familiar with the technological status of EV research. In this survey, we pursue consumer "prejudices" that may play an important role in the decision whether or not to purchase an EV. Factors such as reliability, auto manufacturers' support, safety, ease of operation, resale value, and others may play a more important role than previous research has indicated. CTRIWS allows us to determine whether or not a specific group of consumers (Internet users) will alter their opinions, at least in the abstract, if they receive education and information about energy security, air quality, EV technology, and their own travel patterns.

Survey Design

The survey begins by exploring how consumers currently view EVs. Using hypertext interactive modeling, the survey ascertains at what level of knowledge about EVs participants are, and what perceptions (whether false or true) they may have about EVs. When a participant makes a false assertion or displays an unfounded prejudice, he or she is given brief informative statements about air quality issues or EVs themselves. Because the hypertext model allows individual participants to "branch off" at different points in the survey process, we are able to track with some precision at what point participants' lack of information or preconceived ideas might prevent them from becoming EV consumers (Figure 4.1).

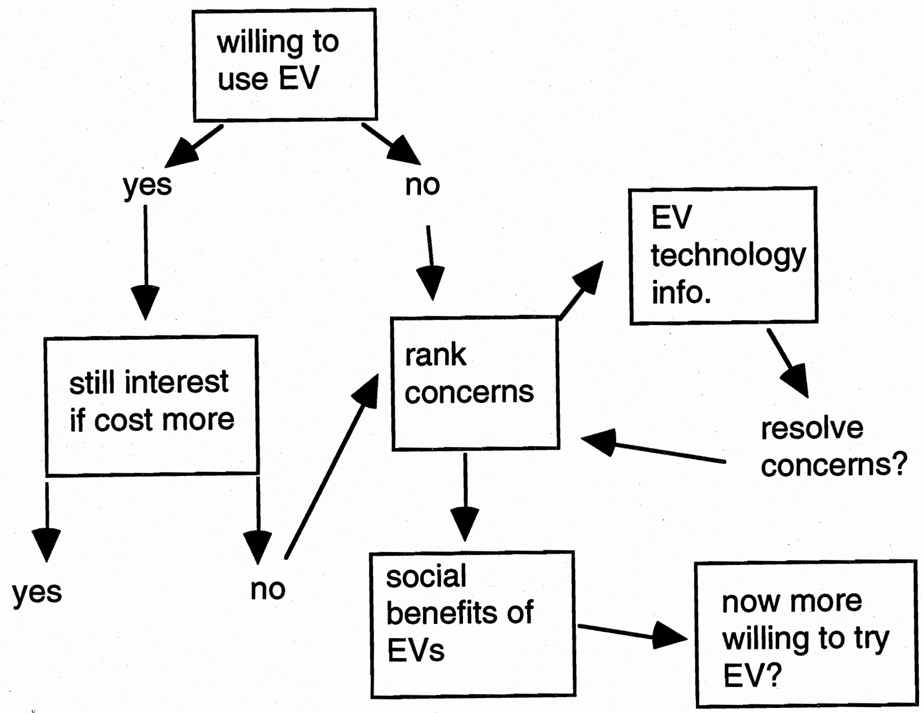

Figure 4.1 Survey Outline

Survey Distribution

One of the distinct advantages of the CTRIWS is its wide availability on the Internet. A memorandum briefly describing the survey and its aims and asking for participants was distributed both to general news groups and to news groups concerning energy, the environment, and automobiles. The most general newsgroups were: utexas.general, comp.infosystems.www.users, comp.infosystems.www.misc, and comp.infosysterms.www.authoring.cgi. More specific interest-oriented groups included those for auto buffs (rec.autos.tech, rec.autos.misc, austin.autos, and alt.manufacturing.misc), for those interested in energy and the environment (sci.energy, sci.environment, and alt.energy.renewable), and a group for progressive Californians (alt.california), since residents of California are potentially the most educated geographic group on issues of EVs in the U.S. By posting the memorandum to the general news groups, we hoped to take advantage of the higher volume of users on such groups. Respondents from general news groups also offered the possibility of a more diverse set of respondents than those selected from interest-specific news groups. On the other hand, we speculated that members of the interest-specific news groups might have a higher rate of response to the memorandum due to their greater motivation to inform themselves on issues of energy, the environment, and automobile ownership. Distributing the memorandum to both kinds of news groups ensured that we would be able to measure the response of something like the "general public" to the survey, but also make sure that we had a numerically sufficient core of responses to use as data.

Of course, the "general public" of Internet users is actually rather specific. It is difficult to get accurate demographic information about Internet users because of "the amorphous nature of cyberspace, with its lack of borders and its culture of anonymity" (Lohr 1995). However, the most complete study done so far suggests the following: of those users with direct access to the Internet, 67 percent are male and over half are between the ages of 18 and 34. Nearly half work in large organizations (those with over 1,000 employees). The majority are in the field of education, but those in sales make up 19 percent of users and those in engineering, 15 percent. Finally, the median household income of Internet users polled is between $50,000 and $75,000 (Lohr 1995).

These demographics intersect in potentially significant ways with the demographics of new car buyers in the United States. A 1994 study found that fifty-six percent of new car buyers in 1994 were male. Fifty-six percent were under the age of 50, and 67 percent had some college level education. The median household income was $50, 930. (All statistics from AAMA 1994: 55.) Thus, both Internet users and new-car buyers are likely to be male, have higher-than-average incomes, and have more education than average.

CTRIWS was distributed via the Internet for several reasons. Like the PIREG survey, the

CTRIWS is somewhat personalized in its gathering of data. That is, the survey can flexibly accommodate a variety of responses drawn from the participants. CTRIWS does this via the interactive capabilities of the Internet, in which participants can follow different information paths based on their differing responses to survey questions and statements. Thus, in distributing CTRIWS on the Internet, we hoped to replicate some of the strengths of the PIREG survey.

There are three important differences between PIREG's face-to-face interview method and CTRIWS's interactive response method. The first is that participants in CTRIWS are not interacting with another human being but with a computer. This difference poses a limitation because the survey design had to anticipate and hypothesize participants' potential responses, rather than answering the actual questions participants have as those questions develop, the way a human researcher can. On the other hand, because there is no incentive for participants to have a pleasant social interaction with another human being, we speculate that participants' responses to questions about what degree of inconvenience they are willing to accommodate might be more accurate than they would be if participants were talking in a face to face interview.

The second difference is the vastly lower cost of distributing an interactive survey on the Web as opposed to conducting intensive house-to-house surveys in person. The PIREG interviews cost $2,000 per household to conduct (Sperling 1995: 60). By contrast, once CTRIWS in on-line, it costs less than ten dollars a year in computer time to maintain. Thus, the pool of respondents for PIREG must remain necessarily small due to the high cost of conducting the survey. For CTRIWS, however, each additional household from which responses are gathered costs nothing. In addition, CTRIWS can remain available and operative over a potentially limitless span of time. During that time the survey can be inexpensively amended or changed as the data is analyzed. Thus, CTRIWS has the potential not only to have a greater impact on the public, but also to provide researchers with a far greater database than PIREG.

But the most important difference between PIREG and CTRIWS is their different strategies. Although there are stated-preference questions in CTRIWS, it is not a game-type survey based on a previously-amassed travel diary. This is a limitation of CTRIWS, in the sense that participants do not get the benefit of seeing their travel patterns laid out for them, as opposed to responding with their perceptions of what those patterns are. This is one way in which CTRIWS has less power to educate the potential EV consumer than PIREG. While researchers will gain information about consumer perceptions and travel patterns, consumers themselves will not necessarily have their perceptions about travel patterns challenged. However, respondents to CTRIWS do get some minimal analysis of their travel patterns when the survey informs them whether or not their travel patterns fit into the range of current EV technology.

CTRIWS strikes a balance between informing consumers about EVs and air quality, and advocating EV use. While CTRIWS participants may not have their preconceptions challenged as thoroughly as participants in PIREG, by that same token CTRIWS may provide a more realistic assessment of how much consumers are willing to change their perceptions and habits in order to accommodate EVs. Since market-wide intervention on the scale of PIREG's house-to-house interviews is unrealistic, the interactive method of CTRIWS may offer a more practical basis for assessing a potential EV market.

Summary of Data Collected by Survey

The survey went on-line July 13, 1995 through August 20, 1995 and again from November 14, 1995 through December 7, 1995 at the following address: http://daisy.cc.utexas.edu:7071/. During these two time periods, there were 203 responses. Respondents were not required to answer every question in order to participate in the survey. Therefore, the total number of answers varies from question to question.

Demographic Information. The survey respondents were overwhelmingly male. Of 190 persons who identified their gender, 174 are male and 16 are female (Table 4.1).

The respondents are also, for the most part, well-educated. One hundred ninety-two persons answered the question about their level of education: three participants had not finished high school (all were under 21, so perhaps they were not old enough), six people had a General Equivalency Diploma, 33 persons had some college education, 12 had an associate's degree, 64 had a bachelor's degree, 55 had a master's degree, 15 had doctorates, and four had professional degrees (Table 4.1).

Not surprisingly, participants tended to have higher than average incomes. There were 178 responses to the question about household income. Sixteen persons indicated that they had an income of under $20,000 per year. Twenty-eight responded that their income was between $20,000 and $40,000 per year. Sixty-one gave an income between $40,000 and $60,000 per year. Twenty-five participants said they had an income of between $60,000 and $80,000 per year and 39 persons indicated an income of over $80,000 per year (Table 4.1).

In terms of geographic location, the greatest number of respondents in one state live in California--forty-six. Twenty-four respondents live in Texas, seven in Massachusetts, five in New York, and eight in Canada.

TABLE 4.1 SURVEY DEMOGRAPHICS

Gender		Education		Income	
male	174	not comp. hs	3	<$20,000	16
female	16	GED	6	$20,000-$40,000	28
# of responses	190	some college	45	$40,000-$60,000	61
		bach. degree	64	$60,000-$80,000	25
		graduate degree	74	>$80,000	39
		# of responses	192	# of responses	169

Travel Information. Merely one-fourth of those taking the survey live in households that own one car or fewer. Fourteen persons taking the survey did not have a vehicle in their household. Forty-two persons had one car in their household. Of these 42 households, 17 had only one licensed driver, 19 had two licensed drivers, and the other six had three licensed drivers. Sixty-three persons answering this question had two cars in their household, 38 persons had three vehicles in their household, 33 had four cars in the household, and four participants chose not to answer this question. Of the 192 survey participants who answered both questions (giving information about the number of vehicles and the number of licensed drivers in the household) there is a ratio of approximately 1.07 cars per licensed driver.

Most respondents had access to electricity in the area where their cars are parked. Of the 179 people who answered the question of whether or not they had a garage or carport equipped with electricity, 60 said no and 119 said yes.

The vast majority of respondents make average daily trips that fall well below the most conservative estimates of the maximum range of current EV technology--60 miles. Seventy participants estimate their average daily travel to be between 0-20 miles. Seventy-five participants estimate this travel to be 21-40 miles. Twenty-two estimate it to be between 41-60 miles, seven participants travel 61-80 miles and five travel 80 miles or more. Twenty-four persons did not answer this question. Clearly, according to the range constraints of current EV technology, 167 of the 203 households described by respondents could accommodate an EV.

Participants' responses to Electric Vehicles. Depending on how many vehicles were in a participants' household, the following questions were asked. Before giving the survey participant any information, the respondent was asked if they would be willing to use an EV. If respondents did not currently own vehicles, they were asked if they would consider buying an EV in the future. If the respondent lived in a household with one vehicle, they were asked if they would replace their current GV with an EV if the cost were the same. If the respondent's household had two or more vehicles, the respondent was asked if he or she would be willing to replace one existing vehicle with an EV. A surprisingly large number (101 respondents) were immediately willing to accept an EV, while 91 said no, ten chose not to answer, and one person already owned an EV. Of the 101 that said yes immediately, 72 participants said they would be interested in an EV if it cost $1,000 more per year to own and operate than a GV, while 22 said they would not and seven did not answer this question. Of the 91 people who initially said they would not be interested in acquiring an EV, 53 participated further in the survey by ranking their concerns. The primary concern for 14 people was their concern that EVs would not be suitable for long-distance trips. Given a brief bulletin about the current range of EVs, five of these 14 changed their mind and said they would now be willing to consider acquiring an EV. Out of the 53 participants ranking their concerns, 12 said their primary concern was the fear that the EV would be too expensive to maintain. After reading some brief information about EV costs, five of those 12 changed their minds and said they would now consider acquiring an EV. Six of the 53 participants were primarily concerned that an EV would be inconvenient to recharge. When they had read a brief informative statement about fast recharging and the convenience of overnight recharging, five of the six said they would now consider acquiring an EV. Six of the 53 were primarily concerned that an EV would take too long to recharge. When informed about fast and overnight recharging, five of these six said they would now consider acquiring an EV. Four of the 53 were primarily concerned that the EV would not be fast enough. When informed about the current average and top speeds of EVs, only one of these four said they would now be willing to acquire an EV. Six of the 53 were primarily concerned that EVs would not have auto manufacturers support. After some brief information on this subject, two persons said they would now be willing to acquire an EV. Two people were primarily concerned that the EV would not be dependable enough. When informed about the dependability of the electric drive train, one person indicated a willingness to acquire an EV.

The 91 participants who initially said no to an EV also received information about various social benefits of EVs. These bulletins included information about energy security, air pollution, and greenhouse gases. These participants were then asked if knowing about any of these three issues made them more willing to acquire an EV. Eighty-four of the 91 received the information about energy security. Of these, 50 said that they were now more willing to acquire an EV; 34 said no. Eighty-five out of the 91 received information about air pollution. Of these, 51 said they were now more willing to acquire an EV, while 34 said no. Eighty-six of the 91 participants received information about greenhouse gases. For 52, this information made them more willing to acquire an EV, while for 34, it did not change their minds (Table 4.3).

TABLE 4.2 PRIMARY CONCERNS OF RESPONDENTS UNWILLING TO CONSIDER AN EV

Primary concern listed	no. of responses	no. willing to consider EV after more info	% on which more info had positive impact
Not suitable for long-distance trips	14	5	36%
Too expensive to maintain	12	5	42%
Inconvenient to recharge	6	5	83%
Too long to recharge	6	5	83%
Not fast enough	4	1	25%
Not supported by manufacturers	6	2	33%
Not dependable enough	2	1	50%
Did not rank concerns	41	0	0%
Total	91	24	*26%

*There was a presumtion that those who did not rank and read additional information concerning EVs would not reconsider their original decision.

TABLE 4.3 IMPACT OF INFORMATION ABOUT SOCIAL BENEFITS ON RESPONDENTS INITIALLY UNWILLING TO CONSIDER AN EV

Social Benefit	no. reading benefit	no. willing to consider EV after more info	no. not willing to consider EV after more info	% on which more info had positive impact
Energy security	75	49	26	65%
Air pollution	76	51	25	67%
Greenhouse gases	76	51	26	66%

Conclusions of Survey

Respondents to CTRIWS were overwhelmingly male and had incomes and education above the U.S. average. This demographic feature also reflects the profile of the typical Internet user, and may say more about who has access to the Internet than it does about who is interested in EVs.

Clearly, although the survey participants were better educated than the average citizen and may even have had an initial interest in or awareness of EVs, further education about EV issues made a difference to their willingness to acquire an EV. The more information they had about both technical attributes and social benefits of the EV, the more likely they were to consider acquiring an EV. The survey also indicates that people who are willing to consider EV acquisition from the outset are willing to pay more for an EV than for its gasoline counterpart. This willingness, however, may be contingent on the relative affluence of the survey respondents.

In the future, it would be profitable to post the survey in places that might attract a wider range of respondents--on newsgroups set up for women, for example. It might also be useful to copy the survey to a disk and circulate it to diverse workplaces, schools, and community groups. Such strategies might more directly target the populations currently underrepresented in the survey results.

However, the demographic specificity of the respondents does reflect the demographics of both Internet users and new car buyers. Thus, the very limitations of this survey's demographic distribution may suggest that this group (well-educated males with higher-than-average incomes) merits further research. They may well be the most likely group to consider EV purchase <u>because</u> of these traits, which make them more likely to take financial risks and more likely to be interested in new technology, new vehicle purchases, and consumer goods of any kind. Acquiring more detailed information about the decision-making practices of this group, as CTRIWS does, may well provide the basis for a more accurate model of the potential EV market.

EVALUATING THE PREFERENCE ELICITATION PROCESS FOR ELECTRIC VEHICLE MARKET RESEARCH

As the above discussion indicates, researchers attempting to use market surveys to determine a market for EVs confront a fundamental problem: because consumers are unfamiliar with the new EV technology, such surveys must both educate participants and also gather information about consumer preferences. The potential conflict between these two goals has implications for the way questions are framed in EV market research. Traditional surveys such as travel, stated-preference, and attitude surveys are framed to accomplish only one of these goals: gathering the empirical information needed to determine a market for EVs. PIREG constitutes a breakthrough in EV market research because it takes seriously the necessity of bringing consumers up to speed on the new technology before discussing preferences. The wide availability of CTRIWS is thus all the more important in that CTRIWS extends this breakthrough, taking seriously in its design both the educational and the empirical tasks of a survey that would successfully elicit consumer preferences on the subject of EVs. In fact, PIREG and CTRIWS can be said to have shifted the emphasis in EV market research from eliciting preferences to creating the conditions necessary to determine with any accuracy what consumer preferences might be.

The unique problem facing EV market research is threefold. First, researchers must contend with consumers' unfamiliarity with EV technology. Second, in order to get consumers to genuinely compare EV and GV ownership, researchers must create a survey framework in which a new technology, rather than bringing the consumer a totally new kind of experience in the way that computers or microwave ovens did when they were first introduced, is being offered as a replacement for an existing good--the gasoline vehicle--with which consumers may not feel dissatisfied. Researchers must be aware of the consequences of doing this. Third, in order to create the basis for genuine comparison, researchers must in a sense create that dissatisfaction by asking consumers to take public goods such as air quality as seriously as private goods. In effect, market research that accurately elicits consumer preferences must radically alter the usual basis for consumer decisions--individual preferences cut off from their social costs.

Reference Points

Theoretical work on the question of reference points is one helpful way of understanding the complexity demanded of EV survey research. When eliciting preferences either for a single attribute or for an outcome, an important concept is that of the reference point in which the options are framed. Because outcomes are commonly perceived as positive or negative in relation to a reference outcome that is judged neutral, varying a reference point can determine whether a given outcome is evaluated as a gain or as a loss. In addition, the difference between options can loom larger when framed as a disadvantage of one option rather than as an advantage of the other option (Tversky and Kahneman 1981: 456).

In this case, in which EVs are a new technology and potential EV users generally have no experience with them (usually they have not only never driven them but they don't recollect even having seen one), the gasoline vehicle is the reference for a vehicle. In various EV survey methods this phenomenon expresses itself in different ways. The hypothesis of this report is that the task of educating people about the attributes of EVs cannot truly be separated from the act of asking people what they think about them. Education must occur not only because of the newness of the technology but because of the potential social (as opposed to individual) benefits of EVs. In attitude surveys this education occurs in a simple exchange of information between a facilitator and a participant. In game-type surveys the participant is educated in a more active manner. The participant takes part in an activity that has the ability to change his or her perceptions. In general, the goal of educating the consumer can be viewed as a desire to change the reference point.

Related to this last point is an interesting debate discussed by Kahneman (1992). He states, "studies of framing effects have often been couched in terms of the adoption of one reference point or another. Indeed, one of the important implications of framing effects is that people are usually unaware of the possibility that their views of a problem might change with a different formulation--for example, that risk aversion could be replaced by risk-seeking when the same problems were framed in terms of losses rather than gains. However, there are many situations in which people are fully aware of the multiplicity of relevant reference points and the question of how they experience such outcomes and think about them must be raised" (Kahneman 1992: 305). Kahneman suggests that acts and attributes of outcomes can be evaluated in relation to multiple discrete reference points, without fully resolving the conflict between these values. As a consequence, the same aspect of an outcome can be both attractive and aversive, a gain and a loss (Kahneman 1992: 307).

The idea of multiple reference points certainly corroborates the findings of much of the research done on EV market penetration. In fact, it could very well explain the difference between information gathered in travel behavior surveys, attitude surveys, and stated-preference surveys. The notion that consumers should be willing to accept EVs (especially in terms of range) according to travel behavior studies and are enthusiastic about EVs according to many attitude surveys but appear not to want to own and operate EVs (particularly the limited range aspects) according to stated-preference surveys may well be due to the problem of multiple reference points. EV research until now has treated all attributes and constraints as if they were the same. As stated earlier, a reference point may change with the framing of the question. For example, the same consumer may perceive an EV differently in response to the question, "Can you accommodate limited range?" versus "Do you want improved air quality?" But what about the question, "Would you be willing to give up a given amount of range for a given amount of improvement in air quality?" This question may be more difficult for the respondent and be seen as both a gain and a loss. A more flexible framework such as multiple reference points is helpful for understanding what has previously been seen as a contradiction in research.

In addition, Kahneman (1992) expands on this theory by considering the different valuations of owners and choosers. He states that owners and choosers face precisely the same choices. Subjectively, however, the situations of choosers and owners are quite different: the former evaluate a good as a gain, the latter as something to be given up. He poses the question, "does ownership increase fondness for a good, or merely induce a dislike for giving it up?" He answers that mere ownership of a good does have an effect: it greatly increases the preference for that good over an alternative in a direct choice. The general principle is straightforward: when an option is compared to the reference point, the comparison is stated in terms of the advantages and disadvantages of that option. A particularly important case arises when the reference point is the status quo, and when the retention of the status quo is an option. Because the disadvantages of any alternative to the status quo are weighted more heavily than its advantages, a powerful bias in favor of the status quo exists (Samuelson & Zeckhauser, 1988).

In any type of EV survey at this time in history, respondents are more likely to be owners of gasoline vehicles than choosers. The attachment of owners to their current gasoline vehicles is likely to be a factor in their response and should be taken into account. One difference between PIREG and CTRIWS is that CTRIWS does allow those who do not presently own a car to participate in the survey. CTRIWS does not assume that persons who do not presently own a car are not potential consumers of EVs. Rather than trying to frame the questions in such a way as to make EVs seem technologically attractive to consumers, CTRIWS offers information about air quality, energy use, and the environment so as to provide participants with multiple reference points. PIREG, by focusing on range as the major impediment to EV acquisition in consumers' eyes, may shift participants' reference point somewhat as they understand their gasoline vehicle use more realistically, but it cannot really offer participants the opportunity to trade off a private good such as range against a public good such as cleaner air. But it is precisely such tradeoffs that are most likely to motivate consumers to accept the new technology of the EV.

New Technology

The introduction of AFVs will increase the diversity, complexity and uncertainty of the personal-use vehicle market. EVs will have attributes unfamiliar to consumers, including home refueling, reduced refueling ranges, different noise levels, safety, and performance characteristics. Also, the reduced emissions and greater energy security associated with EVs will make personal vehicle selection and use a more prominent public issue. Researchers are not fully aware of what are these differences in vehicle attributes and the prominence that social concerns will have on vehicle purchase and travel behavior.

Turrentine and Sperling (1992) note that while many attributes can be tested on a limited basis, such as performance, many attributes of automobiles are experience attributes, such as maintenance, reliability and seasonal performance. This is problematic for EVs since consumers have less experience with them (Turrentine and Sperling 1992: 10).

In the next decade, the EV market is expected to develop and expand. Demographic trends and price-unit reductions, although common to all product life cycles, will have a unique impact on AFVs because of their reliance on technical changes and emissions mandates. These factors will spark many shifts in the attributes of vehicle selection. Such attributes as range, refueling time, home refueling, shifts in maintenance routines, performance changes, and preferences for clean fuels will be subject to changing consumer perceptions. Under such rapidly changing conditions, "consumers must experiment, investigate, and imitate in order to make selections from the array of new alternatives." Clearly, consumers' vehicle choices will be influenced significantly by education and information and these factors may be even more influential than preferences alone (Turrentine and Sperling 1992: 12).

Public Goods

Because the GV is generally the reference, consumers often view the EV as a smaller, less versatile vehicle: one with less range, speed, space, etc. As Tversky and Kahneman note, "the displeasure associated with losing a sum of money (read here: speed, range, etc.) is generally greater than the pleasure associated with winning the same amount."

The observation complicates our understanding of the choice between a GV and an EV because losses associated with replacing a GV with an EV are individual losses where the gains usually associated with this same trade are seen as public gains. Proponents of EVs usually describe the benefits of them in terms of improved air quality and reduced consumption of foreign oil. It has been observed that the relation between such goods and individuals is as follows: everybody wants them, no one wants to pay for them. The improved air quality, decreased greenhouse gases, and improved national fuel security that are the prime benefits of AFVs cannot be enjoyed or demonstrated directly by individual consumers. Economists call these benefits a "public good" while environmentalists refer to the dilemma as the "tragedy of the commons." It will take many consumers switching to alternatives before the effects can be demonstrated, and such improvements cannot be restricted to those who make the switch. Therefore, despite popular support for improving air quality, questions remain as to whether individual consumers will act on their good intentions by purchasing AFVs (Turrentine and Sperling 1992: 15).

The normal assumptions undergirding stated-preference surveys are highly speculative for new technology products, with whose attributes consumers may have no experience. Transitivity and communicativity, the definitional properties of preferences, for example, may not be obtained because of the instability and lack of longitudinal data in the EV market. As this report has demonstrated, these problems are more generally true of the other types of surveys examined as well. Prior work concludes that innovative survey and interview methods will be needed to provide both consumers and researchers with an adequate context in which to understand the decisions made by consumers in relation to EVs (Kurani et al. 1994).

CTRIWS, like PIREG, frames its questions in such a way as to take into account that consumers need information before they can make a decision about a new technology product with the specific market location of the EV. Because CTRIWS can remain available indefinitely and inexpensively on the Internet, it goes even further than PIREG in its ability to reach and educate consumers. CTRIWS addresses the necessity, at this moment in EV market development, of an open-ended, ongoing process in which consumer education and market development loop back into one another, and both are changed in the process.

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APPENDIX A

EMISSIONS FROM HIGHWAY VEHICLES

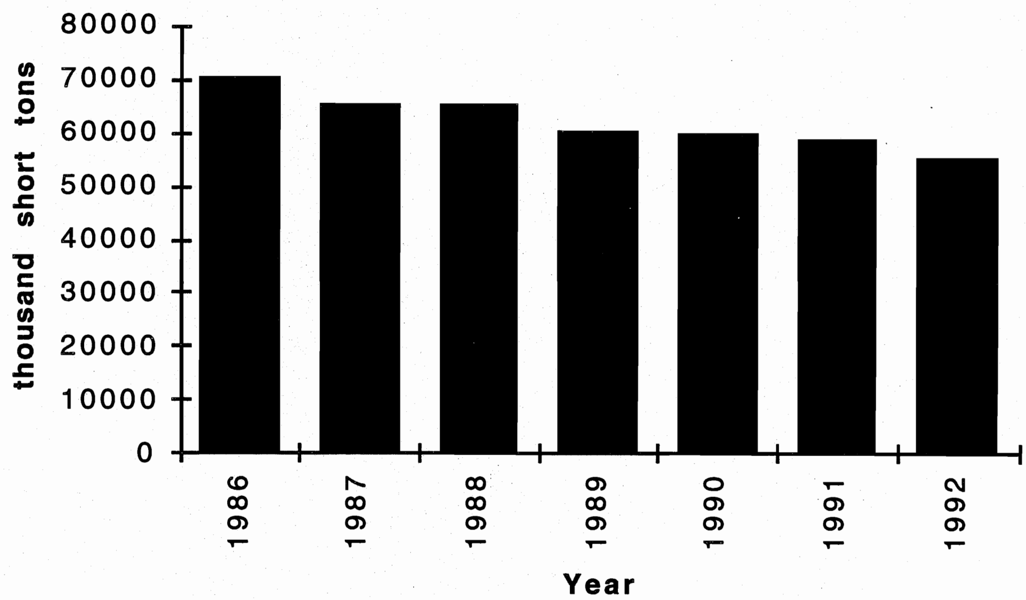

Figure A.1 CO Emissions from Highway Vehicles

Source: EPA 1993: A-5

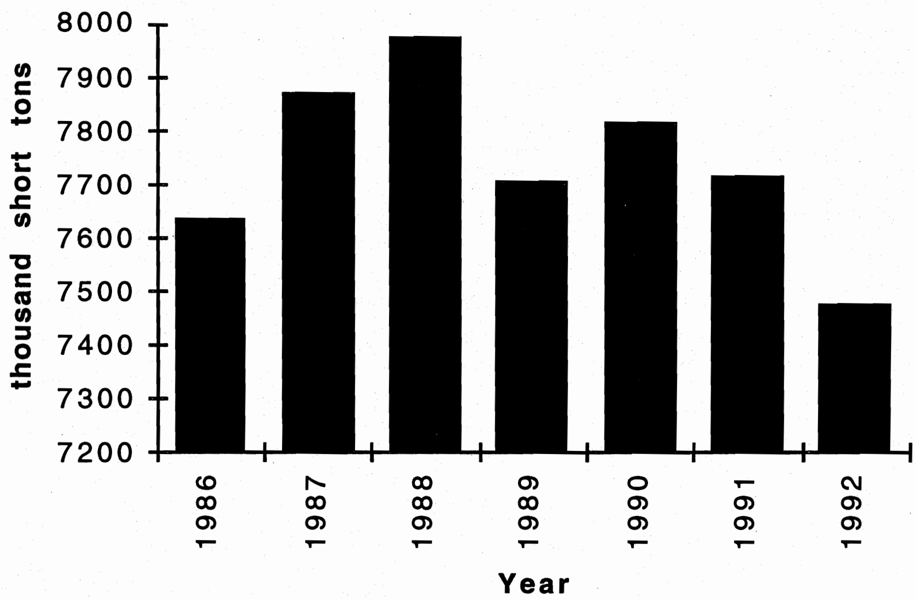

Figure A.2 NOx Emissions from Highway Vehicles

Source: EPA 1993: A-10

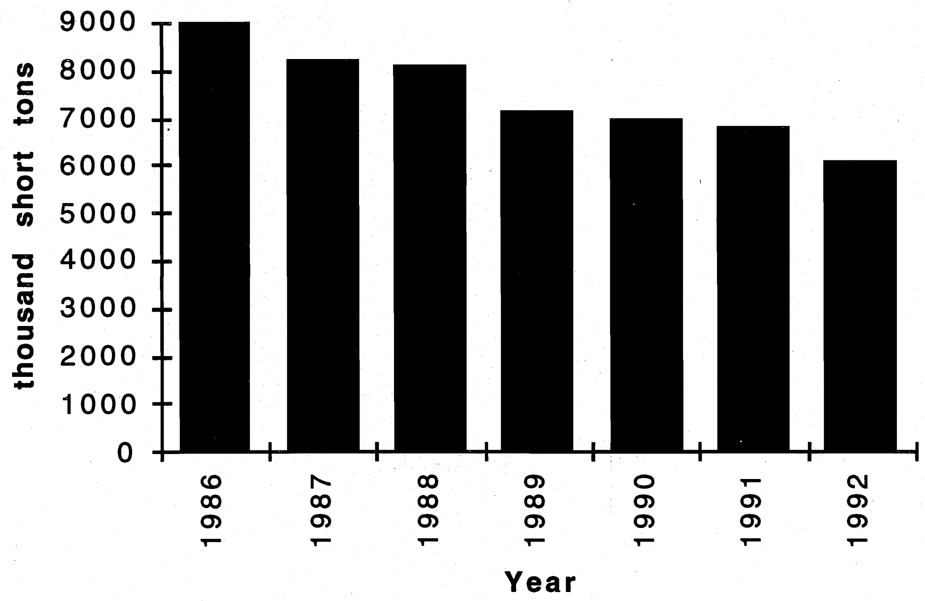

Figure A.3 VOC Emissions from Highway Vehicles

Source: EPA 1993: A-20

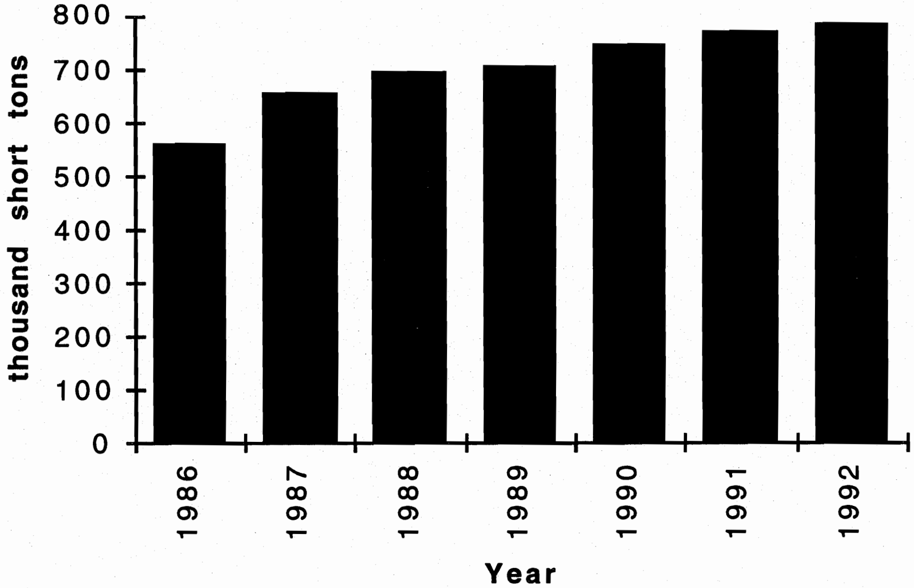

Figure A.4 SO_2 Emissions from Highway Vehicles

Source: EPA 1993: A-27

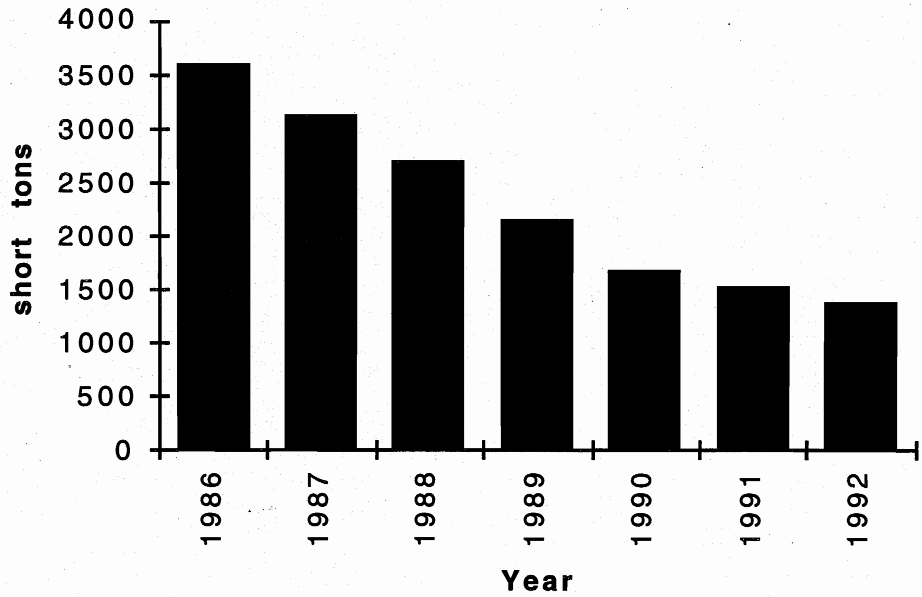

Figure A.5 Pb Emissions from Highway Vehicles

Source: EPA 1993: A-30

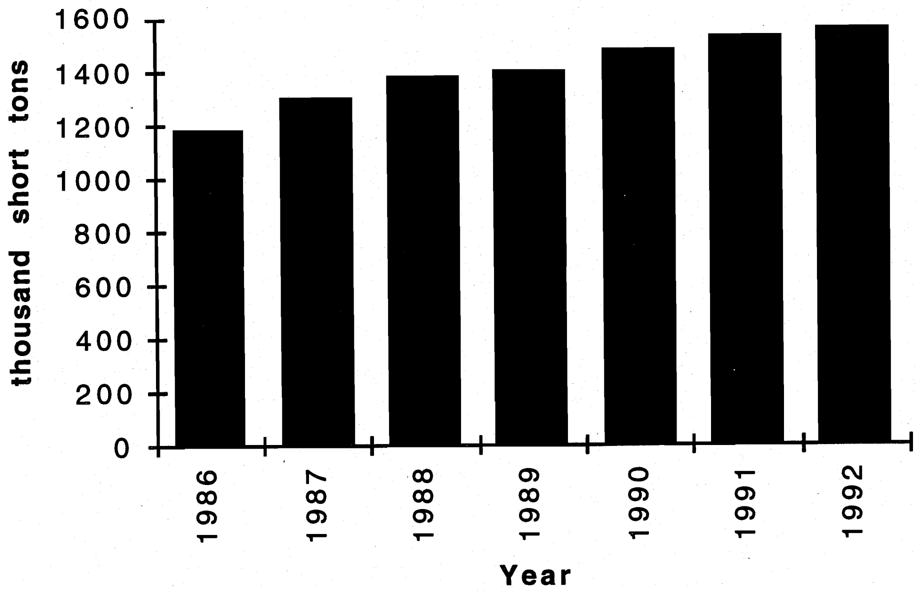

Figure A.6 PM-10 Emissions from Highway Vehicles

Source: EPA 1993: A-32

APPENDIX B

OWNERSHIP AND OPERATING COSTS OF ELECTRIC VEHICLES AS COMPARED TO GASOLINE-POWERED VEHICLES

TABLE B.1 OWNERSHIP AND OPERATING COSTS OF A COMPACT GV (CASE 1)

Ownership Costs	Annual	Cents/Mile	Cents/Km
Depreciation	$991.32	9.26	5.75
Finance	$174.53	1.63	1.01
Insurance	$835.41	7.80	4.85
Registration fee	$58.80	0.55	0.34
Local fee	$11.50	0.11	0.07
Inspection fee	$10.50	0.10	0.06
Taxes:			
State Vehicle Excise Tax	$61.96	0.58	0.36
Total Ownership Costs	$2,144.02	20.02	12.44
Operating Costs			
Fuel (excluding taxes)	$382.24	3.57	2.22
Maintenance	$375.25	3.50	2.18
Oil	$19.05	0.18	0.11
Tires	$98.91	0.92	0.57
Taxes:			
State:			
Fuel	$93.69	0.87	0.54
Maintenance	$30.02	0.28	0.17
Oil	$1.52	0.01	0.01
Tire	$7.91	0.07	0.05
Subtotal State Taxes	$133.14	1.24	0.77
Federal:			
Fuel	$86.19	0.80	0.50
Total Operating Costs	$1,094.79	10.22	6.35
Total Owning & Operating Costs	$3,238.80	30.25	18.80

TABLE B.2 OWNERSHIP AND OPERATING COSTS OF AN INTERMEDIATE GV(CASE 2)

Ownership Costs	Annual	Cents/Mile	Cents/Km
Depreciation	$1,247.74	11.65	7.24
Finance	$219.68	2.05	1.28
Insurance	$841.14	7.86	4.88
Registration fee	$58.80	0.55	0.34
Local fee	$11.50	0.11	0.07
Inspection fee	$10.50	0.10	0.06
Taxes:			
State Vehicle Excise Tax	$77.98	0.73	0.45
Total Ownership Costs	$2,467.35	23.04	14.32
Operating Costs			
Fuel (excluding taxes)	$439.76	4.11	2.55
Maintenance	$400.30	3.74	2.32
Oil	$19.05	0.18	0.11
Tires	$114.34	1.07	0.66
Taxes:			
State:			
Fuel	$107.78	1.01	0.63
Maintenance	$32.02	0.30	0.19
Oil	$1.52	0.01	0.01
Tire	$9.15	0.09	0.05
Subtotal State Taxes	$150.48	1.41	0.87
Federal:			
Fuel	$99.16	0.93	0.58
Total Operating Costs	$1,223.09	11.42	7.10
Total Owning & Operating Costs	$3,690.44	34.46	21.42

TABLE B.3 OWNERSHIP AND OPERATING COSTS OF A COMPACT EV (CASE 1A)

Ownership Costs	Annual	Cents/Mile	Cents/Km
Depreciation	$2,079.53	19.42	12.07
Finance	$366.12	3.42	2.12
Insurance	$835.41	7.80	4.85
Registration fee	$58.80	0.55	0.34
Local fee	$11.50	0.11	0.07
Inspection fee	$10.50	0.10	0.06
Taxes:			
State Vehicle Excise Tax	$61.96	0.58	0.36
Total Ownership Costs	$3,423.81	31.97	19.87
Operating Costs			
Fuel (excluding taxes)	$286.68	2.68	1.66
Maintenance	$281.44	2.63	1.63
Oil	$0.00	0.00	0.00
Tires	$98.91	0.92	0.57
Taxes:			
State:			
Fuel	$70.26	0.66	0.41
Maintenance	$22.52	0.21	0.13
Oil	$0.00	0.00	0.00
Tire	$7.91	0.07	0.05
Subtotal State Taxes	$100.69	0.94	0.58
Federal:			
Fuel	$64.65	0.60	0.38
Total Operating Costs	$832.36	8.71	5.42
Total Owning & Operating Costs	$4,256.18	40.69	25.29

TABLE B.4 OWNERSHIP AND OPERATING COSTS OF A COMPACT EV (CASE 1B)

Ownership Costs	Annual	Cents/Mile	Cents/Km
Depreciation	$1,456.95	13.61	8.46
Finance	$256.51	2.40	1.49
Insurance	$835.41	7.80	4.85
Registration fee	$58.80	0.55	0.34
Local fee	$11.50	0.11	0.07
Inspection fee	$10.50	0.10	0.06
Taxes:			
State Vehicle Excise Tax	$61.96	0.58	0.36
Total Ownership Costs	$2,691.62	25.14	15.62
Operating Costs			
Fuel (excluding taxes)	$286.68	2.68	1.66
Maintenance	$281.44	2.63	1.63
Oil	$0.00	0.00	0.00
Tires	$98.91	0.92	0.57
Taxes:			
State:			
Fuel	$70.26	0.66	0.41
Maintenance	$22.52	0.21	0.13
Oil	$0.00	0.00	0.00
Tire	$7.91	0.07	0.05
Subtotal State Taxes	$100.69	0.94	0.58
Federal:			
Fuel	$64.65	0.60	0.38
Total Operating Costs	$832.36	8.71	5.42
Total Owning & Operating Costs	$3,523.99	33.85	21.04

TABLE B.5 OWNERSHIP AND OPERATING COSTS OF AN INTERMEDIATE EV (CASE 2A)

Ownership Costs	Annual	Cents/Mile	Cents/Km
Depreciation	$2,505.95	23.40	14.54
Finance	$441.20	4.12	2.56
Insurance	$835.41	7.80	4.85
Registration fee	$58.80	0.55	0.34
Local fee	$11.50	0.11	0.07
Inspection fee	$10.50	0.10	0.06
Taxes:			
State Vehicle Excise Tax	$77.98	0.73	0.45
Total Ownership Costs	$3,941.35	36.81	22.88
Operating Costs			
Fuel (excluding taxes)	$329.82	3.08	1.91
Maintenance	$300.23	2.80	1.74
Oil	$0.00	0.00	0.00
Tires	$98.91	0.92	0.57
Taxes:			
State:			
Fuel	$80.84	0.75	0.47
Maintenance	$24.02	0.22	0.14
Oil	$0.00	0.00	0.00
Tire	$7.91	0.07	0.05
Subtotal State Taxes	$112.77	1.05	0.65
Federal:			
Fuel	$74.37	0.69	0.43
Total Operating Costs	$916.09	9.61	5.97
Total Owning & Operating Costs	$4,857.44	46.41	28.85

TABLE B.6 OWNERSHIP AND OPERATING COSTS OF AN INTERMEDIATE EV (CASE 2B)

Ownership Costs	Annual	Cents/Mile	Cents/Km
Depreciation	$1,783.39	16.65	10.35
Finance	$313.98	2.93	1.82
Insurance	$835.41	7.80	4.85
Registration fee	$58.80	0.55	0.34
Local fee	$11.50	0.11	0.07
Inspection fee	$10.50	0.10	0.06
Taxes:			
State Vehicle Excise Tax	$77.98	0.73	0.45
Total Ownership Costs	$3,091.57	28.87	17.94
Operating Costs			
Fuel (excluding taxes)	$329.82	3.08	1.91
Maintenance	$300.23	2.80	1.74
Oil	$0.00	0.00	0.00
Tires	$98.91	0.92	0.57
Taxes:			
State:			
Fuel	$80.84	0.75	0.47
Maintenance	$24.02	0.22	0.14
Oil	$0.00	0.00	0.00
Tire	$7.91	0.07	0.05
Subtotal State Taxes	$112.77	1.05	0.65
Federal:			
Fuel	$74.37	0.69	0.43
Total Operating Costs	$916.09	9.61	5.97
Total Owning & Operating Costs	$4,007.66	38.48	23.91