Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

AHS Alternative Propulsion System Impact

U.S. Department of Transportation
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FOREWORD

This report was a product of the Federal Highway Administration's Automated Highway System (AHS) Precursor Systems Analyses (PSA) studies. The AHS Program is part of the larger Department of Transportation (DOT) Intelligent Transportation Systems (ITS) Program and is a multi-year, multi-phase effort to develop the next major upgrade of our nation's vehicle-highway system.

The PSA studies were part of an initial Analysis Phase of the AHS Program and were initiated to identify the high level issues and risks associated with automated highway systems. Fifteen interdisciplinary contractor teams were selected to conduct these studies. The studies were structured around the following 16 activity areas:

> (A) Urban and Rural AHS Comparison, (B) Automated Check-In, (C) Automated Check-Out, (D) Lateral and Longitudinal Control Analysis, (E) Malfunction Management and Analysis, (F) Commercial and Transit AHS Analysis, (G) Comparable Systems Analysis, (H) AHS Roadway Deployment Analysis, (I) Impact of AHS on Surrounding Non-AHS Roadways, (J) AHS Entry/Exit Implementation, (K) AHS Roadway Operational Analysis, (L) Vehicle Operational Analysis, (M) Alternative Propulsion Systems Impact, (N) AHS Safety Issues, (O) Institutional and Societal Aspects, and (P) Preliminary Cost/Benefit Factors Analysis.

To provide diverse perspectives, each of these 16 activity areas was studied by at least three of the contractor teams. Also, two of the contractor teams studied all 16 activity areas to provide a synergistic approach to their analyses. The combination of the individual activity studies and additional study topics resulted in a total of 69 studies. Individual reports, such as this one, have been prepared for each of these studies. In addition, each of the eight contractor teams that studied more than one activity area produced a report that summarized all their findings.

Lyle Saxton
Director, Office of Safety and Traffic Operations
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and Development

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16. Abstract
The program described by this eight-volume report, a resource materials document type, identified the issues and risks associated with the potential design, development, and operation of an Automated Highway System (AHS), a highway system that utilizes limited access roadways and provides "hands off" driving. The AHS effort was conducted by a team formed and directed by the Calspan Advanced Technology Center. Primary Team members included Calspan, Parsons Brinckerhoff, Dunn Engineering Associates, and Princeton University. Supporting members of the team were BMW, New York State Thruway Authority, New York State Department of Transportation, Massachusetts Department of Transportation, the New Jersey Department of Transportation, Boston Research, Vitro Corporation, and Michael P. Walsh of Walsh Associates. Calspan provided overall management and integration of the program and had lead responsibility for 5 of the 17 tasks. Parsons Brinckerhoff provided transportation planning and engineering expertise and had lead responsibility for 5 tasks. Dunn Engineering provided traffic engineering expertise and had lead responsibility for 2 tasks. Princeton supported the areas of transportation planning and automated control.

The 17 task reports (A through P plus Representative Systems Configurations) are organized into 8 volumes. This volume describes the analysis of Alternative Propulsion System Impact performed under Task M, supervised by John A. Pierowicz of Calspan and supported by Robert S. Mydzian of Calspan, and consultants Patrick MacDiarmid and Nicholas Schmitt.

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VOLUME VI — AHS ALTERNATE PROPULSION SYSTEM IMPACT (TASK M)

1.0 EXECUTIVE SUMMARY

1.1 APPROACH

The objective of this task was to evaluate the effect of alternative propulsion vehicles (APVs) on the Automated Highway System (AHS). This entailed research and literature reviews, in-house knowledge and interviews with experts in applicable fields. Background information on APVs were gathered to gain a understanding of the technology issues and problems facing APVs.

An alternative propulsion vehicle does not rely on a internal combustion (IC) engine as its primary power source. Three types of vehicles were evaluated in this task. They are:

- Electric vehicles (EVs) - All power is supplied by rechargeable onboard batteries.
- Hybrid vehicles - There are two types of hybrids, series and parallel.
  - Series: A combustion engine is used to charge the vehicle batteries directly.
  - Parallel: The combustion engine can be used to either charge the batteries or to directly power the vehicle.
- Roadway powered electric vehicles (RPEVs) - RPEVs are electric vehicles that can be charged dynamically while moving, receiving power through induction from a powered roadway.

All of these APVs are similar in that they have batteries and electric motors. The differences lie in how power is supplied to their batteries.

Electric vehicles are moving from technology demonstrators, of the 1970s and 1980s, to consumer vehicles that will be produced within the next ten years. Our EV research consisted of battery technology, performance parameters, use, and emissions. Hybrid vehicles may be the transition vehicles between today's conventional and electric vehicles. Several different types of hybrid vehicles were researched, along with their advantages and disadvantages for AHS use. Roadway powered electric vehicles are a derivative of EVs. They can be used to extend the range of EVs for AHS travel. We have analyzed the use of RPEVs, along with problems and advantages of an RPEV system. This task describes the relationship that APVs will have with their environment, the AHS, and their interaction with other vehicles.

The technical approach used assumptions based on our estimates for APV influence in the near-term vehicle population. We assumed that APVs may only reach the levels stated in California Air Resources Board (CARB) regulations. Estimates of battery storage capacity are stated within the calculations that they are used in. No breakthrough battery that increases range by a factor of two or three times is likely. More details concerning assumptions are provided in the individual examples cited. We believe our assumptions are real world, moderate in nature; unlike many inaccurate assumptions made about APVs in previous years. The APV goals of range, performance, refueling, and consumer acceptance have not been met.

1.2 CONCLUSIONS/KEY FINDINGS

The current and future generation of alternative propulsion vehicles (APVs) researched suffer decreased performance compared to most conventional spark ignition (SI) vehicles. These deficits encompass all aspects of vehicle performance, from acceleration and braking to vehicle range. The performance deficiencies, most notable in vehicle acceleration, result from the lack of an adequate power storage media for electricity. Current designs compromise vehicle performance for range, with battery technology the limiting factor. The present-generation batteries store only limited, and inadequate, amounts of electric charge. The range deficiency is the major drawback for APV market potential. This feature inhibits the manufacture of APVs with range and performance comparable to conventional vehicles. Therefore, because of interstate travel, AHS effectiveness will be reduced if APV battery technology is not improved.

The current and near-future APVs may encounter problems on the AHS, depending upon the system's speed limit. Although many APV designs are capable of speeds in excess of the current national speed limit, these vehicles are electronically limited to speeds in the range of 110- to 130-kmh (68- to 81-mph) to maintain battery charge. The operating speed limit will be critical to APV impact on the AHS.

The acceleration performance of most APVs are within the range of current economy class vehicles and light trucks. These values are acceptable for the acceleration and deceleration lanes of current highways under American Association of State Highway and Transportation Officials (AASHTO) guidelines. No modifications are required of the road infrastructure to incorporate APVs.

At present, a large proportion of APVs are conventional SI vehicles that have been converted to APV use. These vehicle conversions result in substantially higher design weights. This factor, along with low rolling resistance tires and a modified weight distribution, can seriously impair vehicle dynamics. Without changes to vehicle braking systems, APV braking distances are significantly longer than the original vehicle. This will cause problems for AHS platooning and emergency maneuvers. Ground-up electric vehicle designs do not suffer from these braking difficulties; at present, only one vehicle, the GM Impact, falls into this "purpose-built" category. The limited number of purpose-built vehicles illustrates the high costs involved in vehicle development. For the near-future, the APV fleet will consist predominantly of converted SI vehicles, and have a negative effect on performance.

Vehicle range is the biggest handicap facing alternative propulsion vehicles today. Electric vehicle (EV) range is dependent on the battery storage system utilized. The only certainty of battery technology is that it is uncertain; it is difficult to extrapolate into the future. In the 1960s, researchers were predicting that electric vehicles would be commonplace in the seventies. This prediction was repeated in the seventies. Because current battery technologies do not provide APVs with range and performance comparable to SI vehicles, this prediction has not yet come to fruition. Research is making evolutionary progress in battery technology with no "revolutionary" breakthroughs on the horizon. The pace of battery system development will presage the closing of the performance and range gap of APVs to SI vehicles. Because of these trends, battery-powered electric vehicles will not have AHS interstate travel range.

As with battery technology, electric vehicle recharging is advancing at a slow pace. Newer, quicker ways of vehicle charging need to be developed for consumer acceptance to rise. Goals for recharging of vehicles need to be in minutes, not hours, as is currently the case.

Without the installation of special charging equipment, home electric vehicle recharging cannot be performed in one- to three-hours. Older homes may not have the capacity to use this equipment without a complete rewiring. For apartment dwellers, the problem is magnified. The specialized charging equipment will initially require charging stations similar to gas stations to allow quick-charge of these vehicles. Electric vehicle quick-charging will have to be performed at recharging stations, possibly co-located with gas stations or AHS service areas.

If the future holds a breakthrough battery, the interim solution may be hybrid vehicles, due to their increased range capabilities and reduced emissions. Of the two types of hybrid vehicles, series and parallel, series hybrids hold the most promise since they are less complex, produce fewer emissions per distance traveled, and operate as zero emission vehicles (ZEVs) for a greater portion of their driving cycle. With the use of a small onboard SI engine, hybrids have greatly extended range capabilities as compared to EVs, and therefore provide promise as AHS vehicles.

Decreased emissions is a major goal of future transportation systems. However, APVs must represent a large share of the vehicle population, or the benefits will be insignificant. Regionally, the reduction in emissions depends directly on the different types of fuel used (the generation mix) to generate electric power. A vehicle’s emissions may one day be a selling point similar to present-day features like styling, safety equipment (anti-lock brakes, airbags) and fuel consumption. APVs, especially electric vehicles, will have the lowest emissions of all vehicles. The major manufacturers’ disdain for APVs is similar to their general attitude toward small cars, catalytic converters and airbags in earlier years.

Vehicle reliability will be equal to or greater than conventional SI vehicles, and electric motor reliability may be much greater. Depending on the type of APV, the need for instrumentation monitoring may decrease because of the less complex overall system. The only specialized training needed is training for AHS operation, which may be identical for all vehicles. Overall, APVs will be easier to use (less complex, no transmission, less maintenance) than comparable SI vehicles.

Fleet use is the first and best use for APVs. Even with the limited present range (approximately 160-km), APVs can be used as many types of delivery vehicles. Initially, APVs will be developed for fleet use, independent of the AHS. With further development, they may be suitable for AHS operation. Our findings, on daily kilometers driven, match other surveys. The majority of fleet vehicles travel less than 133-km per day, which is within the range of present APVs. In this regard, electric vehicles can safely operate on the AHS, but they will have limited range. Initially, EVs will be best suited for inner city travel and not for intra city or cross-country travel.

The use of roadway power as a range extender for EVs complements electric vehicle driveability. Roadway powered electric vehicles (RPEVs) will initially be used in transit/commercial applications where the vehicle routes are always the same. Initially, RPEV deployment will consist of public transportation operations. Roadway power presents a practical solution for eliminating emissions in densely populated areas. RPEVs are ideally suited for bus routes, shuttle services, airport shuttles, and use in pollution sensitive areas. RPEVs can play a significant role in transit applications if EV range does not improve. A battery breakthrough could render commuter RPEVs obsolete, while transit RPEVs would be modified to electric-electric vehicles. With battery advancements, RPEV status may change. Transit station recharging could be eliminated if an APV is able to recharge quickly for a entire day’s use. RPEVs are still in the experimental stage but the technology is available, mature, and appropriate for present day systems. RPEVs for transit use are a deployable system. Rubber-tired RPEVs would make an excellent replacement for diesel buses, trams, and trolleys.

RPEVs can be operated on the AHS with minimal effect. The electro magnetic field (EMF) emitted by RPEVs is equivalent to household appliances or less. This is acceptable at the present known standards. No interference should occur with non-RPEVs operating on or near a powered RPEV roadway or vehicle. There does not appear to be a problem with EMF emissions from RPEV induction. But, RPEV EMF needs additional study due to the potentially serious consequences of EMF in general. The RPEV induction system is a likely candidate to be used for EV recharging, as it eliminates plugs and cables and is passive to use. If use of RPEVs is widespread in the future, it will tax power resources in New York State beginning around the year 2011.

The inductive coupling required in the RPEV/AHS lane could act as a lateral guidance system available to all vehicles. Many EV designs are adapting “fly-by-wire” steering to reduce weight in the vehicle. Inductive lateral guidance systems have already been adopted and proved effective.

The emissions reductions achieved using an RPEV-based AHS would be much larger than those of a non-RPEV AHS. This is an attractive alternative which promotes compliance with the 1990 Clean Air Act.

Accidents related to APV technology on the AHS will not be a major concern. Battery safety has improved such that battery spills will cause no great threat or harm to the environment and can be safely dealt with by trained emergency crews. Use of APVs will be a stimulant to the businesses created to manufacture, design, and develop these vehicles. Considerable expertise in APVs lies not only in major auto manufacturers, but in vehicle converters and small businesses. APVs are efficient in their conversion of energy to propulsive power, are as safe as a conventional vehicle, and less harmful to the environment.

The top design issues jointly affecting APVs and AHS are:

- Range/charging - If current battery and charging technology are not improved by the time of AHS implementation, APVs will experience reduced AHS capabilities. Limited vehicle range can impair AHS interstate travel.

- Top speed - Future APV designs must be capable of matching AHS design speeds. Limited top speed can negatively impact AHS throughput and increase travel time.

- Fleet/Transit use - To meet CARB mandated sales goals, designers have focused on APVs for fleet use. This feature will facilitate AHS equipment implementation.

- RPEV lane design - If RPEVs are used on the AHS, overall lane design must be standardized and power, billing, and EMF issues resolved. RPEV lanes can provide lateral guidance to all vehicles using the RPEV/AHS road.

The major limitation is the range issue. The use of hybrid vehicles, which can extend the range of APVs, transitions the use of all the different types of APVs on the AHS. The differences in performance characteristics (acceleration, braking, and handling) between APVs and SI vehicles is decreasing and may be eliminated by the time AHS is implemented.

1.3 RECOMMENDATIONS FOR FURTHER RESEARCH

Further research is recommended in the following areas:

- Advancing battery technology is the most pressing problem affecting alternative propulsion vehicles and their use on the AHS.
- Quick (less than ten-minutes), safe recharging must be developed simultaneously along with advancements in battery technology.
- APV safety research and testing is lacking; this issue needs further investigation before AHS implementation.
- Further study is needed on long range (20 to 50 years) electric power requirements of electric vehicles and RPEVs, and the projected generating capacity, generation mix, and emissions at that time.
- Hybrid vehicles, especially series hybrids, as extended range APVs, may bridge the gap between internal combustion and electric vehicle performance. Hybrid vehicles may resolve APV's AHS performance limitations.
- Roadway powered electric vehicles (RPEVs) are the least researched APV technology. RPEVs may provide EVs with the range and performance capabilities necessary for AHS.
- The effects of weather (snow, ice) on powered roadways and the AHS are unknown. Safety impacts must be assessed.
- Lateral and longitudinal guidance of RPEVs on the powered roadway/AHS. RPEV lanes can provide measures of vehicle lateral control.
- Alternative energy storage systems (mechanical batteries, ultracapacitors, fuel cells) may overcome current-generation APV range and performance limitations. These systems could provide APVs with adequate AHS performance.
- Any adverse electro magnetic field (EMF) effects of RPEVs on humans and AHS/equipment need to be addressed.
- APV research is advancing rapidly; further study of both domestic and foreign APV advancements is needed. With technological advancements, the APV performance limitations discussed may be remedied.

2.0 INTRODUCTION

2.1 ANALYSIS OF THE IMPACT OF ALTERNATIVE PROPULSION VEHICLES ON THE AUTOMATED HIGHWAY SYSTEM

The automated highway system (AHS) will provide a higher level of safety, convenience, and improved efficiency to drivers in the next century. The make-up of the automotive fleet that will utilize the AHS will comprise conventional spark ignition (SI), and compression ignition (CI) vehicles in use today. In addition, the AHS will have to accommodate an increasing population of vehicles utilizing other propulsion sources. In this analysis, the term alternative propulsion vehicle (APV) refers to vehicles which use propulsive power other than SI or CI type engines. Included in this group is electric drive, hybrids (SI/electric), fuel cell electric, and mechanical batteries (flywheels).

This task, performed under the direction of the Federal Highway Administration (FHWA), examined how these alternative propulsion concepts could impact the design of the AHS. The FHWA awarded contracts to multiple contractors to allow examination of this subject with emphasis on different aspects of this problem. The Team examined electric vehicles with specific, detailed examination of the roadway powered electric vehicle (RPEV) concept. The research performed in this task investigated electric vehicles with emphasis on automobile manufacturers' efforts in the area of prototype vehicles and technology demonstrations. These experiments by the manufacturers indicate the line of thought being pursued to solve the problem of APVs. The vehicle designs were categorized as technology demonstrations, which are built to determine the feasibility of specific technology, or production prototypes, which are intended for production. The technology demonstrators include many entries by numerous manufacturers; the prototype category is populated by few entries.

Of special interest was the examination of the concept of roadway powered electric vehicles. These electric vehicles draw power from a system of inductors imbedded in the roadway. This concept, and its application to an AHS, is investigated in this task. Under the direction of FHWA, we performed a thorough analysis of RPEVs and the potential impact that incorporating them would have on an AHS.

This report details the analyses performed as a part of the Precursor Systems Analysis of the Automated Highway System. The reasons for investigating these concepts as well as the methodology followed in the course of this study are discussed. The results of this research, as well as the conclusions resulting from these analyses, are described.

2.2 THE DRIVE FOR ALTERNATIVE PROPULSION SYSTEMS

The advent of the "green" revolution has brought about a higher respect and new standards for our environment. Each part of society is being asked to change the way they do business in order to reduce, or prevent, pollution of the air, water, and land. This effort culminated in the passage of the Clean Air Act of 1990, a legislative action that imposed far-reaching goals on every industry, including transportation.

The vanguard of this legislation is the California Air Resources Board (CARB) Clean Air regulations. These regulations mandate the introduction of lower pollution-generating vehicles in the state. Using vehicles presently manufactured as benchmarks, CARB regulations call for an increasing number of cleaner vehicles to be produced. These vehicles range from low emission vehicles (LEVs), to ultra-low emission vehicles (ULEVs). The culmination of these steps is the zero emission vehicle (ZEV). This vehicle theoretically has no tailpipe emissions as it operates. At present only electric vehicles comply with this designation. (The CARB mandated emissions standards are shown in table E1 of appendix E.) The mandate for ZEVs in California requires that two percent of the vehicles sold by a manufacturer in 1998 be ZEVs. This number rises to five percent in 1999, and ten percent in 2002. Only those manufacturers who sell over 30,000 vehicles per year in California are subject to this mandate.

The imposition of these rules has spread to the Northeast. Driven by the same legislative pressures, these states have imposed similar regulations on manufacturers. Faced with ever-restrictive pollution regulations, manufacturers have increased research into alternative propulsion system for automobiles.

2.3 TASK METHODOLOGY

In the course of this study, we used an investigative methodology that started with a broad view of the subject. This view was narrowed as the apparent impact of each area on the AHS became clear. Research was initiated with a survey of automobile manufacturers' efforts in meeting the California Air Resources Board 1998 mandate to introduce ZEVs. All candidate ZEVs being considered for introduction are electric vehicles, relying on battery storage of the electrical energy. Identifying the potential vehicles that could be introduced into the automobile fleet allowed us to determine potential problems with these vehicles. An initial result of this methodology was the revealing of a performance deficit in these vehicles. The range, acceleration, top speed, and braking performance of current ZEVs was determined to be sub-standard with the bulk of the automotive population.

The identified performance characteristics of these vehicles was used to extrapolate the consequences on the automated highway. Since the automated highway will not be deployed for a number of years, it was important to determine if the issues uncovered might be solved. A tracing of the root cause of each problem allowed an examination of the technology to determine if a breakthrough that could alleviate this problem is possible. This methodology was performed for electric vehicles then subsequently for RPEVs. The problems and deficiencies were identified and the technology state-of-the-art was assessed.

3.0 TECHNICAL DISCUSSION

3.1 INTRODUCTION: ELECTRIC VEHICLES AND THE AUTOMATED HIGHWAY SYSTEM

Electric vehicles (EVs) are viewed as the most promising means of complying with state requirements for zero emission vehicles. EVs are being vigorously researched by the large automotive manufacturers (General Motors, Ford, and Chrysler) as well as by numerous vehicle converters (US Electricar, Solectria). Vehicle types range from two-seat commuter cars to mini-vans. Only General Motors has completed a purpose-built electric vehicle for production. This vehicle, the Impact, was withdrawn from production plans due to a limited market. Other automobile manufacturers such as Ford and Chrysler have used existing vehicle designs as the basis of their electric vehicles. In this sense, electric vehicle design and manufacturing in this country is still in its infancy.

In order to determine the impact of an electric vehicle on the automated highway system, parameters concerning vehicle performance, size, weight, and configuration must be acquired. For the analyses described, a survey was performed of various electric vehicle concepts and prototypes. The intent was to determine the direction EV design was taking and the generation of parameters that could be used for AHS impact assessment. Vehicle designs from virtually all the automobile manufacturers from America, Japan, and Europe were reviewed. Of particular interest were the vehicle ranges, acceleration times, and top speeds. The range of the vehicle is of particular interest because of the acknowledged deficit in this area; typical vehicle ranges are between 96- and 160-km. Range is important to note because it limits the market potential for EV applications. Vehicles with ranges of 160-km and long recharge times cannot be used effectively to travel cross-country. The important performance characteristics of electric vehicles are acceleration and top speed. Current electric vehicles are electronically speed-limited to 96- to 130-kmh to conserve battery power. If AHS configurations seek to increase transit speeds in order to increase traffic throughput, this deficit would limit the applicability of EVs to the AHS. The acceleration rates of electric vehicles are currently sub-standard to their ICEV counterparts. This fundamental performance measurement is utilized every time a vehicle merges with a line of traffic, particularly on ramps to highways.

This section will describe the current state in electric vehicle technology, trends in the state-of-the-art, and the impact of these vehicles upon the AHS. Also presented is information on battery types used in EVs. Battery technology is the single "show stopper" for electric vehicles. The types of batteries now in use, their positive and negative safety attributes, and their possibilities for recycling are discussed.

3.1.1 Catalog of Electric Vehicles

The adoption of the 1990 Clean Air Act by Congress has led to a dramatic increase in EV research and development. Prior to passage of this legislation, electric vehicles were more novelties being investigated by automobile manufacturers than legitimate pre-production concepts. Now, however, electric vehicles are being seriously considered to fulfill the Clean Air Act requirements.

The vehicles investigated include the Chrysler TEVan, the Ford Ecostar, and the General Motors Impact. The first two entries are conversions of vehicles presently on the road. The General Motors Impact has been withdrawn from production plans because of the limited market for this vehicle’s configuration (a two-seat commuter vehicle). The Impact is included in this section however, because of its innovative concepts and performance characteristics. This vehicle is a benchmark in EV design and manufacture. The Impact uses conventional battery systems in conjunction with power conditioning and HVAC (heating, ventilation, and air conditioning) innovations not utilized in other EV designs. The Impact matches conventional SI vehicle performance characteristics in top speed and acceleration. The only component lacking in its list of performance features is acceptable range; just as for many other EVs, the range of the Impact is only 160-km.

The vehicles previously described are attempts by the large automobile companies to comply with increasingly strict emission regulations; another population of electric vehicles is marketed by smaller companies. These small manufacturers convert electric vehicles by adapting existing SI designs; removing the SI engine and support systems and replacing them with electric power trains. Two leading manufacturers in this area are US Electricar and Solectria, which supply conversions of such models as the Chevrolet S-10 Pick-up (Solectria and Electricar) and Toyota Corolla (Electricar). The configurations of the vehicles chosen in this analysis are specifically meant to illustrate the present state-of-the-art in electric vehicle design and to show the direction of design trends. A complete listing of the vehicles included in the analysis is contained in appendix B.

The catalog of electric vehicles presented in appendix B contains important information on vehicle performance. The electric vehicles’ configurations listed are all limited to ranges of 180-km on a single battery charge because of the limited energy density of the current generation of batteries. Table 1 illustrates the ranges on a number of electric vehicles.

Table 1. Range Characteristics for Selected Electric Vehicles

Vehicle Model	Battery Type	Range (km)/(miles)
Chrysler TEVan	Nickel - Iron	193/120
Ford Ecostar	Sodium Sulfur	161/100
General Motors Impact	Sealed Lead Acid	160/100
BMW E -1	Sodium Sulfur	215/134
Solectria S-10 Pick-up (Vehicle Conversion)	Sealed Lead Acid	96/60

The ranges listed are manufacturers' values and do not reflect the seasonal ranges that could be expected. Hot/Cold weather performance is another area where electric vehicles are distinct from spark ignition vehicles. In an SI or CI type vehicle, vehicle range does not change significantly on a seasonal basis. The range of electric vehicles, on the other hand, can differ dramatically from season to season and from one geographic region of the country to another. One cause is due to the electrochemical thermal efficiencies of the batteries used. Overall, batteries operate best at moderate to warm temperatures. Below freezing, some batteries experience high self-discharge rates, decreasing efficiency. Another cause is related to the means by which each of these vehicles produce and utilize engine heat. A fossil-fuel powered vehicle burns oil or gasoline to produce motive power; heat is a by-product of this combustion process. The engine is used to drive an alternator to produce electricity for environmental systems in the vehicle. This cycle uses the same fuel to produce two useful products: heat and electricity. Electric vehicles lack this engine heat source and the alternator to produce electricity for environmental controls; instead, the same batteries being used to provide motive power are used to supply electricity for HVAC needs. With varying seasonal needs for HVAC in the country, an electric vehicle with acceptable range in one part of the country may not have acceptable range in another.

Similar power limitations are reflected in the top speeds of this category of vehicle. These vehicles are electronically limited to top speeds of 100- to 130-kmh in order to allow maximum extension of range. A listing of typical vehicle top speeds is shown in table 2.

Table 2. Top Speeds for Sample Electric Vehicles

Vehicle	Top Speed (kmh/mph)
Chrysler TEVan	104/65
Ford Ecostar	112/70
General Motors Impact	128/80
Electricar Sedan (Toyota Corolla Conversion)	128/80

The top speeds referenced in table 2 are cataloged for a number of vehicles in table B2 of appendix B. Top speed limitations can adversely affect the AHS if vehicle speed is used to increase system efficiency and through-put. In order to increase the top speeds of these vehicles, a more efficient means of storing electric charge must be developed. Current batteries, top speed, and performance must be traded against vehicle range. As a point of reference, the range and top speeds of EVs were compared to a 1993 Ford Taurus and 1993 Honda Accord. The Taurus and Accord were chosen because they are popular "main stream" vehicles with average performance and range. Figure 1 illustrates the comparison of these two types of vehicles. Note that all of the electric vehicles are clustered in the left portion of the graph, reflecting their lower ranges. The Taurus and Accord are in the upper right quadrant of the graph, reflecting their 190-kmh top speeds and ranges greater than 700-km.

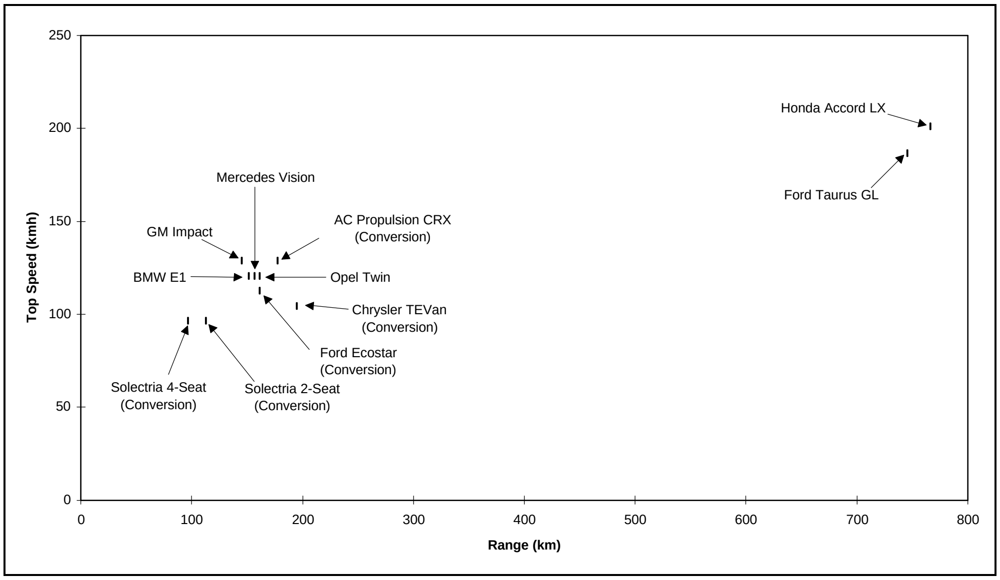

Figure 1. Range and Top Speed of Selected APVs Versus Conventional ICEVs

The range and speed deficits of electric vehicles can be rendered irrelevant if they are appropriately applied. While EVs may be poor cross country touring vehicles they can be very good commuter vehicles.

The following sections discuss various aspects of electric vehicles and their relationship to the AHS.

3.1.2 Electric Vehicle Battery Technology

Sufficient fuel storage that provides a vehicle with adequate performance and range is a critical short-coming of present electric vehicle designs. A spark ignition vehicle is designed to carry enough fuel to support that vehicle's performance over an acceptable range. The fuel used in most spark ignition vehicles is gasoline. The gas tank is the repository for the fuel, sized to allow the vehicle to operate over an acceptable range. The electric vehicle analogue to gasoline and gas tank is the battery and the amount of electric charge it can store. The energy density (amount of energy per unit weight) of current batteries is inferior to gasoline. Table 3 (adapted from Fukino, et al., 1992) compares the energy density of current batteries to gasoline.

Table 3. Comparison of Battery Energy Density vs. Gasoline

Battery Type	Energy Density (Wh/kg)	Energy density vs. Gasoline (%)
Lead - acid	40	1.28
Nickel - iron	60	1.85
Nickel - zinc	80	2.56
Sodium - sulfur	120	3.70
Lithium	240	7.69

Table 3 illustrates the problem for the electric vehicle designer. Even the most efficient battery can store only a small proportion of the energy of gasoline. To maintain range and performance, a designer would have to increase the battery size used in these vehicles, an unacceptable approach. In a gasoline-powered vehicle, fuel typically accounts for four to five percent of the vehicle mass. In most electric vehicle designs, batteries account for 25 to 30 percent of the total vehicle weight. Packaging this volume of batteries in an acceptable vehicle is difficult. Most vehicle designers have determined minimum levels of performance and range that are acceptable for the vehicle and have accommodated the required battery pack.

Currently, General Motors Corporation, Ford Motor Company and Chrysler Corporation have combined efforts under Government direction and encouragement to form the United States Advanced Battery Consortium (USABC). In this forum, these three companies can combine their resources with those of Government research laboratories, to attempt to develop a battery for use in alternative propulsion vehicle designs. The following is a summary of current and near-future promising battery technology. Appendix C catalogs current and future electrochemical battery alternatives for use in alternative propulsion vehicles.

3.1.2.1 Current Battery Technology

3.1.2.1.1 Lead-Acid

Lead-acid battery technology is essentially unchanged since its introduction in the 1800s. These batteries are heavy and large but currently the best affordable energy source for today's electric vehicles. Operating at room temperature, lead-acid batteries consist of solid lead electrodes and an aqueous electrolyte consisting of sulfuric acid in solution. The lead electrodes tend to corrode during reaction, forming metal oxides and resulting in oxygen and hydrogen gas evolution. As a result, early lead-acid battery designs required excessive maintenance including watering and gas venting. Technology advancements now provide sealed, maintenance-free operation but have resulted in only moderate improvements in battery performance.

Lead-acid batteries suffer from poor cold weather performance. Therefore, some designers have turned to using auxiliary, fossil-fuel powered heaters to keep the battery pack warm on cold days. Consequently, these external heating sources, in addition to producing pollutants, add weight, complexity, and cost to the batteries.

One advantage to lead-acid batteries is that an economically viable infrastructure already exists to recycle them. From a safety perspective, a lead-acid battery electrolyte spill can be more easily neutralized than an equivalent gasoline spill, with less harm to the environment. In fact, with proper design, no electrolyte leakage will occur when the battery is damaged. In these cases, the battery electrolyte is in gel form, which will not flow even if the battery case is ruptured. For example, the battery used in the GM Impact employs a mat which holds the sulfuric acid gel by surface tension, preventing battery leakage in the event of an accident.

3.1.2.1.2 Lead Cloth (Horizon®) Battery

The Horizon® battery is an advanced, maintenance-free lead-acid system developed by Electrosource, Inc. of Austin, Texas with funding from the Electric Power Research Institute (EPRI). This battery is a high specific energy, long life cycle, valve regulated lead-acid system made from a lead-tin alloy. This alloy is coextruded onto a high tensile strength core material, making a small-diameter dimensionally stable wire that can be woven into lightweight, bipolar mesh grids. These grids are then coated with a proprietary paste and assembled into batteries. A unique feature of this battery is its horizontal plate arrangement, which delivers more charge/discharge cycles with increased energy and power per pound than conventional lead-acid technology.

There are a few minor problems with lead cloth battery technology. A tube is used to vent off the gases (mostly oxygen) formed at the end of each charge cycle. A backup fan system ensures that the tubes are cleared, but the amount of gas released is small. For cold weather environments, a heater is required to maintain proper battery function. Finally, heat shields are recommended as a primary means for keeping external heat sources from entering the battery tub.

Safety and environmental concerns are minimal. The battery is totally recyclable using the current lead-acid battery recycling infrastructure, it is made from stable and safe materials, and it does not vent gases under normal operation. Additionally, the modern “green” manufacturing process used to produce the Horizon battery is environmentally friendly, does not release any harmful products into the air or water, and recycles and reuses materials during production. In addition, if the battery is ruptured in event of an accident, no acid will spill. (Electrosource, Inc., 1994)

3.1.2.1.3 Nickel-Iron

Nickel-iron batteries are aqueous, room-temperature batteries that utilize an alkaline electrolyte solution containing potassium hydroxide (KOH). These batteries provide better range for APVs than lead-acid technology, but are expensive, require excessive maintenance, and have poor energy efficiency. As a result, NiFe batteries can require up to a 50 percent overcharge. And, because hydrogen gas is evolved during charge/discharge cycles, nickel iron batteries cannot be sealed. The current production method, which takes about a week, involves sintering the electrodes from a nickel slurry and impregnating them with NiOH. However, high volume production would lead to automation of the manufacturing process, bringing overall costs down (Reizenman, 1992).

In general, NiFe batteries are lighter and more powerful on an equal energy basis than lead acid, have long cycle lives, are tolerant of mechanical and electrical abuse, and are environmentally benign. Moreover, a high residual value ensures their recyclability. Electrolyte safety concerns for nickel-iron systems are minimal. The battery electrolyte breaks down into a potassium equivalent of baking soda in prolonged exposure to air. Electrolyte exposure damage to human and animal tissue can be avoided if exposed areas are rinsed off quickly. The hydrogen gas evolution and maintenance issues need to be explored further.

3.1.2.1.4 Nickel-Cadmium

This battery is a favorite of Japan because it offers high energy efficiency and excellent range. High material costs, the toxicity and scarcity of cadmium, as well as life cycle issues have caused concern among some automobile manufacturers. NiCd batteries can be produced maintenance-free by the inclusion of trace excess amounts of cadmium hydroxide ($Cd(OH)_2$) placed in the electrodes to prevent unwanted gas evolution during overcharge and overdischarge. In a few instances, in scaled-up versions used to power electric vehicles, these batteries have experienced sealing problems. Recent research has shown that the “memory effect" of NiCd batteries, caused by frequent shallow discharges, can prevented by proper EV controller designs.

In the opinion of some researchers, NiCd batteries can be recycled economically; other sources disagree. Environmental concerns are a problem in the United States since cadmium does not pass the EPA's 1990 material toxicity standards. This limits the potential of NiCd battery disposal since specially lined landfills are required. States such as Minnesota and Connecticut have passed laws requiring manufacturers to label the electrochemical content of these batteries for sorting purposes. To facilitate removal and recycling, the batteries must also be accessible in their products. Some thirty other states are considering passing, or have passed, similar legislation. In addition, states are considering incentives to make consumers recycle NiCd batteries. Manufacturers such as NIFE of Sweden have offered to accept NiCd batteries for recycling but have been unable to obtain enough waste batteries for recycling to be practical. Also, because cadmium is a toxic waste, community-based collection and sorting centers would be expensive due to the processing and permit costs involved when dealing with hazardous materials. (Erickson, 1991)

3.1.2.1.5 Nickel-Metal Hydride (Ovionic Battery)

The nickel-metal hydride battery is seen as a breakthrough technology providing high performance without the material toxicity and scarcity problems of NiCd batteries. These cells are ambient temperature, maintenance-free batteries which store hydrogen in the solid hydride phase. Nickel-metal hydride batteries are tolerant of overcharge and overdischarge, made from nontoxic materials, and recyclable using existing technology. In addition, these cells offer high energy density, high power, long life, quick charge capability, and operate over a wide range of temperatures.

Unlike other nickel-based alkaline batteries fabricated from relatively pure elemental metals, nickel-metal hydride battery reactions reversibly incorporate hydrogen into the metal alloy. Therefore, nickel metal hydride electrodes remain metallic during reaction, so electrical conductivity is always high. This process avoids the performance deficiencies of the non-hydride based systems which result from changes in electrode mechanical integrity and surface morphology that occur during oxidation. (Ovshinsky, et al., 1993)

The metal hydride electrode is a critical design issue. The amount of hydrogen a material can absorb determines the energy storage capacity (vehicle range) of the battery. Another key issue is the oxidation and corrosion resistance of the metals. Because the battery is a sealed environment, it must be able to tolerate the consequences of the chemical reactions that occur with overcharge (oxygen gas evolution) and overdischarge (hydrogen gas evolution). These factors, along with material conductivity, make material selection issues critical. Nickel makes an ideal electrode material choice because it possesses a weak bond strength, acts as a catalyst for the disassociation of hydrogen, and is resistant to oxidation.

Safety concerns involve only the battery electrolyte, which has a concentration of 30 percent KOH by weight in solution. Since these batteries are nontoxic, they can be safely disposed of in landfills or recycled into metallurgical additives for cast iron, stainless steel, or new NiMH electrodes using existing technologies. (Lyman and Palmer, 1993) However, the commercial viability of recycling depends on the process economics involved.

3.1.2.1.6 Sodium Sulfur

This is a high operating temperature (300 to 400°C) battery seen as a USABC mid-term EV battery solution (see table E3 of Appendix E). These batteries offer high energy density (long range) and excellent efficiency with long life cycles and low self-discharge rates. The low self- discharge capability is achieved through the battery electrolyte, which acts as an electronic insulator allowing sodium ions to pass but not electrons (so the battery lacks a self-discharge path).

In normal use, the battery maintains its own operating temperature but insulation is used to help sustain it. If the battery freezes, a process that adds stress to the battery and drastically reduces its cycle life, internal heaters can be used to remelt the electrolytes. However, if the battery is left on the charger during periods of non-use, this freezing problem will not be encountered. The added insulation and internal heaters increase the cost and weight of these batteries, but material costs are low and sodium and sulfur are relatively abundant.

As for safety, molten sodium and sulfur are extremely hazardous materials and must be packaged for crashworthiness. Current battery production methods separate the battery into hundreds of stainless steel cells, making large-scale spills unlikely but possible. Further compounding safety design issues, a thin, brittle ceramic (beta alumina), chosen because it is an excellent ionic conductor, separates the electrolytes in the battery. In addition, sodium sulfur battery systems have experienced fires during in-vehicle testing programs by Ford, but these problems have since been resolved.

3.1.2.1.7 Zinc Bromine

Zinc bromine batteries are ambient temperature batteries utilizing carbon electrodes and zinc in solution. The zinc is plated onto one of the electrodes when the battery is fully charged and returns to solution upon discharge. To prevent self-discharge, the batteries are divided into two parts: an active stack of plates and reservoirs of electrolyte solution. A unique feature of these batteries is their design flexibility. ZnBr batteries can be optimized for high energy or high power applications. If maximum power is needed, the bulk of the battery serves the stack. For maximum energy, the bulk of the battery goes to the reservoir.

One advantage of these systems is the circulating bromine electrolyte, which serves as a coolant. However, the pumps, piping, insulation, and valving required to circulate the electrolyte make for a bulky battery. Costs are reasonable, however, because automated production is possible and zinc and bromine are relatively inexpensive.

Bromine has numerous safety concerns. It is highly reactive and noxious, causes eye and throat irritation and skin lesions, and is difficult to seal in pumps and piping.

3.1.2.1.8 Zinc-Air

Zinc-air technology is seen as an excellent USABC mid-term electric vehicle battery solution. Zinc-air batteries offer good energy density but have very low power densities compared to other battery technologies. To resolve power issues, these batteries can be used as part of a hybrid battery system. An electronic flywheel of load- leveling batteries can be used to minimize cell size and cost and still have adequate power for vehicle acceleration. This hybrid system also prolongs zinc-air battery cycle life through elimination of high current peak demands.

The optimal operating temperature range for these batteries is generally 10 to 50°C. Above these temperatures the gelled electrolyte loses water, reducing battery performance and increasing maintenance requirements. To attain long life, the reaction air stream usually needs humidification during discharge in addition to being scrubbed of carbon dioxide. The carbon dioxide scrubber, which adds complexity and cost to the system (as well as increased maintenance), must be replaced periodically. (Cheiky, et al., 1990)

Other issues include hydrogen gas evolution, low temperature startup problems, and air electrode life. Furthermore, the battery must be kept in sealed storage when not discharging (except for oxygen pressure release during charging). Potential advantages include planar construction, low material costs, possibility for automated manufacture, and recyclability of the battery.

Safety concerns are minimal. The battery uses KOH electrolyte and has a short circuit-proof chemistry which prevents fire or explosion in event of damage, making them acceptable for automotive uses.

3.1.2.1.9 Aluminum-Air

Aluminum-air batteries store electrical energy in the form of aluminum. The aluminum reacts with oxygen in the presence of a water-based electrolyte, sodium hydroxide, to produce electricity and hydragellite (aluminum hydroxide). The cathode (the air side of the battery) is a porous, “spongy” composite produced from Teflon® and high grade carbon. The cathode contains a catalyst, usually platinum, which acts as a current collector and an inert site for the electrochemical reaction.

In aluminum-air systems the incoming air is directed to the fuel cell, where aluminum plates are dropped between air cathodes and the alkaline electrolyte is pumped around for the reaction to take place. The battery system includes the aluminum air cell stack, an electrolyte storage tank, and a storage area for the hydragellite, oxygen and electrolyte flow systems. Although these systems are considered bulky, some researchers believe they take up less space than a conventional internal combustion motor and its supporting systems.

Drawbacks to aluminum-air batteries are that they must have their incoming air source scrubbed of carbon dioxide and they require frequent periodic service intervals. The aluminum plates, made from a relatively expensive alloy, must be replaced every 1,600- to 3,200-km after they are used up in the electrochemical reaction. However, this feature provides rapid “refuelability” (making these batteries mechanically rechargeable). Other periodic servicing (around every 250- to 500-km) includes adding water and removing the waste aluminum hydroxide. In addition, the sodium hydroxide electrolyte may need replacement every two years. (Rudd, 1989)

These service intervals can be performed at home, the reaction product can be stored safely in a garage, and a year’s supply of aluminum occupies only seven cubic feet of space. Safety concerns might preclude electrolyte replacement from being a do-it-yourself exercise.

Aluminum-air battery systems are recyclable, with few potential safety and environmental implications. The sodium hydroxide used in the reaction can cause burns along with eye, nose, throat, and lung irritation with prolonged exposure, but can be easily neutralized. On the positive side, aluminum is an abundant resource, and the hydragellite formed from the electrochemical reaction can be stored, returned, and reused as feedstock for future aluminum production.

3.1.2.2 Promising Future Battery Alternatives

3.1.2.2.1 Lithium Metal Sulfide

Primary (non-rechargeable) lithium batteries have been used for years in a variety of applications where long-life batteries are needed and high discharge current density is not of concern, e.g., watches, cameras, and calculators. (Tekehara and Kanamura, 1993)

Lithium metal-sulfide batteries are high operating temperature (300 to 400°C) maintenance-free batteries which provide high power, high energy, low weight, small size, and costs comparable to today's inexpensive battery technologies. Issues include life cycle lengths and the insulation needed to maintain battery operating temperatures (which adds weight and cost to the battery system.) In addition, lithium is more expensive and less abundant than sodium.

Lithium batteries are environmentally safe and have the possibility for complete recyclability. SAFT America is currently developing this technology for use in EVs.

3.1.2.2.2 Lithium Polymer Electrolyte

Lithium polymer batteries, which have not yet been tested in EVs, are slated for production beginning in 2003. These cells utilize a thin-film, solid polymer electrolyte and operate at ambient temperature.

Lithium polymer electrolyte batteries can be inexpensively manufactured from structural components of the anode, cathode, and electrolyte laminates. Laminate construction allows for a solid-state modular battery which can be produced in a variety of shapes and sizes. The bipolar configuration minimizes weight, provides high energy and power densities, and reduces self-discharge rates by preventing intercell current leakage. The polymer-based electrolyte also serves as a separator in the battery acting as an electrical insulator between the anode and the cathode. As a result, the polymers must maintain good dimensional stability for proper function. (Abraham, 1993)

Lithium polymer batteries have much lower ionic conductivity than those of aqueous electrolyte-based lithium batteries. However, in order to maintain the performance of the aqueous based systems, larger electrode surface areas and thinner electrolytes are needed to reduce internal resistance.

These batteries have shown high power and energy densities in laboratory testing. Possible advantages include low self-discharge rates, high reliability, safety, and recyclability. Lithium reactivity safety issues have been resolved by developers using lithium ions rather than lithium foil in their applications. Potential disadvantages include reaction with the lithium negative electrode, gas venting, and the need for sophisticated seals to contain the organic liquid electrolytes.

These batteries, which have not yet undergone in-vehicle testing, are environmentally benign; researchers are addressing recycling and safe disposal issues.

3.1.2.3 Battery Charging / Infrastructure

Today's automobile is part of a complex transportation system which includes roads and signals, and associated automobile support agencies. These infrastructure elements were not in place when the first automobiles were introduced in the early 1900s. However, because there was little competition, the infrastructure grew to facilitate automotive use.

Electric vehicles can take advantage of most of the infrastructure systems already in place, but, battery-powered EVs require some unique infrastructure considerations. These infrastructure changes will affect both the consumer and the utility industry. From a consumer viewpoint, current EV technology needs improvement. EV users will require longer vehicle ranges and rapid recharging ability available in five minutes or less. In addition, the charging procedure should be easy, safe, and readily accessible. On the opposite side, utilities need to supply electricity in a managed way to minimize adverse impacts on other customers and overall system operations.

For EVs to be truly accepted, these infrastructure elements need to be implemented before these vehicles can be sold in larger numbers. Market penetration by electric vehicles will most surely drive infrastructure development. The problem is that there is no past experience to dwell on. Consumer research needs to be conducted as to the number of vehicles being purchased, the performance expectations of the consumers, and where the majority of the vehicles will be operated. Only then can planners forecast which areas will need the most attention. Furthermore, vehicle charging procedures and equipment need to be standardized to avoid consumer problems. The present system of gasoline stations presents a logical starting point for APV recharging stations. Rest areas on the interstate highway system/AHS present ideal areas for APV charging facilities as well.

To smooth the transition of electric vehicles into the marketplace, the Electric Power Research Institute (EPRI) created the Infrastructure Working Committee (IWC) to help resolve EV infrastructure issues. In 1991 the IWC established the Infrastructure Research and Development Plan. This plan consists of five elements: connecting, connecting stations, electric utility load management, health and safety issues, and utility information and consumer education. (O'Connell, 1992)

3.1.2.3.1 Connecting

Battery charge characteristics depend on battery depth of discharge, charger technology, and battery temperature. Moreover, chargers need to protect batteries from overdischarge in order to increase battery cycle life. Since peak demand occurs at the beginning of the charging cycle, charge-limiting technologies can be applied when draw is highest to prevent battery overcharge.

Electric vehicles will require built-in charge flexibility to afford maximum opportunity charging. The IWC has established standardized charging voltages of 120-, 240-, and larger than 240-V for the United States. Plug and cord issues must also be resolved. The IWC has outlined the following concerns for plug and cord development; physical and electrical characteristics, environmental ruggedness, standardization, safety, user convenience, and cost. Manufacturers have other priorities. Automobile manufactures would prefer that the cord systems be part of the charging stations, reducing vehicle weight and initial purchase costs. Charger manufacturers prefer that the cords be part of the vehicle so that operators can use public charging facilities, and to reduce the potential for vandalism. A detachable cord that offers portability is a third alternative to be explored. The IWC has suggested that at least for residential use, one or two possible cord sets may be needed.

Another alternative is inductive charging, which could eliminate the need for a physical connection altogether and the multiple plug configurations that go along with them. In this configuration the vehicle would be parked over a plate that would charge the vehicle's battery through induction. This feature can further be expanded to the development of a roadway-powered electric system.

3.1.2.3.2 Connecting Stations

Research has shown that most EV users will be best served by home recharging performed at night during off-peak hours. However, people who live in large cities and don't have a "home base" may not have this option available to them. As a result, opportunity and quick recharge stations need to be developed to satisfy all consumer needs.

Opportunity-charging will be available to the general public, while the vehicle is parked. These stations may provide added security to the EV user by allowing them to avoid deep battery discharges. Charging and billing issues for these facilities are the major issue to be resolved.

Quick-charging, on the other hand, may need to be supplied by specially outfitted facilities or mobile systems. Quick-charge stations must be capable of supplying the high voltages needed to charge the batteries in a safe environment by qualified personnel. However, the need for specialized equipment and trained operators will make these quick-charge stations expensive.

Battery-swapping stations have also been proposed. The object of these stations is to provide rapid refueling in the same time it takes to refuel a conventional automobile. The concept involves replacing the vehicle's low state of charge battery with a freshly charged battery. Ideal for fleet operations, battery recharging can be accomplished at off peak hours when there is less utility load demand. The Arizona Public Service Company, in conjunction with Diversified Technical Systems, is currently operating and testing battery-swapping stations in Arizona.

3.1.2.3.3 Electric Utility Load Management

The electricity generating plants and power grids that supply electricity to homes and businesses are already in place. Therefore, the electricity distribution needed to supply energy to EV batteries should not be a problem. Furthermore, off peak EV recharging will allow utility companies to use their generating capacity more efficiently, and gradual EV market penetration will allow for planned, gradual growth of power generation facilities.

Electric vehicle recharging presents its own unique problems. EV chargers behave non-linearly, draw large current loads, and have the possibility of being portable. Charger non-linearity deserves some attention. Utilities usually produce voltages in a sinusoidal wave form at 60-Hz frequency. Nonlinear electrical appliances, such as battery chargers, do not draw current in this form. One drawback is that these nonlinear profiles are a source of harmonics.

Harmonics are defined as high-frequency currents that exhibit, in this case, n x 60-Hz behavior. Harmonics can adversely impact electricity supply, causing malfunctions in customer and utility equipment and increasing system losses. The systems losses create larger costs for the customer. (Mead, 1994)

Other problems could be encountered when electric vehicle charging stations are implemented. If most of the opportunity and quick charging occurs during peak hours, electricity generating plants may experience shortages. As a result, more generation capacity may be needed. Special scheduling strategies and load management issues will need to be resolved. To discourage peak charging use, utilities may provide special rates to EV users during off-peak hours.

Quick-charge facilities pose their own unique issues since they require large amounts of electrical draw for short time durations. This could have serious consequences on the utility companies. To alleviate these problems, utilities will need to study the effects quick-charging stations will have on the electricity distribution network and peak demand. Another possibility is to study the vehicle population to determine where and how many of these stations will be required to meet the consumer's needs.

Other utility issues center on the electric vehicle buyer. Home charging could require modifications to existing household electric services. This, in turn, might require the utility to install new electrical transformers to supply the required electricity. A survey, conducted by AUS Consultants, which took place from April 5 to August 19, 1993, looked at 314 homes in California. Results were stratified by residence type, age of the dwelling, building shell characteristics, and household income. It was found that, for a typical single family household built between 1950 and 1980 with an attached garage, the cost of retrofitting a home for EV charging equipment averaged $805. Furthermore, homes with detached garages cost up to $226 more to retrofit while residences needing service panel upgrades cost $731 more. These costs, in 1993 US dollars, included all the electrical components necessary to provide power to an EV charger. The components considered consisted of the weatherhead, entrance conductor, panel, circuit breakers, wiring, conduit, elbows, and receptacles. The analysis did not include the cost of load management devices, second meters or off-board chargers. (AUS Consultants, 1993) Through careful preplanning with automotive dealerships and utilities, costs to consumers can be reduced and complications avoided.

3.1.2.3.4 Health and Safety

Like any electrical appliance, electric vehicles are designed to meet existing electrical safety codes. However, electrical code issues for homes and buildings must be resolved and standardized before these charging facilities become readily available. Standards already exist for golf cart recharging facilities which can be expanded to accommodate electric vehicles. New buildings must be built to these standards and older construction updated.

Because EVs are relatively scarce in today's marketplace, medical and emergency personnel are not trained to deal with specific electric vehicle emergencies. These professionals need to be trained so they can adapt to the market as EVs gain more acceptance. Other health issues include reducing electrocution possibilities and studying the effects of electro magnetic fields (EMF).

3.1.2.3.5 Utility Information and Customer Education

As mentioned previously, research must be conducted in order for the utility industry to design appropriate supporting infrastructure systems. With proper analysis, utilities can determine incentive requirements needed to promote EV use and off-peak charging, market penetration strategies, and consumer expectations for electric vehicle performance. This analysis can also be used to determine the utility's role in regard to business opportunities such as installing and operating charging stations and leasing and recycling vehicle batteries.

A sample of APV battery recharge requirements is provided in table B3 of appendix B.

3.1.3 Performance Characteristics of Alternative Propulsion Vehicles

Alternative propulsion vehicles have significantly different performance characteristics from conventional spark ignition vehicles. The characteristics that could have the greatest effect on the AHS are vehicle range and performance. The vehicle performance can be summarized as vehicle acceleration, braking, and top speed. This section details the differences in the performance characteristics and describes how these can affect the AHS.

3.1.3.1 Range

At present, no standards exist for measuring the ranges of electric vehicles. The Society of Automotive Engineers (SAE) has developed an SAE J227a electric vehicle test standard, but most manufacturers data on range does not reference this test procedure. Table B2 of appendix B cites the ranges for a sample of current APVs. Notice that Japanese producers of APVs site high vehicle ranges, but at low vehicle velocities (usually 40-kmh). An interesting vehicle is the Toyota Town Ace Van, which achieves a range of 140-km at a modest 25-kmh. These figures are not representative of real-world driving conditions. An increase of vehicle speed for these figures would degrade vehicle range.

To improve range performance, APVs use low rolling resistance tires with small contact patches inflated to high pressures from 345- to 414-kPa (50 to 60 psi). Although these tires are more efficient than conventional tires when considering range, they seriously degrade vehicle dynamic characteristics. The current sample of APVs often have electronically governed top speeds in the 110- to 130-kmh range. This is a result of a trade-off in top speed to increase the range of the vehicle. This limitation may preclude the use of pure electric vehicles on an AHS with speeds above 130-kmh unless a suitable battery is found to extend range or a roadway power source is implemented to periodically charge vehicle batteries. The RPEV approach, envisioned to compensate for range limitations of APVs, is discussed in section 3.3 of this report.

In general, the alternative propulsion vehicles designed from the ground-up achieve better ranges than converted EVs. This is primarily attributed to the highly efficient aerodynamic designs of EVs and lower overall vehicle masses. Research has shown that a reduction in weight of 10-kg in an automobile can lead to a range increase of two-km. Thus, vehicle mass is a critical issue in any automotive design. One advantage of electric motors is that since they do not idle while the vehicle is stationary, they do not suffer losses at zero velocity like conventional IC engines. Range is dependent on the vehicle battery as well; vehicles whose batteries have high storage capacities generally achieve better ranges; e.g., Ford Ecostar, BMW E1 and E2, DEMI/APS Saturn, and Mercedes Vision. The high-capacity batteries in these vehicles encompass new technologies. Therefore, as battery technology improves, so will APV range.

3.1.3.2 Acceleration

Most APVs (electric, hybrid, and conversions) have acceleration and top speed characteristics comparable to sub-compact economy vehicles. Only a very select few have performance that equals or exceeds SI vehicles (example: GM Impact). Figure 2 compares acceleration of two electric vehicles and a Ford Taurus against the AASHTO (American Association of State Highway and Transportation Officials) guidelines. The AASHTO guidelines are used for the design of roadways. The BMW E2 is a purpose-built EV, while the Ecostar is a conversion of a Ford Escort van. The acceleration gap between the EVs and the SI vehicles increase with increasing velocity. Comparing the time-to-speed capabilities of the EVs, (table B2 in appendix B) shows that EVs are close to the AASHTO minimum for acceleration levels used to determine lengths for entrance terminals. This acceleration deficit has the potential to cause difficulties for APVs operating in traffic. With the difference in acceleration characteristics from SI vehicles, APVs may have trouble operating in both AHS and non-AHS traffic environments. In the AHS, the acceleration deficit could cause difficulties for APVs merging into the traffic flow or in platoons. While APVs are within AASHTO guidelines, their reduced acceleration affects the length of the acceleration lane for the AHS.

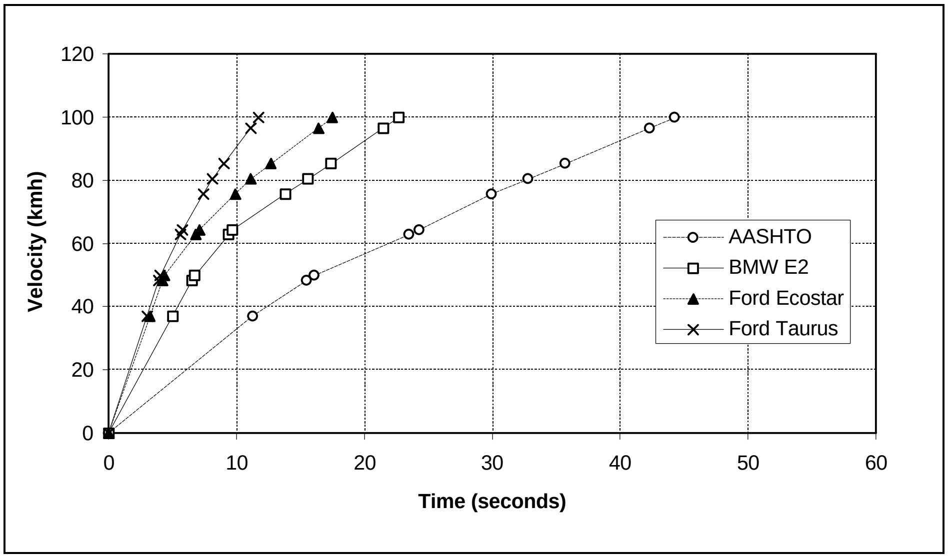

Figure 2. Comparison of APV and SI Vehicle Acceleration Times to AASHTO Guidelines

3.1.3.3 Deceleration

The braking characteristics of APVs are an area of concern. The present generation of APVs and converted EVs have braking performance that is difficult to quantify since braking data is generally unavailable. From the available literature on APV braking, braking capabilities can be characterized as poor. As in the acceleration performance, braking performance is within the AASHTO guide for minimum deceleration for exit terminals, but much worse than the average automobile. This can be attributed to several reasons:

- Additional weight of batteries (adding 180- to >270-kg)
- Weight distribution, due to battery weight and location
- Low rolling resistance tires
- Small contact patch
- High inflation pressure 345- to 414-kPa

Poor braking performance is an overlooked area. These concerns are amplified in wet driving conditions. APVs with poor braking performance reduce the margin of safety in everyday driving and especially in collision avoidance maneuvers. Stopping at intersections may cause concern due to the superior capabilities of surrounding non-APVs, with conventional vehicles requiring shorter braking distances. In an AHS environment, the poor braking characteristic of APVs may require longer headways during AHS platooning, thereby reducing overall capacity of the AHS. As seen in figure 3, a conversion of a Honda CRX, falls well outside the braking distances of a regular CRX, or even a relatively poor braking 4x4. The braking distance of the conversion is 39 percent longer than the vehicle it is based on. On many converted vehicles, the brakes have not been upgraded to take into account the problems associated with the conversion (such as greater weight and low rolling resistance tires). The effect of an upgraded braking system (ABS, traction control, intelligent regenerative braking, etc.) has not been readily seen on converted electric vehicles. In spite of all these problems, however, APV maneuvering performance (acceleration and braking) is steadily improving, as more attention is being paid to it. An APV that does not perform at or near SI performance will have a difficult time in the marketplace both in public and private service. APV manufacturers recognize this fact, and are steadily increasing their vehicles' performance. Within the time of AHS implementation, APV performance is expected to equal to SI vehicle acceleration and braking performance.

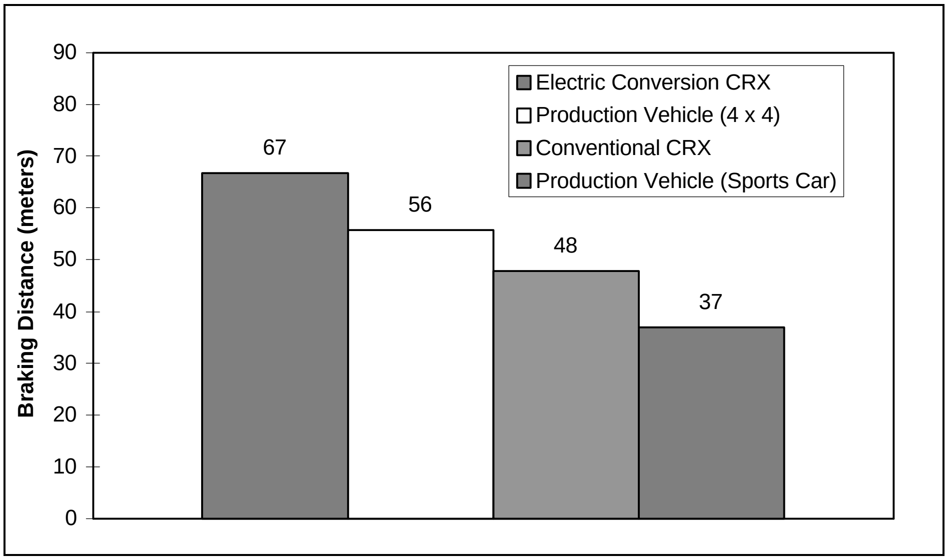

Figure 3. Braking Distance Comparisons From 96 to 0 kmh

3.1.3.4 Effect of Performance of APVs on AHS Roadway

Electric vehicle range and top speed may be the largest issues concerning automated highway design. Figure 1 compared the range and top speed of selected APVs against two of the best selling conventional ICEVs in the United States, the Ford Taurus and Honda Accord. When considering highway performance, it is quite evident that current EV technology does not lend itself to smooth integration with conventional vehicles. If the AHS design selected includes a higher mean operating speed, this APV deficit will be magnified, putting the APV at a greater disadvantage on the AHS.

As mentioned earlier, AHS transition lane design may be impacted if EV acceleration and deceleration performance, which does not meet current ICEV standards, is not improved when AHS is implemented.

3.1.4 Pollution and Emissions of Electric Vehicles

In the last decade, interest in producing a practical, affordable, electric car has increased. Driven by ever restrictive Federal and state regulations for automotive tailpipe emissions, virtually all auto manufacturers have EV research and development programs proceeding. On the AHS, even with increased throughput compared to today's highways, there would be decreased tailpipe emissions if APVs represented a large portion of the vehicle fleet. Other advantages include reduced dependence on imported oil, the ability to use renewable resources for the production of electricity needed for electric vehicle "refueling", and the creation of new industry based on the electric automobile. There is a misconception by the public that the electric vehicle is "pollution-free," and therefore environmentally friendly. This view is altered when one analyzes the total energy cycle for electric vehicles; that is, the pollution produced by the vehicle (a mobile pollution source) as well as the power plant (stationary pollution source) required to produce the electricity. On the other hand, pollution-reduction technology may be implemented more efficiently at power plants as opposed to the vehicle fleet. Zero tailpipe emissions reduce the exposure of the population to unhealthy vehicle emissions; power plants have the advantage of scheduled maintenance and monitoring of pollution. In the automotive environment, with maintenance schedules that range from regular to non-existent, it is much more difficult to reduce pollution and maintain pollution control equipment. SI vehicles, in fact, show deterioration of emission controls as vehicle kilometers accumulate. The following sections provide an overview of the emissions from electric, hybrid, and internal combustion engine vehicles.

Spark ignition (SI) vehicles - In the US, 40 percent of hydrocarbons (HC) and oxides of nitrogen (NO_x), and 70 percent of carbon monoxide (CO) come from transportation sources. The US transportation fleet releases approximately 400 million tons of carbon per year into the air, while consuming over 25 percent of the total energy used in the US. Automobiles account for over 30 percent of US carbon dioxide (CO_2) emissions. The primary tailpipe emissions that can be used to compare the impact of electric vehicles are CO, HC, CO_2, NO_x, and oxides of sulfur (SO_x). SI vehicles have continually improving emissions, with vast improvements over the past 20 years. New emission-reduction technology is focusing on reformulated gasoline and on the use of pre-heated catalysts. With an internal combustion engine, large amounts of pollutants are emitted during the first few minutes of a cold start. Use of pre-heat catalyst technology, the focus of present ICEV emission research, greatly reduces cold start emissions. SI emissions can be compared to the power plant emissions created during electricity generation.

Hybrid electric vehicles (HEVs) - Hybrid vehicles present more complex emission issues than SI vehicles because they use both battery power and an internal combustion engine. Few studies on hybrid vehicles have been done. Two types of hybrids exist: the series and parallel hybrids, discussed in section 3.2. A parallel hybrid uses the IC engine in combination with an electric motor for vehicle propulsion. However, for low energy drive cycles, a parallel hybrid can operate on electric power only. In the series hybrid, the electric motor provides vehicle propulsion while the IC engine is used to generate electricity for the vehicle's batteries. With the series hybrid, generator operation is typically based on the battery state of charge (SOC). When the battery is at a high SOC, the generator is typically not needed. When the battery charge falls or increased vehicle performance is needed, the generator can be turned on. Therefore, the series hybrid operates as a zero emission vehicle for a greater portion of its operating range than a parallel hybrid. In addition, pre-heat catalyst technology is more easily incorporated in series hybrid designs.

Electric vehicles (EVs) - EVs have zero tailpipe emissions. Power comes from the battery, which is charged from electric utility power plants. Although there are no tailpipe emissions from the vehicle, emissions from the electric utility generation plants must be considered. These emissions are usually measured in grams per distance traveled. Roadway powered electric vehicles (RPEVs) are a sub-type of EV that draws power from the road. Power is transferred to the RPEV by means of induction. RPEVs are similar to EVs, in that they both use battery power. However, an RPEV's battery can be much smaller, from one fifth to one tenth the size of a pure EV battery. An RPEV has an inductive pickup that is used to transfer power to the vehicle. Power requirements are very similar for the two types of vehicles.

With only four to five percent of electric utility power coming from oil, and of that 50 percent imported, electric vehicles have the potential to drastically reduce the dependence on foreign imported oil. The US electric power breakdown, which is primarily from domestic sources, is as follows (Dabels, 1992):

Coal	54 %	
Nuclear	19 %	
Renewable	14 %	(includes hydro-, solar-, and wind-power)
Gas	9 %	
Oil	4 %	

The following are five important emissions from both ICEVs and power plants.

Carbon Monoxide (CO) - Over 50 percent of carbon monoxide emissions are attributed to passenger cars and light duty trucks in the US. In large concentrations, CO is detrimental to human health. Produced from the incomplete SI fuel combustion process, CO is odorless, tasteless, and colorless. No matter which type of fuel is used to generate electricity in the power plants, the emissions are significantly less than from IC engine vehicles. A study on emissions impact of roadway powered electric vehicles (RPEVs) in California, showed a reduction of CO emissions from 90 to 100 percent, depending on the type of vehicle. That paper (Miller, Dato, and Chavala, 1992) excluded the plants having negligible emissions (such as hydro, solar, wind, etc.). The California generation mix shows 40 percent of plants with emissions, 60 percent with negligible emissions. For RPEVs, as the roadway power percentage is increased, slightly greater reductions in CO, HC, particulate matter and NO_x are seen. All evidence we have reviewed shows that large reductions in CO emissions will occur with electric vehicle use.

Hydrocarbon (HC) - Hydrocarbons react in the atmosphere to produce smog. Ozone concentration is used to evaluate the degree of this photochemical reaction. Like CO reductions, hydrocarbon emissions from power plants have similar percent reductions in comparison with IC vehicles. A report by BMW shows that EVs provide 10 times less HC emissions than IC vehicles. (Braess and Regar, 1991) RPEVs such as automobiles, light domestic vehicles, and buses show HC emission reductions similar to those in CO. Research shows HC decreases from 98 to 100 percent when compared to IC vehicles. (Wang, DeLuchi, and Sperling, 1990)

Oxides of Nitrogen (NO_x) - Oxides of nitrogen are ingredients in both smog and nitrogen dioxide. Passenger and light-duty trucks account for 15 percent of NO_x emissions. NO_x emissions are very dependent on the fuel used in the utility power plants. With 60 percent of the US power plants burning coal, NO_x emissions are expected to increase with EV use. Reports show that NO_x emissions can range from moderate reductions to moderate increases. These results are directly attributed to the utility generation mix and vehicle efficiency assumptions. Projecting future power plant generation, natural gas, which uses very efficient, planned generation processes, with stringent emissions controls, should be favorable for NO_x emissions. In Europe, using current German generating capacity, a factor of 10 times less emissions of NO_x as compared to a ICEV was reported. (Braess and Regar, 1991)

Oxides of Sulfur (SO_x) - Like NO_x, SO_x emissions depend on the utility generation mix. Using natural gas, SO_x emissions are reduced; but they increase when other generating fuels such as coal are used. SO_x emissions are very regionally oriented. Using EVs in California would reduce SO_2 emissions, since California has only a small amount of power plants that use coal. Using EVs in Chicago would result in negligible SO_x emissions since most of Chicago's power comes from nuclear power. (Wang and Santini, 1993) It is safe to assume that SO_x emissions will increase as EV use increases, because of the increased use of coal and the associated SO_x emissions from power plants. Under the Clean Air Act Amendment of 1990, however, national levels of SO_x emissions will not be allowed to increase. The only way for this to be accomplished is for the utilities to implement stronger emission controls. EVs have a greater impact on SO_x emissions outside of California, because other regions of the United States rely more on coal to generate electric power.

Carbon Dioxide (CO_2) - CO_2 emissions are also dependent on the electricity generation mix, which varies by region. The primary contributor to CO_2 emissions is burning fossil fuels such as coal, oil, or natural gas. Transportation use accounts for 15 percent of CO_2 emissions worldwide. Presently, use of any electric power will reduce CO_2 emissions to some degree. From the year 2000 on, research suggests that EVs will have a CO_2 emissions advantage greater than two times that for ICEVs. The degree of CO_2 reduction highly dependent on the assumptions used in the calculations of IC vehicle emissions; whether they are stringent, and how efficient the IC vehicles are.

The five discussed emissions types are the most researched in the comparison of EVs and ICEVs. In addition, IC vehicles and power plants have other emissions including suspended particulates, lead, fine particles, carcinogens, irritants, and toxins. The literature available does not allow a more in-depth analysis. As better emission controls for power plants are designed and put into place, EVs will increase their emission advantage over conventional IC engine vehicles. Also, non-emitting renewable resources such as hydro-, solar-, and wind-power can be used for electricity generation. Nuclear power generation does not emit any of the substances discussed here. Future energy generation is increasingly designed for more efficient use of resources. Countries (particularly in Europe) with few natural resources and large dependencies on imported oil are also analyzing the environmental impacts of EVs, primarily because of congestion in cities and energy security needs.

When considering emissions from different vehicles, one must also look at emissions from “cradle to grave." Emissions from an EV change only at the electric generating facility source, which can take advantage of new improvements in efficiency and pollution control in its lifetime. Another concern is that ICEVs emissions controls deteriorate with vehicle use.

Analyzing the worldwide emissions impact, vastly different power generation mixes are seen. Many European countries derive a great deal of power from non-emission sources such as hydro-power and nuclear power. They do not emit any of the five pollutants discussed. Great benefits in emission reductions, due to the use renewable resources, are possible in Japan and European countries.

Of the emissions described, solid evidence points to reductions in emissions of hydrocarbon, and carbon dioxide. The other three emissions, oxides of nitrogen, oxides of sulfur, and carbon dioxide, are sensitive to the power generation mix. Using nuclear or renewable resources results in no emissions of NO_x, SO_x, or CO_2. Different regions of the US have very different generating sources. Major cities such as Los Angles and Chicago use either clean burning fuels or nuclear power. The trend in new construction of power plants is toward clean burning fuels such as natural gas, and renewable resource use. A major impact on emissions can only be obtained with a large share of EVs in the national vehicle fleet.

3.1.5 Fleets

3.1.5.1 Potential Market and Uses of EVs

Current design trends of electric vehicles fall into two main categories:

- Compact commuter vehicles
- Light duty cargo vans

These categories are the focus of both the large automakers and the smaller vehicle converters for several reasons. First, large numbers of these vehicle types are sold to both the public and to fleet operators. In addition, they make a logical starting point for electric vehicle design. Secondly, under CARB regulations for California, commuter and cargo vehicles have the most potential for meeting the required sales percentage goals for 1998 as zero emission vehicles (see table E2 in appendix E). Research on APVs has focused on compact commuter vehicles. Designs typically employ two-passenger or two-plus-two seating configurations. With their limited range of 96- to 160-km, current APV designs are intended for short-distance commuting, as in the suburbs to the city, with recharging taking place overnight.

The second category, light duty cargo vans, have been primarily SI vehicles converted to electric power. Examples of these are the Ford Ecostar (based on a Ford of Europe panel van), Chrysler TEVan (based on their mini-van platform), and Electricar Pick-up (a conversion of a Chevrolet S-10). Converting existing vehicles is less expensive than the effort needed to launch a ground-up, purpose-built vehicle. But conversions produce compromises in vehicle capabilities. Conversion vehicles are often heavier than purpose-built vehicles, have slower acceleration, and poor braking characteristics. More information on both types of vehicles are included in table B1 of appendix B.

Light duty cargo vans have a tremendous opportunity in the fleet vehicle market. In California alone, approximately four million trucks (under 2,720-kg average vehicle weight) are registered, out of 38 million in the US. The Government operates almost three million automobiles and trucks itself. (American Automobile Manufacturers Association, 1993) Cargo vans are used by a wide variety of users. These range from utility companies, cable companies, delivery services, repair fleets, US Postal Service, national, state, and local governments. Cargo vans represent a great potential for electric vehicle implementation.

Currently there are no purpose-built APVs in regular production in the US. The GM Impact was canceled, and only 50 demonstration vehicles are planned. In addition, Ford Motor Company and the Chrysler Corporation have electric vehicle demonstration projects underway in the United States, while Japanese have models available in their home market. However, there are several manufactures who convert SI-engine vehicles, mostly small commuter cars or pick-up trucks usually sold to utility companies and fleet operators.

Fleet use is a superb application for electric vehicles. The limited range and performance of APVs, while not up to SI passenger vehicle performance, are well suited for fleet operators. Fleet operations provide the following advantages:

- Centralized maintenance
- Refueling/recharging
- Uniform fleet vehicle types
- Acceptable daily average range
- Adequate performance requirements
- Controlled operating conditions

Centralized maintenance is a benefit that can be applied to both EVs and ICEVs. Many fleets operate the same types of vehicles, usually of one make and model, in addition to being optioned the same. With centralized maintenance, stocks of spare parts can be easier managed (battery packs, electronic controllers, etc.), vehicle downtime can be reduced and recharging can be more easily performed. When recharging, all the necessary equipment could be centrally located for EVs, and charging profiles developed to take advantage of lower-cost electric power. Another feature of electric vehicles for fleet use is their operating conditions. Many fleet vehicles are used in urban/suburban driving situations, with only a small percentage of highway driving. Fleet vehicles do not typically cover long distances on the highway; they are usually uniform, either one type of passenger vehicle or one type of pick-up truck. Fleet vehicle operation may also provide an ideal situation for retrofitting APVs with AHS equipment.

Using APVs for fleet operations can be further enhanced by the Government, either by equipping its own fleets with APVs (which they are slowly doing) or by providing some type of financial assistance to APV fleet operators, (tax breaks, etc.) to stimulate the sale of APVs. These fleet vehicles, while not intended for extended highway use, will be operating on interstate/AHS for a small portion of their operation. Fleets also provide a tremendous testbed for APV manufacturers, to evaluate their products under semi-controlled conditions, and to quickly accumulate operation hours and experience.

The most promising advantage of APVs in fleet operations is the daily average range requirements of fleet vehicles. The fleet operators surveyed were a combination of local, statewide, and nationwide operators; local and state utility companies; cable companies; and a regional bus operator. On the nationwide level, express delivery companies and the US Postal Service were contacted, along with a national department store repair fleet (see table 4). These fleet vehicles, for the most part, well suit APV and specifically EV use. The vehicles used ranged from mini-vans and pick-up trucks to large transit buses. Primarily, information was gathered on the daily driving range and the typical fleet minimum/maximum driving ranges. The average daily distance driven was 103-kilometers (an average of all sources); a range within the present-day APV capabilities. The daily minimum and maximum driving ranges varied greatly: from two to 320 kilometers-per-day, with the high end value of 320-km logged by utility company supervisory personnel. While the 320 kilometers-per-day value is out of the question for present-day EV capabilities (without recharging), a range of 160-km or less is possible, which is the range of the vast majority of vehicle fleets surveyed.

Table 4. Daily Ranges of Selected Fleet Vehicles

Fleet	Daily Average (kilometers/day)	Daily Range (min, max)	Vehicle Type
Niagara Mohawk (utility)	80	48 to 160+	3/4 ton van
National Fuel (utility)	48	8 to 320	Vans and pick-ups
Adelphia Cable	est 80 to 96	est 40 to 180	Astrovans
NYSEG (utility)	160	N/A	Astrovans, Caravans, Step vans 16K GVW
Fedex	32,000 / year (112)	Similar to daily average, (112)	Econolines to cube vans
US Postal Service	19 to 24	8 to 96	1/2 ton
National Department store repair fleet	N/A	64 to 160	C-150, C-250, Aerostar
UPS	145	3 to 320	3/4 ton to 2 ton
Metro Bus (regional bus company)	43,500 / year (city) estimated 167	64,400 / year (suburban), estimated 248	Transit bus
Overall Average	**103-km**	**8- to 320-km**	**-**

The initial use of EVs will be seen in fleet service such as utility and delivery service companies because the present range is within current fleet vehicle requirements. Fleet vehicles will not have a high amount of use on the AHS, as much of their service use will be in city/suburban traffic situations, and not on the highway. It is estimated that highway use will account for only 15 percent of the distance traveled by these fleet vehicles, but this will be a very important first step toward private commuter EV use on the AHS.

3.1.5.2 Types of Vehicles

No new special designs are needed for alternate propulsion vehicles. APVs look the same as ICEVs, and will come in the same types of vehicles: vans, mini-vans, commuter cars. The cargo vans (Ecostar, TEVan) are of the two-passenger configuration, while the Electricar model is a conversion of a regular pick-up.

3.1.6 Trends in Design of Electric Vehicles

Trends in APV design are moving from conversion of existing vehicles to ground-up, purpose-built new designs. The designers are focusing on commuter type vehicles, but this may shift to include commercial delivery vehicles. An excellent example of this new generation of electric vehicles is represented by the General Motors Impact. This vehicle has performance comparable to that of an SI vehicle. The Impact illustrates the trends that are likely to be observed in the next generation of purpose-built electric vehicles. Some of the highlights of this vehicle are:

- Lightweight vehicle structure
- AC induction motor of 102-kW
- Aerodynamically efficient body
- High efficiency HVAC system

Vehicle designs of APVs presently use purpose-built and existing vehicle conversions. The commuter designs typically employ two-passenger or two-plus-two seating configurations. With their limited range of 96- to 160-km, current APVs are intended for short-distance commuting; e.g., suburbs to city, with recharging taking place overnight.

Light duty cargo vans have been primarily SI vehicles converted to electric power. Examples of these are the Ford Ecostar, Chrysler TEVan, and Electricar Pick-up. Conversion of existing vehicles is much cheaper than the major effort needed to launch a ground-up, purpose-built new vehicle, but produces a compromise in vehicle capability.

Although there are currently no purpose-built APVs in regular production, there are several EV manufactures who do conversions of SI engine vehicles, mostly small commuter cars or pick-up trucks. These are usually sold to utility companies and fleet operators.

To gain consumer acceptance, future electric vehicles should be indistinguishable from conventional vehicles in their performance characteristics. However, small deficiencies in vehicle range and top speed might be acceptable. The generic type of commuter vehicle we may see in production for the year 2004 should have these characteristics:

- Four-passenger
- 240-kilometer range
- Recharge in two hours (from 80 percent DOD), with special equipment
- High efficiency HVAC
- Meets all safety standards
- Acceleration time of 0- to 96-kmh in nine seconds
- AHS compatible

APV designs will not adversely impact the AHS. However, AHS design speed may impact APVs. Currently, APV manufacturers limit vehicle top speed to increase range. In the future, if a suitable battery is unavailable when the AHS is implemented, APV designers may govern vehicle top speed to equal the maximum AHS design speed.

3.1.7 Conclusions

Newly designed APVs are being introduced by manufacturers world-wide at a record pace. Currently, APV highway performance lags ICEV performance because of battery technology limitations. Battery performance is increasing incrementally but no breakthrough is anticipated in the near-future. If APV acceleration performance is not improved, AHS transition lane designs could suffer. Lower APV top speeds will increase travel times and decrease throughput on the AHS.

Vehicle range is the most critical design element preventing EVs from becoming viable transportation alternatives. Currently, APVs can not perform interstate travel effectively. If this trend continues, APVs will be unable to efficiently use the AHS. Although advanced battery technologies have provided better vehicle range, cost and safety concerns are precluding their widespread use in EVs.

Overall pollution on the AHS and in cities will be reduced by the use of electric vehicles, in fact, noticeable decrease can only be accomplished with electric vehicles as a large share of the vehicle population. European automakers have very severe pollution problems in their home countries; with their favorable utility generation mix, they have a great incentive to exploit consumer use of EVs.

Fleet use is the first widespread use of electric vehicles. This is where manufacturers will gain their real world knowledge about EVs, and the public will be exposed to them as delivery vehicles and by utility companies. Fleet operation may also facilitate the installation of AHS equipment upgrades on APVs.

3.2 INTRODUCTION: HYBRID VEHICLES

To overcome the range and acceleration performance limitations of electric vehicles, automakers have turned to internal combustion engines (ICEs) as range extenders. This combination of an electric motor and combustion engine in the vehicle power train is termed a hybrid electric vehicle. Hybrid vehicles are configured in two forms: series hybrid, which uses a fossil fuel motor to act as a generator to charge the vehicle batteries (e.g., Volvo ECC), or in parallel configuration, where the ICE is used to power the vehicle as well as to charge the batteries. The LA 301 and Volkswagen Chico employ a parallel hybrid configuration. In any type of hybrid configuration, the vehicles can be powered in electric only mode in order to meet ZEV standards for city use; on the highway, the ICE can be used while still meeting the ultra-low vehicle emission (ULEV) standards set by CARB.

3.2.1 Series Hybrid Electric Vehicles

The series hybrid electric vehicle (SHEV) uses a combustion engine/generator to supply electrical energy to the vehicle batteries when they are discharged where that they can no longer provide power to propel the vehicle. In the SHEV configuration, all torque to the vehicle's drive wheels is supplied by the electric motor. The SHEV configuration is shown in figure 4. (adapted from Burke, 1992)

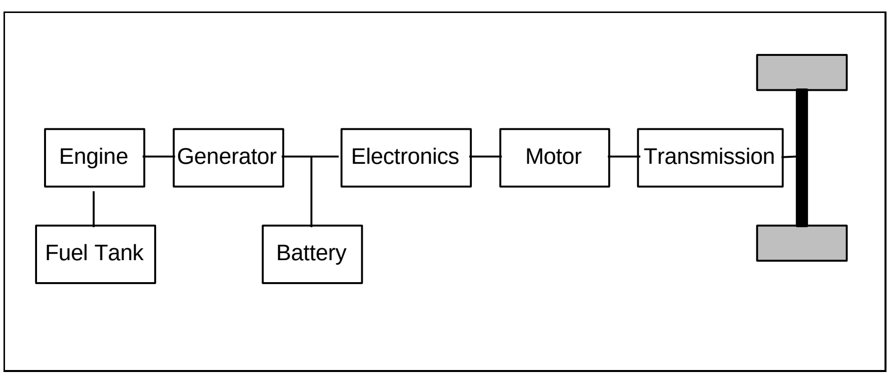

Figure 4. Series Hybrid Electric Vehicle Driveline Block Diagram

The primary function of the engine/generator in the series hybrid configuration is to extend the range of the vehicle beyond what is possible with the batteries alone. Therefore the range of a SHEV is limited only by the size of the vehicle's fuel tank. The Volvo ECC (table B1 in appendix B) is one example of the series hybrid configuration. This vehicle uses a turbine engine to generate electricity for charging the vehicle batteries. In series operation, the Volvo ECC still meets California's ultra low emissions vehicle (ULEV) standards.

Series hybrid configured vehicles can achieve performance and range similar to today's internal combustion engine vehicles. The performance of SHEVs is limited only by the power density of the battery and the size and weight of the engine that powers the generator. For example, the Volvo ECC, when operating in hybrid mode, can accelerate to 100-kmh in 13 seconds and travel more than 640-km while still meeting ULEV standards. In electric only mode, however, the Volvo's performance drops dramatically, 0- to 100-kmh acceleration takes 23 seconds, and range drops to 85-km.

The emissions concerns of series hybrid vehicles are reduced if a pre-heated catalyst is used. Under normal operation, an electric vehicle's battery heats up under load, allowing for pre-heating of the engine's exhaust catalyst. To reduce emissions associated with engine start-up and warm-up conditions, the vehicle controllers can prevent the engine from starting until the precatalyst meets the required temperature. Because most vehicles undergo a brief urban/suburban drive route before highway performance is needed, this entire process can be performed without major driveability problems. Internal combustion engines have optimum design speeds where they achieve peak efficiency with reduced emissions. Hybrid controller strategies can be designed to take into account the ICE's ideal operating range, thereby increasing vehicle efficiency while reducing environmental impacts.

The IC engine in the series hybrid configuration does not run continuously. The duration of IC engine operation depends on the ratio of the average power needed to propel the vehicle to the power output of the engine/generator. This simplifies the vehicle control strategy since the IC engine use can be based on battery state of charge (SOC). For example, the combustion engine is required when the battery falls below a predetermined level of 20 percent SOC; in turn, when the battery increases to a level of 30 percent SOC, the engine can be shut down. If increased vehicle performance is needed; e.g., highway operation, the engine can be operated to provide extra power to the electric motor.

The drawbacks of series hybrids compared to electric vehicles include increased weight, reduced emissions performance, and added complexity. SHEV design issues include vehicle packaging constraints, cost, and engine efficiency.

3.2.2 Parallel Hybrid Electric Vehicles

Like the series hybrid, a parallel hybrid electric vehicle (PHEV) consists of an electric motor and combustion engine. However, in parallel hybrid designs both the electric motor and IC engine, either separately or together, provide torque to the vehicle's drive wheels. Shown in table B1 of appendix B are two examples of parallel hybrid vehicles, the LA 301 and Volkswagen Chico. A PHEV block diagram is provided in figure 5. (adapted from Burke, 1992)

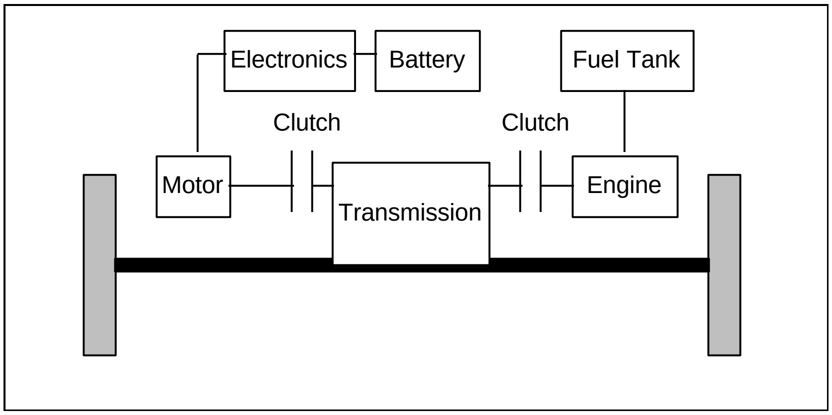

Figure 5. Parallel Hybrid Electric Vehicle Driveline Block Diagram

Unlike the series configuration, which bases combustion engine operation on the battery state of charge, the parallel drive system is based on load sharing. With this concept, both the electric drive and a conventional drive system are used in conjunction to power the vehicle regardless of the battery's SOC.

In general, the combustion engine isn't needed during light load conditions. Under these circumstances, the electric drive system provides power. As a result, the combustion engine may be turned on and off frequently. Usually, there is a sixty - forty torque split favoring the combustion engine over the electric drive. This operating principle complicates vehicle control logic, but there are more options available than with the series configuration. For example, parallel hybrid load sharing can be based on vehicle speed and power demands as well as on the battery SOC.

One advantage of parallel hybrids is that battery peak power is not an issue because the combustion engine provides torque directly to the drive wheels. When the engine produces more energy than is needed to propel the vehicle, the engine can provide charge to the battery.

Emissions issues are a larger problem in parallel hybrids because the combustion engine provides torque to the wheels directly. The use of a precatalyst further complicates design issues and increases vehicle costs. Also, due to the intermittent engine operation and the fact that most vehicle emissions are produced at start-up, PHEVs may have a more difficult time meeting California's ULEV standards.

Parallel hybrids are lighter, smaller, and less expensive than series hybrid configurations. On the other hand, because series hybrid systems are more of an extension of EV design, they are less complex, more reliable, have reduced emissions, and shorter development times than parallel hybrids.

3.2.3 Fuel Cells/Flywheels/Other Types of Vehicles

3.2.3.1 Fuel Cells

Fuel cells are one of the more radical sources that can used for vehicle propulsion. They are operationally close to the spark ignition engine family, as they use onboard fuel conversion to energy. The basic operating principle of a fuel cell is simple: electricity can be used to break down water into hydrogen and oxygen; a fuel cell does just the opposite. It takes hydrogen and oxygen and forms water, releasing energy (electricity). The hydrogen fuel can be stored on-board the vehicle and carried in the form of natural gas, methanol, or ethanol. Natural gas is abundant and is already is produced in the quantity needed for vehicle use. Several types of fuel cells must have their fuel pre-treated/reformed to remove any impurities and extract hydrogen. Fuel cells have been used in "cost is no object" space and military applications, and their high cost and hydrogen storage problems have prevented widespread use. The types of fuel cells in development include:

- Phosphoric acid
- Proton exchange membrane (PEM)
- Solid-oxide
- Carbonate
- Alkaline

Phosphoric acid fuel cells are developed, and are in use in utility electric generating stations and in prototype vehicles. The Proton exchange membrane (PEM) is the most promising type of fuel cell for vehicle use. PEM fuel cells have a number of advantages: low temperature operation, compactness, and high-power density, and high efficiency. Solid-oxide fuel cells have tremendous advantages over other types of fuel cells. They are simpler in design and need less maintenance than other fuel cells. But their drawback is their operating temperature of 1,000°C. Carbonate fuel cells also run at high temperatures (650°C), and have the advantage of high efficiency and the ability to run directly on natural gas. Alkaline fuel cells are the most efficient and also the most expensive fuel cells. They are used mainly for military and space applications.

Solid-oxide, carbonate, phosphoric acid, and alkaline fuel cells, while simple and efficient, have disadvantages that make them better suited for utility electric generation. Start-up concerns and low temperature problems with fuel cells must be addressed. Also, the fuel delivery system and the fuel cell have complex control systems. Examples of vehicles using fuel cells include the H-Power Bus, Ballard Bus, and Mazda research.

3.2.3.2 Flywheels

Flywheels are also known as electro-mechanical or mechanical batteries. The operating principle of a flywheel is that electricity is converted into rotational energy and stored by a spinning rotor. In an APV, during battery recharging or regenerative braking, electricity powers a motor that spins the flywheel up to a very high speed. To get electricity out of the flywheel battery, the power flow is reversed and the motor acts as an alternator spun by the flywheel. Flywheels have a great advantage over electro-chemical batteries because they are able to accept a charge or discharge very quickly.

Fiber composite materials are used liberally in flywheel design for both the spinning rotor and the flywheel chamber, due to the high stresses encountered by the rotor, and the need for an extraordinarily strong chamber to contain the rotor in case of a rotor or bearing failure. The flywheel rotor is contained in a vacuum chamber to minimize air resistance. Inside the chamber, the rotor spins on magnetic bearings for support, to further reduce drag on the flywheel. Magnetic bearings are the most critical and sensitive part of the flywheel, as they must prevent the spinning rotor shaft from touching down and damaging itself, while simultaneously supporting the spinning rotor at very high speeds and with no friction. Flywheel batteries, unlike some chemical batteries, have no disposal problem because no hazardous chemicals or materials are used in construction.

3.2.3.3 Others

There are also many other types of vehicle power plants that have been or are being researched. They vary from solar cells, to turbine engines, and alternative fuels. The common point between all the alternatives is that they all have the goal of lower emissions output per distance traveled, and lower dependence on imported energy resources.

3.2.3.4 Advantages/Disadvantages - Reasons for Use and Technology Limitations

Fuel cells have several distinct advantages over other types of APVs. The most important one is the ability to quickly refuel in the same amount of time as a gasoline vehicle (three to five minutes). Fuel cells have efficiencies double/triple that of SI engines, along with high specific energy. These outstanding advantages, however, are outweighed by the disadvantages in vehicle use. The cost per kilowatt is high (approximately 3.5 times for utility applications); less expensive alternatives are needed for vehicle applications. High temperatures are needed in the conversion process, ranging from 80°C for PEM fuel cells to 1,000°C for solid-oxide fuel cells. The hydrogen storage system for fuel cells is complex. Because hydrogen is highly reactive and difficult to contain, systems in use deliver hydrogen from cooled liquid, compressed hydrogen, or more complex methods using activated carbon or metal hydride matrix. Since no fuel delivery system exists for hydrogen (as opposed to electricity from many sources for electric vehicles), the infrastructure would have to be built. Some types of fuel cells are susceptible to contamination of the hydrogen, and reformers are needed, adding complexity to the overall system. Finally, fuel cells degrade over time, and have a limited life span.

Flywheel technology for use on APVs is still in its infancy, but has tremendous potential. The ability to store and discharge energy rapidly gives it a great advantage over other types of power plants used on APVs. Problems exist, however, with the magnetic bearings used to support the spinning rotor and the sensitivity of the system to deceleration resulting from potholes and low-speed crashes (“fender benders”). Flywheel technology must be improved to make the system robust, so that this type of battery is not so easily damaged or needs replacement after a minor shock to the flywheel system.

Although turbine engines and turbine-powered vehicles have existed for some time, they are very expensive. Solar cells do not yet have the required efficiencies to power vehicles, only for auxiliary use or to power accessories. Alternative fuels are being researched as a means to reduce the consumption of foreign oil; various alternative fuels can be derived from alcohol. The most promising of the described power plants are flywheels. The technology is progressing rapidly in this field and there does not appear to be a "show stopper" in flywheel technology that cannot be overcome. The flywheel’s ability to easily charge and discharge, and its high power give it the potential for a practical power plant for alternative propulsion vehicles.

3.2.4 Conclusions

Currently, HEVs suffer from inferior performance when compared to conventional vehicles. Like EVs, these deficiencies are primarily a result of current battery technology constraints and low rolling resistance tire designs. Research has shown that, in general, EVs and HEVs accelerate more slowly, have lower top speeds, require longer braking distances, display poorer handling characteristics, and have shorter ranges when compared to traditional vehicle designs. Although these performance limitations will not drive AHS infrastructure design, they may impact throughput and travel time if AHS speed needs to be adjusted to accommodate APVs. Another issue unique to APVs is the amount of time required to charge vehicle batteries. Presently no infrastructure exists that allows APVs to be charged in a time comparable to a conventional service station visit with an ICEV. As a result, trends in APV design have targeted the commuter and light duty delivery vehicle segments, where performance considerations are not prioritized. When compared to fleet vehicle operations, EVs seem well adapted. Fleet use of EVs also resolves some recharge issues since a centralized approach is used to recharge the vehicle batteries.

As a result, researchers are focusing on battery technology. Attention has been turned to systems using advanced materials and high operating temperatures. However, more studies need to be performed before these batteries become a reality in APVs. Fuel cells and mechanical batteries are seen as another remedy to the range and performance problems of APVs, but, thus far, packaging constraints and high costs have prevented their introduction into commercially available EVs and HEVs.

If range obstacles are not overcome when a national AHS is implemented, an RPEV system may need to be employed to supply power bursts or periodic charging to battery powered vehicles utilizing the AHS. An RPEV system brings with it unique issues that need to be further investigated. Health issues concerning the magnetic fields generated by an inductive RPEV system need to be looked at as well as any adverse effects these magnetic fields will have on vehicle sensors and actuators required on an AHS. Other unique issues include the energy that will need to be generated to power the roadway, as well as any air pollution concerns associated with this excess electricity production and costs to the consumer. In addition, RPEVs may require unique road designs. These RPEV roadway configurations need to be investigated to determine the most cost effective approach.

3.3 INTRODUCTION: ROADWAY POWERED ELECTRIC VEHICLES (RPEVs)

3.3.1 History of Roadway Powered Vehicles

Roadway powered electric vehicles (RPEVs) are a subset of the electric vehicle population which draws power from the roadway. Power transfer from the roadway to the vehicle is by induction, which is similar to a transformer, where a primary coil is built into the road and the secondary coil is on the vehicle. Present roadway inductor designs are only a few inches thick, compared to two feet for the older designs. This facilitates installation into roadways. Microwave power transfer is also being studied. The history of inductive coupling and powered roadways dates back to the 1890s. Highlights are presented below:

- Inductive coupling was patented in the 1890s in both the US and England after the invention of alternating current and transformers.
- 1950s to 1960s: GM and RCA perform research on "The Electric Highway."
- 1960s to 1970s: Ohio State and the Bureau of Public Roads continued research on RPEVs.
- 1970s: Work was performed by Lawrence Berkeley and Lawrence Livermore Labs in proof-of-concept systems.
- 1980s: The California Department of Transportation (CALTRANS) study of an RPEV system in Santa Barbara led to further research in both the public and private sectors.

- PATH, Playa Vista, NYS Two-Year R&D Program. Since the end of the CALTRANS study, two major programs on RPEVs. They are the PATH and Playa Vista projects. The PATH project uses a prototype bus; the Playa Vista Project uses a G-van. Both projects use existing vehicles that have been modified. New York State is searching for preliminary funding for their RPEV program, which has increased substantially in size.

A block diagram of the roadway powered electric vehicle concept is shown in figure 6.

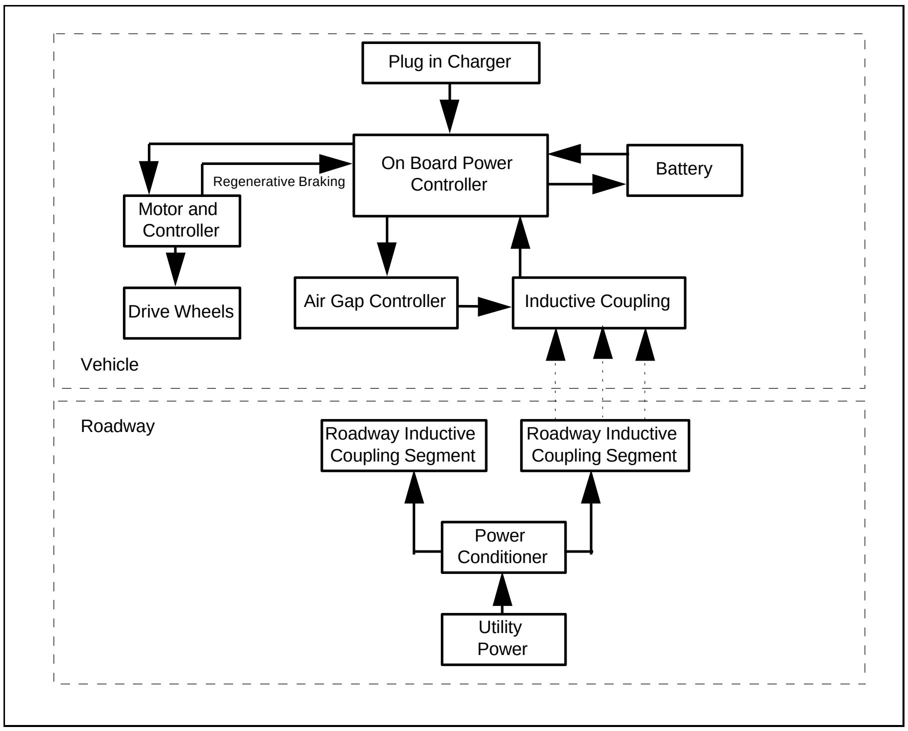

Figure 6. Roadway Powered Electric Vehicle Block Diagram

3.3.2 Use of RPEVs

Roadway power transfer is envisioned as a range extender for electric vehicles. Present-day electric vehicles (EVs) suffer from two main drawbacks that have limited their use in commercial applications, as discussed in section 3.2. The battery is the most serious handicap affecting electric vehicles. Present-day batteries provide only short ranges, 96- to 160-km per charge; and long recharge times, anywhere from four to eight hours, depending on the depth of discharge (DOD) of the battery. Even so called "quick" recharging can take two hours. Some vehicles have fast charging capabilities, which provide only a fraction of a full charge in anywhere from 20- to 30-minutes. While recharge times of four- to eight-hours are acceptable for overnight recharging, they are unacceptable for ordinary refueling situations involving long ranges outside the range of electric vehicles. For an electric vehicle to be comparable to an ICEV in terms of performance and recharge, it would need a many-fold increase in performance such as a 400-kilometer range in cold weather with a three to five minute recharge time. While these limitations do not preclude EV commuter car use, using EVs for general all-purpose transportation is not yet practical. Unless there is a breakthrough in battery technology and recharge time, roadway powered electric vehicles are a viable complement to electric vehicles.

Roadway powered electric vehicles are initially intended for use in high density traffic areas, stop-and go-traffic, and areas that are sensitive to noise and air pollution. At first, RPEVs would not be available for the consumer vehicle market, because of the infrastructure changes needed before/during their introduction to the marketplace. RPEV public transportation uses include the following:

- Public transit/business districts/HOV lanes
- National parks/recreation areas
- Shuttle services/campus routes
- Enclosed locations
- Pedestrian malls

Many of these areas have stations and preferred or special parking/standing for the buses and vehicles used now. These standing zones could easily have powered roadways installed. Between stops, the vehicle would use battery power; at certain stops or layovers (10 percent), the RPEV would draw power from the roadway. Advantages for public transit use include long layovers, measured in minutes; the same routes, and pickup/discharge stations. In national parks, a vehicle that does not produce noise or air pollution in environmentally sensitive areas provides a tremendous advantage. For shuttle services such as airports, hotels, and convention centers, RPEVs would benefit from always using the same routes, with layovers at specific pickup stations. In enclosed locations, no tailpipe emissions give RPEVs a great advantage over internal combustion vehicles. Fleet use would initially suit RPEVs except for public transport, since most fleet vehicles (US Postal Service, delivery services, repair services) are not operated the majority of the time on the highway, or do not operate on planned routes.

3.3.3 Location of Roadway Powered Lanes

With strategic placement, the amount of powered roadway can be minimized, thereby decreasing system cost. For RPEVs used for transit routes, shuttles, and parks, powered roadways would be placed at pickup and discharge stops, layover points, and acceleration lanes. Layovers and stops, where the vehicle is not moving, make an ideal point to transfer energy to the vehicle. Acceleration lanes from the pickup/discharge areas where the vehicle is moving slowly are also a feasible location. The area before a stop would not be powered, since regenerative braking would be used. Taking RPEVs from their use as shuttles vehicles or on planned routes to the automated highway system brings several possible locations for the powered roadway. Ideally, power would be transferred to the vehicle when it is stopped or moving at a low speed, maximizing recharge time, from the roadway. On the highway, exits, rest stops, and AHS check-in would be suitable locations for power transfer. Another possible location would be on hills where vehicle energy requirements increase. The actual highway lanes themselves would be powered only a fraction of their length, anywhere from 20 percent to 10 percent or less, depending on available technology.

The use of modular-designed powered lanes is an efficient method of distributing the available and needed power to the RPEV. This design uses information transfer between the RPEV and the powered roadway to turn on/off and increase/decrease power as needed for small sections of the road. This enables the RPEV to take power as it demands, and at the power level needed. Other non-RPEVs using the powered roadway would be unaffected, as the roadway would be inactive when they pass over it. This feature also prevents power from being wasted. When an RPEV travels over the powered road, the RPEV would act as a shield for non-powered vehicles from electro magnetic fields.

3.3.4 Benefits of Roadway Powered Electric Vehicles

The benefits of RPEVs are similar to electric vehicles. Air pollution reduction and control are major beneficiaries. It is easier to monitor and control emissions at a power plant, as opposed to the tailpipes of internal combustion vehicles. The energy used to power an RPEV generally shows that emissions are extremely low on a per kilometer basis compared to internal combustion engines. Another important benefit is the diversification of energy sources. Electric vehicles and RPEVs can use hydro-, wind-, solar-power, and other renewables, in addition to nuclear, coal, natural gas, etc. to generate electric power. The petroleum savings gained from reducing consumption of imported oil, along with the economic and national security benefits from using domestically originated power, can help buffer the ever-changing situation in oil prices, and the political volatility Middle Eastern countries. Other benefits of RPEVs include noise suppression, since the largest amount of noise coming from an electric vehicle would be wind and tire noise, compared to an ICEVs engine and exhaust noise. Also, EVs have approximately twice the service life of conventional spark ignition vehicles, due to the reliability of electric motors. This is a great benefit to service and fleet vehicles, since these vehicles routinely accumulate a large number of kilometers per year. This would cut down on vehicle engine overhauls, as RPEVs are much less complicated than combustion engines and require less maintenance.

3.3.5 Potential Problem Areas

Several potential problem areas are being researched. One of them is the airgap between the inductor coupling and the roadway. The narrower the gap, the more efficient the power transfer to the RPEV. Difficulties with clearance results in a larger-than-desired airgap. Preliminary PATH trials had a three-inch airgap, later narrowed to two inches. While this narrower airgap increases the efficiency of the power transfer, the reduced airgap has the potential for the vehicle pick-up to be easily damaged by road debris, potholes, uneven road surfaces, and other road non-uniformities. The lateral tracking of centering the inductor over the centerline of the powered roadway also has the potential to cause problems. As with the airgap, the closer the inductor is to the centerline of the road, the better. The drop-off within ± five-cm of centerline becomes severe at ±15-centimeters. The magnetic field gives an indication of the centerline, which can be used to guide the vehicle or inductor to its proper position. This may not be a problem on the AHS, because of the planned lateral tracking capabilities. On the AHS, the vehicle can be tracked to properly position its inductor over the powered road. The expected accuracy of lateral tracking will allow positioning and holding the vehicle over the powered road. The effect of the magnetic field on people and sensors when the roadway is powered, is discussed in section 3.3.5.1.

In the original work on RPEVs done by PATH, acoustic noise emanating from non-RPEVs over the roadway was found to be objectionable when the roadway was powered. Further work reduced it by incorporating different frequencies for the roadway. The New York State Two-Year R&D Program on RPEVs is the first of its kind in the Northeast. The New York State project will attempt to answer many questions, including determining the effect of snow and debris on the powered roadway, and how they will affect power output. Also of interest are the maintenance problems associated with cold weather, such as power transfer efficiency, road damage from freeze-thaw cycles, and other harmful effects of winter weather on the roadway.

3.3.5.1 *Electromagnetic Effects of Roadway Powered Electric Vehicles*

Few studies have been carried out on electro magnetic emissions of RPEVs. The Santa Barbara PATH RPEV is the only RPEV that has been tested to any degree on its electro magnetic emissions. On the subject of extremely low frequency (ELF) EMF emissions, a great many studies have been carried out on the effects of EMF on animals and humans. Testing on the Santa Barbara PATH RPEV, the most in-depth of any RPEV testing was performed in 1985 and in 1990. Various tests were performed ranging from measurements of the magnetic field, acoustic noise, heating of the roadway, objects placed on the roadway, and heating of non-RPEVs. At the beginning of testing, three different road power configurations were tested. They were:

- 400-Hz, 1200-amps
- 300-Hz, 1900-amps
- 180-Hz, 2100-amps

It was found after preliminary testing that 400-Hz, 1200-amps produced the lowest heating of objects by the roadway inductor elements.

Tests were conducted to determine the effect of roadway power on the heating of objects placed on the powered roadway, both with the powered roadway continuously on, and with the roadway cycling on and off, as would be the case in actual operation. With different types of road debris placed on the inductor, measurements were taken. A crushed aluminum can stabilized at a temperature between 38 and 43°C after half an hour. A steel can reached 82°C after one-hour of continuous operation. Other objects placed on the roadway conductor slot included a 15-cm long steel bolt, which reached a temperature of 204°C in five minutes of continuous roadway power. With segment switching (on only when a vehicle is over it), the maximum temperature reached was approximately 60°C. Different types of sheet metal were also tested to determine the effect on them. The worst example reached 232°C in 15-minutes within a 10-centimeter wide zone above the roadway core slot. With segment switching, the highest temperature seen was 138°C, with most of the other types of samples registering temperatures near 93°C. Automobile tires were placed on the powered roadway, and even frayed steel-belted tires showed no signs of temperature rise. Automobiles parked on the powered roadway were instrumented in various locations (gas tank areas, frame, etc.); the highest temperature recorded on a vehicle was 54°C.

The same vehicle emitted an acoustical hum. Masked by ambient noise, the hum was noticeable inside and outside conventional automobiles parked or driving over the roadway inductor. The operating point tested showed undesirable loud acoustic noise in non-RPEVs operating over the powered roadway, particularly while driving at slow speeds or stopped. The powered roadway also affected an AM radio receiver, which further investigation showed could be remedied by using standard radio isolation techniques. The acoustic noise problem was the most surprising finding of these tests. The frequencies and amplitudes of the powered roadway are not commonly encountered in everyday settings. Interference has been seen in:

- Television monitors
- AM radios
- Watches
- Engine controls
- Automotive speed sensors

Tests were conducted to determine if during operation of the powered roadway any heating of underground utilities or structural materials occurred. No effect was seen on any of the underground utility structures.

The 1991 PATH program looked into the problem of acoustic noise on non-RPEVs that plagued the earlier designs. After testing, it was determined that the best way to eliminate the acoustic noise problem was to change the operating point. The roadway frequency was increased to 8500-Hz and the power transfer was lowered to 240-amps. This change in operating point from extremely low frequency band to very low frequency (VLF) band, eliminated the acoustic noise problem entirely. As an added benefit, the change dropped the magnetic gauss levels to extremely low values (less than that received in the home, operating appliances, electric blankets, microwave ovens, and television). Inside a vehicle parked over the powered road, in-vehicle levels of 1- to 2-mG were measured, which is similar to average home exposure of 1-mG. With no vehicle over the powered road, levels of approximately 200-mG have been seen with the roadway powered. Full scale tests on roadway heating, and other issues have not yet been reported at this new design frequency and power.

The electro magnetic force of RPEVs has not been studied as in-depth as other sources of EMF and their effects on humans. The 8500-Hz frequency has not been studied, due to few other sources emitting this frequency, resulting in little interest for this frequency range. Sources in this frequency range include some medical applications, electric furnaces, and soldering. The effects on people are subject to much speculation in scientific circles. The EMF emissions of RPEVs are not just vehicle related, but also occur on RPEV-related equipment, such as power conditioners, roadside power supplies, and utility lines bringing in the electrical power.

Microwave power transmission to an RPEV has also been studied as an alternative to induction. Although microwave transmission has the potential to be very efficient, this method of power transmission has not progressed to a demonstration system. Microwave power may present potentially harmful consequences in the frequency envisioned for an RPEV system.

The biological and health effects of EMF are difficult to quantify. Epidemiologic research infers a likely low-level risk to health, related to ELF EMF and its magnetic components. There may also be what is termed "window effects," where specific frequencies/exposure levels may have bioeffects. With proper design, the magnetic level fields inside a RPEV can be minimal, where the biggest concern regarding EMF would be the RPEVs associated electrical hardware.

The available data is difficult to extrapolate to the human population, and probable health risks with EMF have not been confirmed. The simple answer is that there is no irrefutable proof either way that it causes harm or is safe, only indirect evidence that EMF is harmful. More research on different frequency/intensity characteristics, especially an RPEVs operating point, is needed on this subject before RPEVs are operational as transit/AHS vehicles.

3.3.6 Automated Highway System (AHS) and RPEVs

Roadway powered electric vehicles can be an integral part of the AHS. RPEVs will use the AHS as other conventional vehicles use it. A major difference in using an RPEV on the AHS is that the roadway would interrogate the RPEV on its charge status and would turn the roadway power on and off. Only when an RPEV that needs power is over the powered road module, will the power be turned on. The RPEV would be allowed to enter the AHS only if the vehicle had enough battery power to complete its journey. If the RPEV battery was at a low state of charge, the vehicle would be denied access to the AHS. Lateral tracking is needed unless the inductor is active or "smart," and the inductor tracks itself to the centerline, not the vehicle. This would mean that the inductor has several inches of travel in the lateral direction for positioning. AHS could be used for vehicle tracking, and lateral control to keep the inductor over the powered roadway, or centered on the AHS lane. AHS information transfer and benefits such as collision avoidance, active cruise control, intersection collision avoidance, navigation, longitudinal control, entry/exit, check-in/check-out, and platooning are all compatible with RPEVs and some benefits may be even enhanced.

3.3.7 Future Research

Future research is recommended in the following areas:

- The effect of electromagnetic fields on humans, equipment, and other vehicles should continue to be investigated.
- Areas involving the air gap between the inductor and the roadway, lateral tracking to the powered roadway centerline, and overall clearance problems are very important, as they all have the potential to dramatically reduce the power transfer to the RPEV.
- The impact on utilities: Will there be an excessive burden due to RPEV power requirements?
- The cost per lane kilometer of roadway power and its associated subsystems. Will the capital cost of the powered roadway be an impediment to its use in areas of high traffic density.
- Further work must be done regarding AHS concerns and the relationship with RPEVs.

3.3.8 Electric Power Requirements Study

3.3.8.1 Hypothetical Trip

A simulation was performed on a theoretical RPEV trip from Buffalo, New York, to Albany, New York, a distance of 438.53 km (272.5 miles). This simulation was done to determine the effect of battery recharge times on the length or percentage of powered roadway needed for this trip. The time for this trip at 55 mph would be approximately 5-hours. Many drivers would stop at some point in this trip for a rest stop or refueling; this trip was non-stop. The vehicle used was a GM Impact-like vehicle, with an inductive plate for obtaining roadway power. In this simulation the vehicle was assumed to travel at 100-kilometers-per-hour (62 mph) on level roads, with no head or tail wind. The inductive plate added 90-kg of weight (200 lb), and two 77-kg (170 lb) passengers were on-board. Heating, ventilation, and air conditioning (HVAC) were assumed constant at 750-watts for the entire trip, using estimates of the highest efficiency/low power units available. The total vehicle weight is 1,565-kg.

The constant total power needed at 100-kmh:

$$P_{Total} = P_{Rolling\ Resistance} + P_{Aerodynamics} + P_{HVAC} = 7.034\text{-kilowatts} \quad (1)$$

Using batteries with a capacity of 13.6-kilowatt-hours and assuming an 80 percent depth of discharge (below this level may damage the batteries) gives a range of 155- kilometers (96 miles). We assumed that power can be transferred to the vehicle at 35-kW while traveling at 100-kmh. Using these assumptions, this average trip would require 20.09 percent of the roadway powered, along with a 23-minute recharge time. For different recharge times, varying lengths of roadway power are needed, as shown in table 5.

Table 5. RPEV Recharge Requirements for Buffalo to Albany Trip

Recharge Time	Percent of Roadway that must be Powered
1.43-minutes (86-seconds)	1% Roadway Power (at 464-kW)
2.5-minutes	1.7% (at 268-kW)
5-minutes	3.5% (at 138-kW)
10-minutes	7% (at 72-kW)
20-minutes	14.1% (at 35-kW)
30-minutes	20.9% (at 35-kW)
1-hour	41.9% (at 35-kW)
2-hours 23-minutes	100% (at 35-kW)
3-hours	Trip can not be completed at 35-kW

For the trip with a 5-minute recharge time, 15.35-kilometers (9.5-miles) of lane need to be powered, of the trip's 438.53-km length (272.5-miles). For a 20-minute recharge time, 61.8-kilometers (39.5-miles) of powered lane are required.

Assuming that we have an AHS RPEV lane 1.6-km in length, and that the lane is carrying its capacity of 6,000 vehicles (in this case they are all RPEVs), at a velocity of 100- kmh the lane would require 3,400-kilowatts or 3.4-megawatts, with a transfer to the RPEV of 35-kW as assumed earlier. For RPEVs with a 20-minute recharge time, at capacity, on the trip from Buffalo to Albany, New York, the power requirement would be 134.3- megawatts, requiring 63.6-km of powered roadway.

Initial RPEV systems may use 10 to 15 percent powered roadway as a reasonable estimate. This is dependent on charging technology. Ideally, the least amount of powered roadway is desired, but 3.5 to 5 percent would be a feasible assessment, as this is only a small fraction of the road and it can be installed gradually over time during repairs or construction, with as little disruption as possible.

As the recharge time of the vehicles decreases, the length of the powered roadway needed would decrease dramatically.

3.3.8.2 Hypothetical Trip Range Examples

Range as a function of battery charge level for a hypothetical trip from Buffalo to New York City is illustrated in figures 7, 8, and 9 with different parameters varied to determine their effect. Figure 7 shows the significant effect of changing the grid power and how only at a grid power of 100-kW is the RPEV able to complete the trip with the other given conditions.

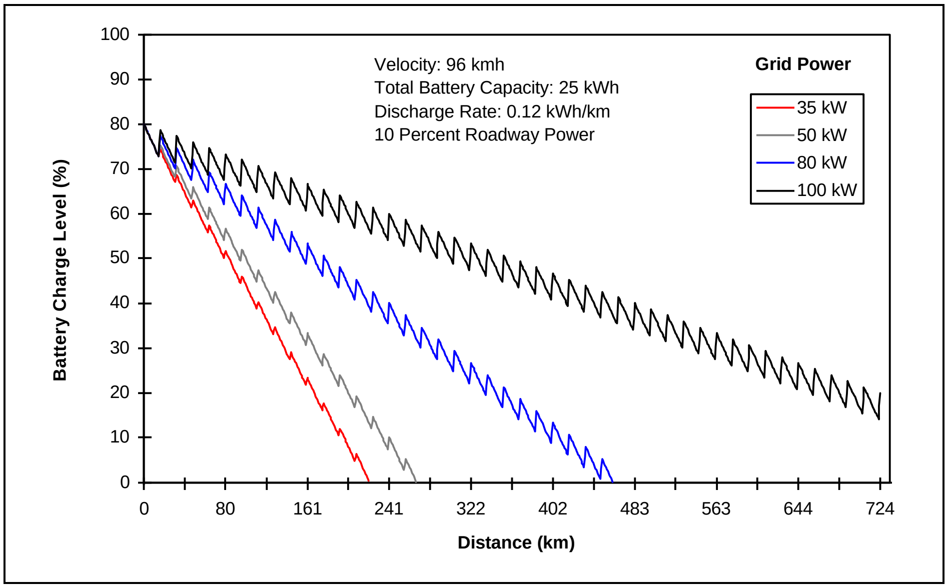

Figure 7. Effect of Grid Power on Buffalo to New York City Trip

Figure 8 illustrates the effect of battery capacity on the RPEV range. Note that battery capacity is not as significant to the range as the rate of power transfer by the grid.

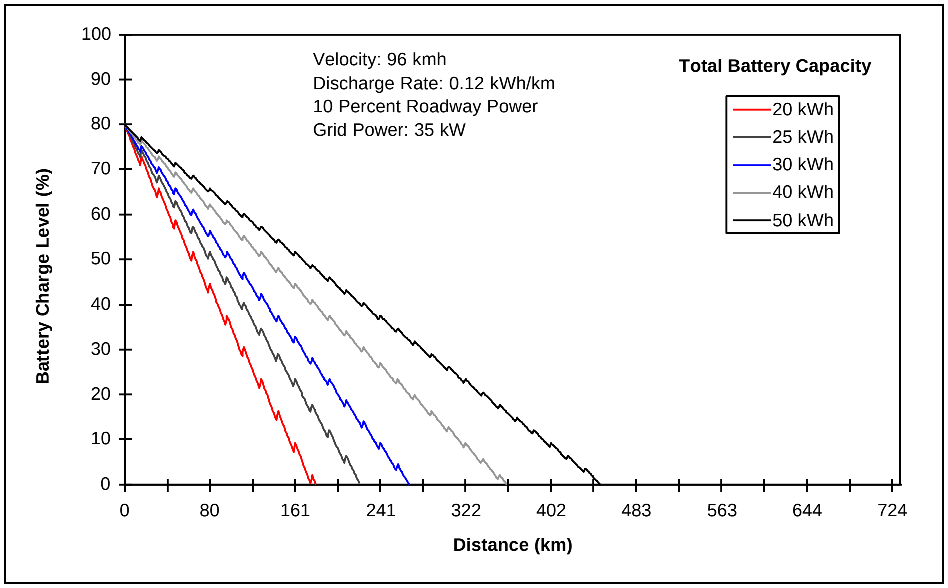

Figure 8. Effect of Total Battery Capacity on Buffalo to New York City Trip

Figure 9 shows that the most significant factor in the range of the RPEV is that due to the percent of the roadway which is powered.

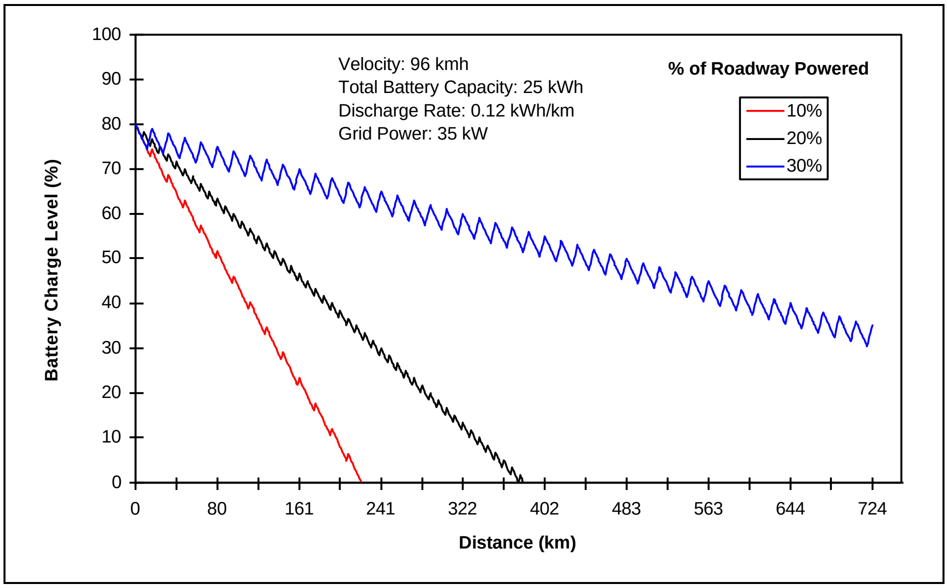

Figure 9. Effect of Grid Length/Spacing on Buffalo to New York City Trip

A hypothetical trip of 725-km from Buffalo to New York City is illustrated in figure 10. This demonstrates the effectiveness of RPEVs as compared to electric vehicles. Using the assumptions given in the figure, the RPEVs range is six times that of the electric vehicle with the same battery capacity.

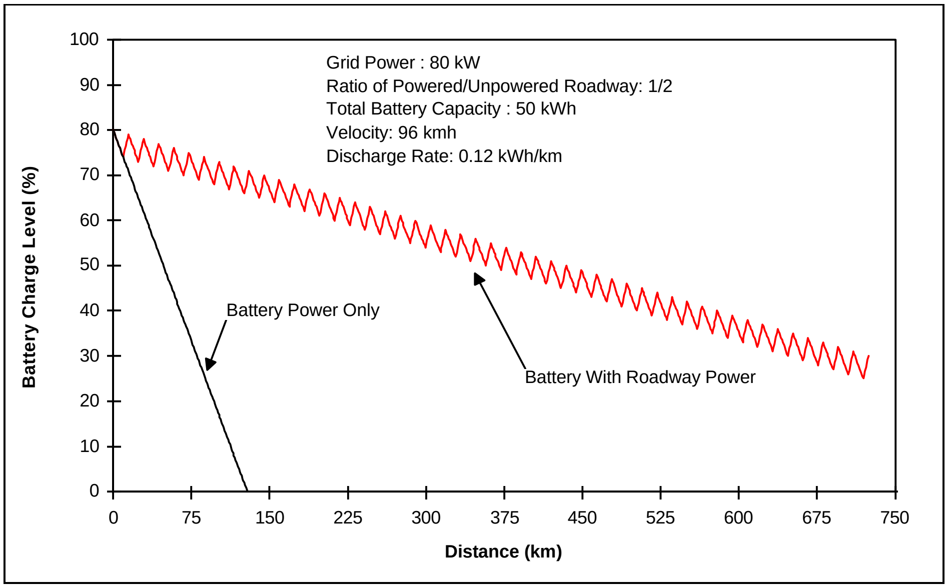

Figure 10. Battery Charge Level vs. Distance Traveled

Figure E1 of appendix E illustrates the major routes that would be roadway powered in New York State. It is assumed that RPEVs would be able to travel within a 64-km radius of any of these routes. Complications such as grade and wind resistance are assumed to be negligible on average. Thus, only a small area within the Adirondack region would be inaccessible to RPEVs (five percent of the state) as illustrated by the dotted area in the map.

3.3.8.3 New York Power Pool/Regional - National Implications

Before implementing RPEVs into the AHS, the effect of their load on electric utilities must first be examined. An increased electric load would eventually create the need for the utilities to upgrade their capabilities. This is a costly endeavor and requires careful planning in advance of the anticipated need. The following analysis on the effect of RPEVs is based on a similar study done by the California Energy Commission on the loading effects of charging electric vehicles.

Assumptions:

- 80-kW roadway power
- 1/3 of all roadways are powered
- 26.7-kW/vehicle average
- 13,000 (or two percent) of new vehicles (only) each year, additive with no removals
- All RPEVs are on the road at once

Assumptions are as follows. An 80-kW roadway was determined from studies done by H. R. Ross in California. Our assumption is to use an 80-kW roadway with 100 percent transmission efficiency. Although it is reasonable to expect only 80 percent transmission efficiency due to environmental heating losses, noise, etc., this model is suitable for the scope of this research. Also from H. R. Ross, it was determined that one-third of a particular roadway be powered. This was found to be an optimal number which reduced construction and utility costs while significantly increasing the range of an RPEV. Since only one-third of any roadway would be powered, a vehicle would consume on average 26.7-kW. Based on 1990 New York State Department of Motor Vehicle statistics, approximately 650,000 new passenger vehicles are registered each year and this number was assumed to remain relatively constant in the future. For this model, it was assumed that two percent of these new vehicles (13,000) would be RPEVs and that all of these would remain in service as the years progressed. A worst case scenario for the utilities is also portrayed in that it is assumed that all RPEVs will be operating at once. A battery capacity of 50-kWh is reasonable to expect in the future.

Based on the New York State Power Pool (NYSPP) forecast for 1994 to 2013, available excess reserve will be able to support RPEVs with the above assumptions through the year 2008 (see figure 11). At this point, the NYSPP will begin to be significantly impacted and upgrades will become necessary. This may not be a tremendous expense since the NYPP is anticipating some utilities going off line and it may only be necessary to bring these back into service. It is reasonable to extrapolate this New York model to other areas in the nation, since other states organize their utilities into power pools. Note that although individual utilities within a power pool have more excess capability, they are required to designate a certain percentage of it to the pool. This is usually 18 percent of the previous year's peak load. When studies were done in California by Southern California Edison and Pacific Gas and Electric on the effects of electric vehicle battery charging, the results were very similar. Note that this is a worst case analysis assuming that all vehicles are operating simultaneously with no RPEVs leaving service.

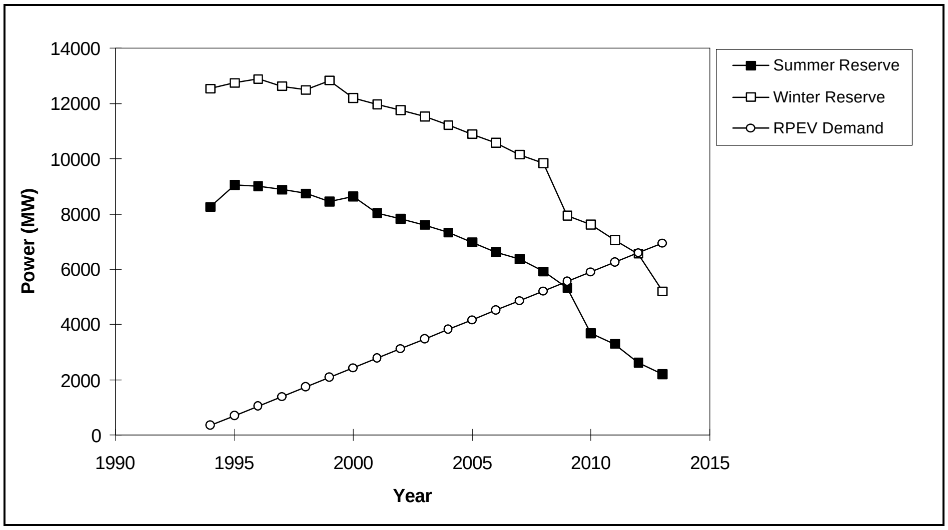

Figure 11. New York Power Pool Actual Reserves vs. RPEV Demand

3.3.8.4 Utilities Peak Load and How It Is Affected

A study of the overall effects of RPEVs on utility capability is very important. It is also important to examine when those effects are most pronounced during a peak load day. This information could help utilities plan when to bring more resources on line throughout the day and make the most efficient use of those resources. This study has shown that not only does the RPEV load increase the peak load, but it also changes when the peak occurs due to the offset of rush hour and peak load times.

Assumptions:

- 80-kW roadway power
- 1/3 of all roadways are powered
- 26.7-kW/vehicle average
- 13,000 (or two percent) of new vehicles (only) each year, additive with no removals

This is what can be expected to happen to the peaks:

<u>Summer Peak Day 2000</u> (see figure 12). The RPEV loads will shift the system peak from 2:00 in the afternoon to 4:00 and 5:00 in the afternoon on this day due to rush hour traffic. The peak itself will also be increased. The morning hours of 6:00 to 10:00 will also experience an increase in load due to RPEVs. Note that this leaves the early morning valley with very little of the additional RPEV load, making inefficient use of the power pool's capability.

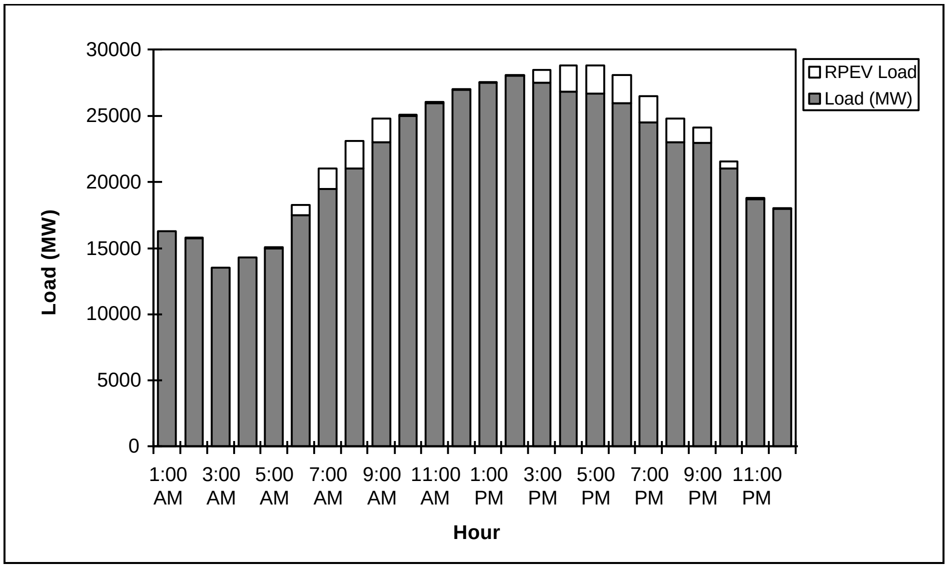

Figure 12. RPEV Impact: NYPP Summer Peak Day 2000

<u>Winter Peak Day 2000</u> (see figure 13). RPEV loads significantly increase the winter day's peak load at 6:00 in the evening. Load in the lower non-evening hours of the day, particularly the early morning valley period, is relatively unaffected. The daily load shape is changed from one that is fairly level throughout the day, to one which shows a significant evening peak compared to daytime loads.

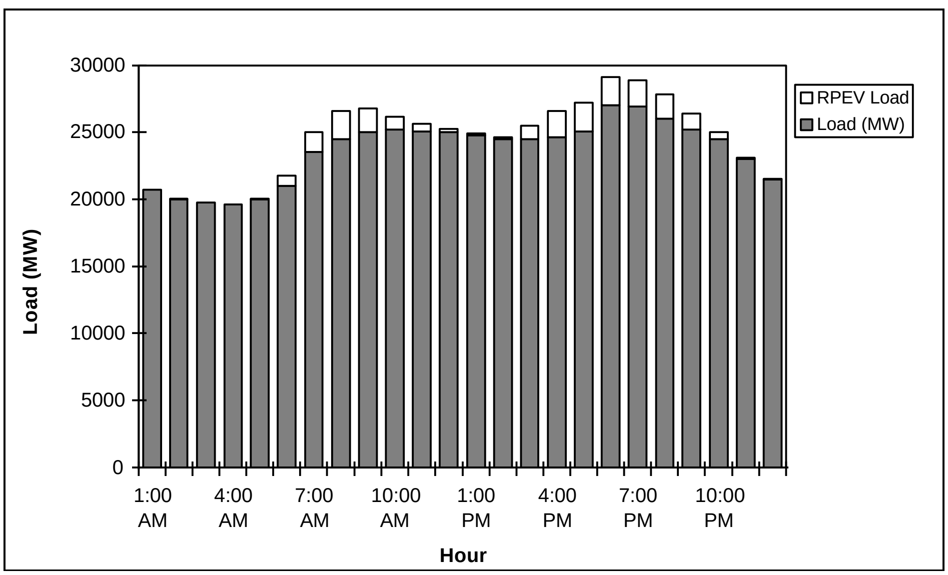

Figure 13. RPEV Impact: NYPP Winter Peak Day 2000

This implies that more and potentially different resources would need to be on to serve the daily peak, compared to the situation without RPEVs. Depending upon the flexibility of starting and stopping these additional resources, they may have to be turned on throughout the day to be available to serve the peak. This would cause changes in the resources serving load even in hours of the day when the RPEV load is small.

Note that it is reasonable to assume that other states would be affected in the same way as peak load, and rush hour times are generally the same from state to state.

3.3.8.5 *Problem Areas - Brownout/Blackout Effects*

During rush-hour traffic, the effects of brownout/blackout can be significant on RPEVs since their heaviest usage coincides with peak load times. Several situations might occur. One, the roadway power might be completely shut down and the RPEVs would depend entirely on their internal batteries. This would have various consequences on the RPEVs, depending on the charge level of the individual vehicles and the length of their particular destinations. Drivers could become stranded in the middle of a road, increasing the chances of a collision with a non-RPEV. The psychological stress and inconvenience of suddenly being stopped for an indefinite period is a non-trivial consequence. Traffic build-up would certainly occur for non-RPEVs because the disabled RPEVs would cause multiple blockages. Another situation, depending on the severity of the brownout/blackout, might be to cause reduced power to the RPEVs with similar albeit less severe consequences. A third possible situation might be to redirect the RPEVs to certain roads or have the AHS instruct them to stop and wait for the power failure to be corrected altogether.

3.3.9 Conclusions

Roadway powered electric vehicles are a complement to electric vehicles. Because of their recharging capability, RPEVs offer a range extension over present EVs. No special roads or lanes need to be built specifically for RPEVs . Existing roads/lanes can be repaved when needed, and at the same time the power strip can be laid down in the road, and the road height built up to it. Earlier designs included power strips requiring two feet of depth for placement and installation, or cylindrical power modules also several feet deep. New designs are approximately two inches thick. RPEVs can be made by converting existing electric vehicles (the major difference would be the addition of an inductive coupling) or conventional SIs. Either platform can be used. Ideally, a ground-up design would prove to be the best design, as it could be optimized for the requirements and special equipment specific to the RPEV (onboard controller, electric motor, batteries). For ground-up consumer RPEVs, new designs would incorporate low rolling resistance tires, much improved aerodynamics (Coefficient of drag (Cd) of .20 or better), low-power heating and air conditioning circuits, and low vehicle weights. Additionally, battery weight would decrease, as a smaller battery could be used on an RPEV. For infrastructure requirements, a great benefit is that other vehicles (non-RPEVs) could use the same roadway as the RPEV, with no effect on them, since the roadway will only provide power to an RPEV that is not only over the roadway, but demanding power from it. With inductive coupling, charging at the workplace, home charging, etc., would be very easy, as no plugs would be required. Service stations offering recharging would involve just driving and parking over a powered inductor/charger.

The initial use of RPEVs will be in the public transit field, where they are a viable economic alternative to the diesel bus, because of lower maintenance, longer service life, along with no tailpipe emissions, and less noise than diesel buses. The use of RPEVs on the AHS will hinge on battery technology. If a quick-charge, high capacity battery is found that provides a 400-km range and five-minute recharging, RPEVs will not be needed on the AHS. If no breakthroughs in battery technology occur, RPEVs will become an integral part of the AHS.

RPEVs are less developed than other APV types such as EVs and hybrids, but their components are readily available/easily designed. No RPEVs have yet carried the general public in transit applications or as commuter vehicles. Due to the need for powered roadway lanes and recharging equipment for the batteries, RPEVs require the largest infrastructure adjustments for AHS. Costs for powered roadways are very difficult to gauge, as none has been built over 305-m. An approximation may be half million to one million dollars per every 1.6-km per lane. This figure may be substantially reduced with updated technology and construction economies of scale.

Potential electro magnetic field effects on equipment and humans need further investigation. Any remote harm to humans must be researched thoroughly and the effects known, before RPEVs can be realized.

AHS and RPEVs may become complementary systems because of their similar needs for information and data transfer, billing for road and/or power use, spacing/platooning, and other AHS issues. Roadway power requirements for RPEVs depend on several items including; battery capacity, power and HVAC requirements, and recharge time. These all have a tremendous affect on range. RPEVs present a range extension means for electric vehicles and they are practical for transit applications. However, RPEVs require infrastructure modifications for mass consumer use increasing overall costs.

3.4 MALFUNCTION MANAGEMENT AND SAFETY ANALYSIS

Alternative propulsion vehicles pose many of the same problems to automated highway malfunction management strategies as conventional motor vehicles. In fact, electric vehicles are considered more reliable than ICEVs because they contain fewer components and require less maintenance. A general vehicle and roadway fault hazard analysis discussion is included in the Safety and Malfunction Management Task chapters found in Volume V of this report.

Presently, electric vehicles make up only a small percentage of the motor vehicle population in the United States. Other APV types, as well as RPEVs, are still in developmental stages and have not yet reached the consumer. Therefore, hard data concerning APV and RPEV reliability and failure mechanisms is unavailable. What follows is a discussion of the unique APV and RPEV failure mechanisms that will impact AHS malfunction management.

3.4.1 APV Safety

Alternative propulsion vehicles and specifically electric vehicles are considered more reliable than their ICEV counterparts for several reasons. Electric vehicles have fewer components than traditional automobiles. EVs have no exhaust and emissions systems to maintain nor do they require transmissions with complex gearing. Furthermore, EVs don't need tune-ups or oil changes, and their motor lives exceed those of ICEVs. Conventional maintenance for EVs includes checking tire pressures and wear, maintaining braking system functions, replacing windshield wiper blades, filling the washer fluid reservoir, and periodically replacing motor coolant. As a result, EVs are prone to most of the same system failures as conventional automobiles. Malfunctions unique to APVs include, controller breakdowns, electric motor failures, and battery problems.

Table D1 of appendix D provides a fault hazard analysis description for failure mechanisms unique to APVs and the impacts on the AHS. It was determined that most APV problems will stem from the battery technology used. Advanced systems like sodium sulfur and zinc bromine batteries may pose the most serious threats to AHS; the electrolytes used in these batteries (liquid sodium, liquid sulfur, and bromine), pose serious health problems to humans and animals. Designers have addressed advanced battery safety issues prioritizing occupant safety. In fact, the current generation of sodium sulfur batteries is designed so large scale electrolyte spills will be highly unlikely.

An interesting issue concerning EV safety occurred in 1994. Two Ford Ecostar electric vehicles, which use sodium sulfur batteries, experienced battery fires; causing Ford Motor Company to remove the entire fleet from the road. The battery problems have been resolved, but they illustrate the dangers that an advanced, high-temperature battery can exhibit.

APVs do not appear to pose serious threats to AHS malfunction management scenarios. Severe AHS impacts might result only if multiple failures occur to more than one vehicle over a short period of time on the same stretch of AHS road. Lateral control failures and sudden stops are the largest hazards to AHS safety; however, it seems there are no unique APV failures that might result in lateral control failure or a sudden stop.

Battery electrolytes are corrosive and could pose dangers to vehicle occupants. Furthermore, sensors and electronics placed on the vehicle or in the roadway surface could be damaged in an electrolyte spill. As a result, designers have considered crashworthiness issues regarding battery placement and design for electrolyte leakage. For instance, most of the battery types being considered for APV use will not leak in event of damage. The lead-acid battery design in the GM Impact traps the acid electrolyte by surface tension in a mat. The electrolyte used in the Impact’s battery is in gel form which will not flow even if the case is ruptured. Zinc-air batteries have a short-circuit proof chemistry which will prevent fire or explosion during an accident.

Safety and emergency medical personnel must be educated to deal with APV mishaps. Hazardous material (HAZMAT) and emergency medical crews must take proper precautions in the event of a large-scale electrolyte spill. Labels outlining vehicle battery information including type, voltage, and electrolyte used may be required. These labels must be located on the vehicle so they can be easily seen by emergency response teams. Automotive technicians and staff at proposed quick-charge facilities must also be trained to deal with APV maintenance problems. Electrocution hazards pose another issue that needs further investigation.

Finally, because electric vehicles are considered electrical appliances, they must conform to the same electric safety standards that apply to household electronics as well as meet the Federal Government’s vehicle safety regulations. These regulations will minimize electrocution possibilities and will ensure that APVs will be as safe as current production vehicles.

3.4.2 RPEV Safety

Roadway powered electric vehicles pose their own unique safety issues apart from those of APVs and conventional automobiles. These issues need to be addressed before an automated highway incorporating RPEVs is implemented. Current RPEV roadway designs call for induction power segments to make up from 10 to 33 percent of the roadway. These segments are to be powered up only if an RPEV equipped vehicle requires a battery charge. This modular configuration allows roadway powered vehicles to share the roadway with other non-RPEVs. Problems such as electro magnetic interference from RPEV systems disrupting the sensors used for vehicle lateral and longitudinal control will be solved by the time these systems are implemented.

Table D2 of appendix D includes the fault hazard management analysis for roadway powered electric vehicle systems. The largest factor affecting an RPEV system may be environmental conditions. As discussed earlier, the closer the vehicle pickup is to the roadway induction source, the higher the system efficiency. In cases of deep snow or ice, the pickup may be too far from the inductive source to pick-up sufficient battery charge. This factor will reduce vehicle range and performance and may disrupt redundant lateral control systems. Of course, under severe environmental conditions, an AHS/RPEV roadway would most likely be powered down.

Problems unique to the roadway include roadway debris or loss of roadway power. It has been established in automated highway systems analysis that objects must be kept off the roadway in order to avoid serious incidents. Roadway powered systems present the unique issue of parasitic heating, which can occur when a metallic object remains over a powered roadway segment for a prolonged period of time. Inductive heating of roadway debris may be rare because the roadway power segments do not operate continuously. Nonetheless, a malfunctioning segment which remains on, or heavy traffic conditions that repeatedly power a segment in a short time interval, could result in parasitic heating. Consequently, roadway maintenance crews called upon to remove debris need to be informed of this possible parasitic heating danger.

Because each of the powered segments must be connected to a roadside energy source, they may be able to supply redundant lateral control to all vehicles using the RPEV equipped AHS roadway. Loss of roadway power could affect vehicle lateral control systems. But, because redundant systems are expected to be used, the driver would experience no adverse effects unless multiple lateral control failures occur. On the other hand, vehicles in need of a charge may experience reduced range and performance. Current RPEV design proposals will provide vehicle opportunity charging every one-third to nine-tenths of the roadway length. In the case of a single segment failure, this interval should be small enough for the vehicle to receive a charge at the next segment without experiencing any driveablilty problems. In the event of multiple segment failures, those vehicles with critically low battery levels would be directed to the breakdown lane or off the system with little adverse traffic impacts.

RPEV problems unique to the vehicle include the vehicle inductor. Loss of air gap maintenance ability or pickup damage will most likely not seriously impact AHS traffic. The vehicle could continue traveling until the batteries discharge to a low enough level to affect performance, then be directed either off the system or to the breakdown lane.

Magnetic field effects are still being studied. Researchers have found that roadside electro-magnetic fields are at similar levels to those of the Earth’s surface. Because the power segments will be cycled on only when an RPEV requires charge, a non-RPEV following the RPEV should not experience any electro-magnetic fields. Conversely, if a power strip fails to shut off, the magnetic field strength encountered, in conjunction with limited vehicle and occupant exposure time, will be small.

3.4.3 Conclusions

In general, APV and RPEV systems present no severe, unsolvable problems when it comes to analyzing overall AHS safety impacts. Because these systems are still in the developmental stages, we are uncertain if more serious hazards exist than those discussed. APV systems must adhere to all Federal vehicle safety standards and battery designers have considered vehicle and occupant safety to be a crucial design element. As with any vehicle operating today, AHS impacts will be severe only if multiple vehicle failures or adverse environmental conditions occur in a short time frame on the same stretch of AHS/RPEV roadway. This would affect all vehicles using the AHS.

For APV systems, battery technology is the most critical issue. Use of advanced batteries introduces the potential for exposure to harmful electrolytes. On the other hand, the battery designs used in operational EVs today will not leak in event of a vehicle collision unless extraordinary conditions apply. No system is designed to be completely safe and malfunction proof, but consumers expect certain standards and APVs must meet consumer expectations to be successful in the marketplace. Until more data on alternative propulsion vehicle systems failures are gathered, no one can be sure as to how to design an AHS to meet required safety standards.

Current work in RPEVs has been experimental. Studies have shown these systems to be safe and effective, but field tests have been limited to vehicles operating on test tracks. Until more data can be collected and any adverse health or safety impacts uncovered, a proper fault hazard analysis cannot be compiled. As more of these systems become available and more people are exposed to them, these issues will be resolved and automated highways incorporating RPEV systems can be planned.

3.5 IMPACTS OF APVs ON OTHER TASKS

Automated highway system tasks have been assigned to three categories, based upon the effect an APV will have on them:

- Transparent - Vehicle propulsion system has no effect on AHS
- Moderate - Minor changes/enhancements must be made to the AHS to accommodate APVs
- Substantial - Changes must be made to the AHS to accommodate APVs

AHS task impacts are summarized in table 6.

Table 6. AHS Task Impact Summary

AHS Task	Transparent	Moderate	Substantial	None
A		X		
B		X		
C	X			
D			X	
E		X		
F		X		
G				X
H			X	
I		X		
J	X			
K				X
L		X		
N		X		
O		X		
P		X		

3.5.1 Transparent Impact on AHS

Task C: Automated Check-Out - Check-out involves returning vehicle control to the driver after travel on the automated highway system. This task is independent of the vehicle propulsion system.

Task J: Entry/Exit - Implementation of entry/exit is also transparent to the vehicle's propulsion system.

3.5.2 Moderate Impact on AHS

Task A: Urban and Rural AHS Comparisons - Electric vehicles will primarily be used as commuter vehicles in inner-city travel. Hybrid vehicles will have an advantage in rural settings due to their extended range over EVs. For RPEVs, the extent of RPEV range will depend upon the expansion of the RPEV network to rural primary and secondary roads. A secondary benefit is the ability to provide lateral control on RPEV equipped rural roads.

Task B: Automated Check-in - Automated check-in protocols will have to take into account the unique operational characteristics of EVs and RPEVs. AHS check-in must be able to differentiate an SI vehicle from an RPEV and EV. Questions that will have to be answered include: What is an appropriate minimum battery level for an EV to gain access to the AHS? How will the AHS determine how far the APV can travel on the AHS? Does the driver input the destination to an onboard computer which passes this information to the AHS? There may be even fewer systems to be checked compared to an SI vehicle. For EVs, the motors used will be more reliable and need less maintenance than conventional IC engines. For hybrids, complexity of check-in may increase compared to an EV, due to the combustion engine and an electric motor. Battery depth of discharge sensing will be the most important system to be monitored, as this will determine useable range.

Task E: Malfunction Management - There is less opportunity for malfunctions due to the simple systems on EVs and series hybrids. Different types of problems exist for the power trains on EVs, with motor and battery hazard problems. Electric motors on EVs are much more reliable than IC engines. See appendix D for more information.

Task F: Commercial and Transit AHS Analysis - EV and RPEV technology is well suited for commercial delivery services and transit applications, but not for heavy truck use. Commercial delivery services would use the AHS only a small percentage of the time. Any use of the AHS by light delivery vehicles would cause interaction between them and passenger vehicles. The differing performance characteristics of these vehicles may restrict their use in platoons and in other traffic smoothing techniques. EVs and hybrids will see their preliminary application in commercial fleet vehicles, while RPEVs will debut in transit operation.

Task I: Impact of AHS on surrounding Non-AHS Roads - Initially APVs in fleet or transit service will be operating on non-AHS roads. There is no major impact with APVs, assuming that no roadway power is used on these non-AHS roads.

Task L: Vehicle Operational Analysis - Electric vehicles are more reliable in operation than SI vehicles. The failure rate of electric motors is much less than for SI engines, giving APVs an advantage over SI vehicles in this area. We have assumed comparable performance of APVs to ICE vehicles, and APV acceptance by the public.

Task N: AHS Safety Issues - Electric vehicles have different failure properties and characteristics from SI vehicles. The electrolytes of a electric vehicle battery are easier to clean up than gasoline. No standard battery has been adopted by manufacturers, so emergency workers who deal with accidents will have to be trained for a wide variety of accidental spills ranging from liquid sodium to acid.

Task O: Institutional and Societal Issues - The pollution reduction advantages of APVs over IC engine vehicles, and societies concerns on air pollution, make a logical case for APV use on the AHS. Environmental hazards such as pollution and possible EMF effects from RPEV must be studied further. Widespread use of EVs will reduce dependence on imported oil, since domestic energy resources can be used for power.

Task P: Preliminary Cost/Benefit Factors Analysis - This covers many issues from other tasks. These are related to APVs by questions like infrastructure, environmental concerns, noise, vehicle costs, safety, etc.

3.5.3 Substantial Impact on AHS

Task D: Lateral and Longitudinal Control Analysis - Electro magnetic emissions from RPEV systems may interfere with lateral/longitudinal control systems, depending on the system used. The galvanic effect of the roadway power system could be used to provide a degree of redundant control to both RPEV and SI systems. APVs would be the same as other vehicles except for RPEVs, which will have advantages with lateral control while on a powered roadway, because the inductor in the road can be used for guidance. This can be used as a backup/redundant system. For longitudinal control, especially platooning, the acceleration and deceleration of the platoon will be limited by the worst performer in the platoon, which may be an APV.

Task H: Roadway Deployment Analysis - There will be a major effect on AHS if an RPEV system is utilized. A phased-in approach to the RPEV system could allow coverage of large portions of states in a short amount of time. RPEVs would operate as electric vehicles when not on the powered roadway. This would limit the range of the vehicle when off the powered roadway. Increased maintenance of RPEV lanes would be required. If RPEV systems are not in use, the deployment of AHS is transparent to EVs. The inductive plate transfer efficiency is related to the air gap between the inductor. Pot-holes and other surface defects would have to be repaired quickly. Present concept of cycling roadway powered segment translates into a non-exclusive lane occupancy for RPEVs. Under AASHTO guidelines, APVs should be indistinguishable from IC vehicles.

3.5.4 No Impact on AHS

Task G: Comparable Systems - APVs are an evolution of conventional SI vehicles. Electric vehicles may experience similar introductions that affected small fuel efficient vehicles, seatbelts, airbags, and catalytic converters.

Task K: Roadway Operational Analysis - Roadway surface for RPEV system must be in good shape.

4.0 CONCLUSIONS

For successful AHS implementation, APVs will have to be indistinguishable from IC vehicles. The majority of present-day APVs, while having adequate performance for highway operation, lag behind IC vehicles. Future vehicles will have adequate performance for AHS operation.

Legislation, environmental concerns, lobbying, and marketing will play an unusually large role in shaping the future of the APV industry. Presently, we see legislation from both the Federal and state government levels affecting the industry, along with environmental concerns shaving a major impact. Intense lobbying by supporters and detractors of APVs along with lawsuits to stop legislation already are shaping the industry. Marketing the viewpoints of the concerned sides in this issue, along with marketing the vehicles themselves, will play a important part in the future, along with informing the consumer and fueling public demand to buy these vehicles.

Electric vehicles are technically the simplest propulsion system, but the battery/range problem is a major stumbling block. They are the only APV to meet the definition of zero emission vehicles (ZEVs). Legislation may be the strong driving point for their introduction and widespread use.

Hybrid vehicles are the easiest technology for implementation and widespread use, since they overcome the range limitations of electric vehicles. On the downside, they are not zero emission vehicles, although they can operate part time as ZEVs.

RPEVs require the greatest infrastructure requirements, and have the largest impact on the AHS, due to the use of powered roadway inductors that would have to be installed in the AHS. RPEVs have only been tested at experimental facilities to date, but the technologies used are readily available and mature. Electro magnetic forces (EMF) from preliminary in-vehicle studies show very low levels, as compared to household exposure levels. Due to the unknown effects of EMF on people, further study is needed for the frequencies on which RPEVs may operate.

4.1 WHERE FURTHER STUDY IS NEEDED / DIRECTED RESEARCH

The Achilles heel of the electric vehicle is the battery. Research has been going on for decades on the problem of increasing energy. Today's batteries are giving vehicle ranges on the order of 160-km, and only on advanced purpose-built vehicles. The effects of cold weather on batteries capabilities also need study. The United States Advanced Battery Consortium (USABC) is currently involved in advanced research on battery problems, but gains in this field are incremental and are developing very slowly. Continued research is needed, until their goals are achieved. Advancing battery technology is the most pressing problem affecting alternative propulsion vehicles.

Along with battery research, battery recharging technology must also be advanced. Although Government research is being done in this area, some significant research by private companies is advancing. Quick, safe recharging must be developed simultaneously with advancements in battery technology.

Electric vehicle safety, such as crashworthiness, etc., has not been in the forefront of APV research and development. Emergency crews will need specialized training on dealing with the particular problems associated with APVs, battery spill, electrical hazards, etc. Safety issues have not been fully addressed by Government or industry because the daunting task of powerplant design in APVs has received the majority of R&D. Ground-up vehicle designs with advanced lightweight structures will be used for future APVs to offset the battery weight. APV safety is lagging in its research and testing.

In the US, electric power generating capacity can supply the projected electric vehicle requirements for the future (20 years). After that period, the situation is not as clear. Further study is needed on the long range (20 to 50 years) electric power requirements of electric vehicles and RPEVs, and the projected generating capacity and generation mix at that time.

Along with increased study of generating capacity, more detailed study of APV emissions is warranted, especially regarding the power plants that supply electricity for electric vehicle recharging. This is a complex subject, due to the varying types of power plants used to produce electricity, and the different geographical regions.

Hybrid vehicles may be the bridge between ICEVs and EVs. Of the hybrid vehicles studied, series hybrids and flywheels hold the most promise: series because of their simplicity and extended range, and flywheels because of their ability to charge and discharge quickly.

Roadway powered electric vehicles (RPEVs) are the least researched APV technology in the automotive community. Further research is needed on RPEV technology overall. RPEVs hold great promise for initial use as transit vehicles, and with some advances, possibly use as passenger vehicles on the AHS. The effects of weather on powered roadways for RPEVs are a unknown, but potentially major problems may be encountered. A research program is slated in New York State, with one of its goals to determine the problems associated with cold/severe weather on the operation of a powered roadway. Many RPEV topics need additional testing and research. This research can also be used by electric vehicles and AHS design. Some of the topics needing further research are:

- Effects of weather on powered roadways
- Vehicle-to-roadside information transfer
- Energy storage system recharging (batteries, flywheels)

- Electro magnetic field (EMF) effects
- Utility power requirements
- Motor controllers
- Electric motors

Foreign use of electric vehicles and other alternative propulsion vehicles should also be studied carefully. The economics of IC engine vehicles in many countries make them very expensive to operate, because of the high cost of gasoline. The use of APVs is a very attractive alternative in other countries, more so than in the United States.

4.2 SUMMARY OF ISSUES AND RISKS

Table 7 lists the associated issues and risks discovered from our analyses of APV and RPEV impacts on the AHS.

Table 7. Alternative Propulsion Vehicles Issues and Risks

No.	Issue Description	Comments	RSC Impact	Where Discussed
1	The APV fleet will consist primarily of converted IC vehicles for the near future.	Converted SI vehicles often possess inferior performance characteristics to purpose-built APVs. This performance deficit will affect the integration of APVs into the AHS traffic stream.	All RSCs	3.1.1
2	The conversion of SI vehicles to APV use often adds considerable weight to the vehicle, affecting safety, from crashworthiness to braking ability.	The lengthening of brake distances of conversion APVs affects the ability of these vehicles to merge into vehicle platoons on the AHS. The reduced braking will require longer vehicle-to-vehicle distances in the platoon, negating part of the benefits of this technique.	All RSCs	3.1.1
3	The electric vehicle is likely to be the predominant APV on the AHS.	The electric vehicle has range and top speed performance problems that increase the difficulty of the AHS to integrate them. The reduced top speeds of these vehicles limit their usefulness on the AHS.	All RSCs	3.1.1

Table 7. Alternative Propulsion Vehicles Issues and Risks (continued)

No.	Issue Description	Comments	RSC Impact	Where Discussed
4	AHS must differentiate between battery-powered and gasoline-powered vehicles on vehicle check-in.	During the check-in of a vehicle into the AHS, the AHS must be able to differentiate between a vehicle powered by a spark ignition (SI), compression ignition (CI), or electric vehicle (EV). Each of these propulsive systems must have different parameters checked and accepted prior to the vehicle's acceptance into the AHS.	All RSCs	3.5.1
5	Destination of traveler must be entered in vehicle to allow AHS checking of adequate vehicle range.	To allow the AHS to determine if there is sufficient fuel in the electric vehicle (battery charge), the driver must input vehicle destination to allow the AHS to compare range to destination and range left on vehicle. This is a critical part of preventing EVs from running out of charge on the AHS.	All RSCs	3.5.2
6	APV that runs out of charge on the AHS.	An APV that runs out of charge on the AHS is treated like an SI vehicle that has run out of gas. This fault/malfunction should be eliminated unless the driver deviates from the planned trip.	All RSCs	Appendix D
7	Some APV battery systems use elevated temperature electrolyte. Deposition of these electrolytes on AHS systems may degrade/ disable AHS system in area of spill.	A number of battery systems under development utilize high temperature electrolytes such as sodium-sulfur. These systems operate at 400°C. Deposition of this material on the roadway can adversely affect the roadway, as well as vehicles passing through this material and any infrastructure components exposed to the material. Sensor systems in the roadway must be able to withstand attack by these materials, or the system must be able to withstand the temporary loss of these sensors.	All RSCs	3.1.2.1.6
8	Batteries in APVs use electrolytes that are toxic, carcinogenic, or hazardous materials.	The use of these battery materials require that HAZMAT teams be equipped and trained to handle them. These teams are equipped to handle electrolyte spills of current lead-acid systems.	All RSCs	3.1.2

Table 7. Alternative Propulsion Vehicles Issues and Risks (continued)

No.	Issue Description	Comments	RSC Impact	Where Discussed
9	Energy density of current battery systems limits vehicle ranges.	Current battery systems contain only a small percentage of the energy stored in a gallon of gasoline. Advances in battery systems are likely to be evolutionary, with small improvements being made periodically, as opposed to revolutionary, where large advances are realized.	All RSCs	3.1.2
10	Series and parallel hybrid electric vehicles are more complicated than electric vehicles, but offer performance and range equal to conventional SI vehicles.	Hybrid electric vehicles (HEVs) offer a bridge between current SI vehicles and pure electric vehicles. The hybrid vehicles operate with a small IC motor, and are able to switch to electric propulsion. These vehicles can overcome the range deficiencies of EVs, but do not contribute as much to pollution reduction as EVs.	Vehicle issue, affects all RSCs	3.2
11	Fuel cells are viable future electrical energy power sources for APVs.	Fuel cells are power sources that combine reactants, such as hydrogen and oxygen, to produce electricity. This technology is routinely used in the Space program, but because of cost has not been applied to transportation.	Vehicle issue, affects all RSCs	3.2.3
12	Mechanical batteries (flywheels) offer potential for long term uses in an AHS vehicle.	Mechanical batteries (flywheels) store energy in a kinetic form. These have many shortcomings to overcome prior to their being suitable for mass-production automobiles.	all RSCs	3.2.3
13	RPEVs are infrastructure/vehicle systems that combine the benefits of electric vehicle pollution reduction with the elimination of EV range deficit.	The roadway powered electric vehicle (RPEV) eliminates the range deficiency of electric vehicles by equipping infrastructure and vehicles with inductors to allow the transfer of electric power from the roadway to the vehicle. This system is particularly attractive in mass transit operation where routes are repeated, and stop locations are encountered. This system can allow electric vehicles to attain performance and range levels comparable with SI vehicles.	RSC 13	3.3

Table 7. Alternative Propulsion Vehicles Issues and Risks (continued)

No.	Issue Description	Comments	RSC Impact	Where Discussed
14	RPEV power transfer system may be used for lateral control of vehicles on an AHS.	The galvanic effect of the inductive power transfer allows for a “built-in” lateral control system. A misalignment of the vehicle and roadway inductor causes a reduction in the power transfer. By allowing a vehicle to track the optimum transfer of power, the vehicle will center itself over the inductor.	RSC 13	3.3
15	Fleet use of APVs in commercial and transit applications can lead to wide acceptance of these systems.	The use of APVs in fleet and transit applications can be an important step in the application of these technologies. Fleet vehicles typically are used daily for short ranges <160 kilometers. This is within the range of current EV technology.	All RSCs	3.5.2
16	The existence of a roadway power infrastructure system for APVs can lead to the design of optimized RPEVs.	The existence of a roadway power infrastructure can lead to the development of vehicles designed specifically to use this supply. The use of power drawn from the roadway can lead to the reduction of the batteries that would be carried on-board, leading to more efficient vehicles.	RSC 13	3.3
17	APV systems are unlikely to be utilized in the commercial trucking industry.	The vehicles used for commercial service, heavy trucks, are not ideally suited for the use as APVs.	All RSCs	3.5.2
18	The check-out of an APV, the handing over of vehicle control from the system to the driver, is likely to be similar to that of conventional SI vehicles.	The check-out of a vehicle from automated control to human control will be independent of the vehicle propulsion system. In all cases the AHS will have to determine driver fitness to assume vehicle control prior to terminating automatic control.	All RSCs	3.5.1
19	Electric vehicles will primarily be used in urban areas where their limited range will not affect their use. RPEVs can alleviate these limitations and allow the use of APVs in both urban and rural areas.	The use of electric vehicles as commuter vehicles, from city suburbs to central business districts, can be accommodated by current vehicle technology. The extended use of these vehicles in rural areas will have to rely on such systems as roadway power to allow for an increase in vehicle range.	All RSCs	3.5.2

Table 7. Alternative Propulsion Vehicles Issues and Risks (continued)

No.	Issue Description	Comments	RSC Impact	Where Discussed
20	Electric vehicle powerplants are more reliable than those in SI vehicles.	The motors used in EVs are more reliable than the SI motors used in automobiles.	All RSCs	Appendix D
21	APVs can substantially reduce the pollution caused by the automotive fleet	The utilization of APVs in the automotive fleet can reduce the pollution caused by transportation. The reduction in "greenhouse gases" is most dramatic with electric vehicles."	All RSCs	3.1.4
22	The use of government mandates may be required to foster the use and acceptance of APV systems.	To foster the use of electric vehicles, government mandates such the Clean Air Act of 1990 and the CARB regulations for ZEVs will have to be expanded and enforced vigorously. Other government actions such as tax credits for fleet operation and adoption of these systems in government fleets can also lead to more use of APVs.	All RSCs	2.2
23	The deployment of an AHS may be more efficient with the initial use of RPEVs.	The initial deployment of the AHS may be more efficient if based upon RPEV designs. This system negates the use of a dedicated lateral control system, and allows the use of purpose-built RPEV/AHS vehicles. This eliminates the potential for poor after-market installations of AHS equipment. An additional benefit is the slower ramp-up in operation for the system that will allow operators to learn how to use the system to full advantage.	RSC 13	3.3
24	The infrastructure to support a large population of APVs has not been deployed.	The requirements of electric vehicle re-charging and maintenance have not yet been properly addressed. The increased use of these types of vehicles will depend upon the infrastructure present to support them.	All RSCs	3.1.2.3
25	Technology must be developed and deployed to allow quick charging of electric vehicle batteries in comparable time to the re-fueling of a gasoline-powered vehicle.	Current technology requires a full charge of EV batteries — up to eight hours. This constrains the availability of the vehicle and reduces the desirability of these systems. A fast-recharging system (five to ten minutes) is required to foster use of APVs.	All RSCs	3.1.2.3

Table 7. Alternative Propulsion Vehicles Issues and Risks (continued)

No.	Issue Description	Comments	RSC Impact	Where Discussed
26	The electric generating capacity of the geographic regions of the country makes the contribution of APVs to pollution reduction uneven.	The reduction in pollution levels that can be realized by EVs depends on the fuel used to generate the electricity. In parts of the country where coal is used to generate electricity, the increased use of electric vehicles may lead to an increase in pollution.	Vehicle issue	3.1.4
27	The electric generating capacity of most areas of the country could support a large APV fleet with no new generating capacity.	All areas of the United States have enough excess electric generating capacity to support a large population of EVs without the need for additional powerplants.	All RSCs	3.1.2.3.3
28	Cold weather affects the performance of many battery-operated vehicles.	The cold weather commonly found in the northern regions of the United States affects the performance of electric vehicles. These battery systems must operate at slightly higher than ambient temperatures to generate sufficient electricity.	All RSCs	3.1.2.1

APPENDIX A. LITERATURE REVIEW RESULTS

Abraham, K. M. (1993). Directions in Secondary Lithium Battery Research and Development. *Electrochemica Acta*. Vol. 38. No. 9, pages 1233 - 1248

The diverse directions in which research and development on ambient temperature secondary lithium batteries is proceeding are discussed. The state of the art in liquid electrolyte based systems containing lithium metal as the anode can be described in terms of the various AA size cells developed; they are capable of 250 to 300 full-depth discharge cycles, specific energies of 100 to 130 Wh/kg and energy densities of 250 to 300 Wh/l. The commercialization of these batteries has been deterred by concerns of safety hazards. Approaches being pursued to resolve the safety issue include the identification of new or improved electrolytes, the use of alternative anodes, such as lithitated carbon with lower lithium activity, and improved microporous separators having smaller pore size, higher porosity and "shut down" capability. The emergence of the carbon anode based lithium ion batteries as a potentially safe system makes it necessary to identify organic electrodes with oxidative stability to potentials up to 5-V vs. Li^+ /Li. Solid polymer electrolyte based solid state batteries are being developed for a variety of military and consumer applications including electric vehicle propulsion. Solid state batteries with performance reminiscent of their liquid electrolyte counterparts can be fabricated with the use of non-conventional polymer electrolytes. These are composed of low volatility organic liquid electrolytes embedded in organic polymer networks and have conductivities of $>10^{-3}$ ohm^{-1} cm^{-1} at 20♣C. A C/$LiMn_2O_4$ cell utilizing such an electrolyte exceeded four hundred discharge / charge cycles.

Amann, C. A. (1993). Technical Options for Energy Conservation and Controlling Environmental Impact in Highway Vehicles. *International Journal of Vehicle Design*, Vol. 14, No. 1, pages 59 - 77

Manufacturers of light duty highway vehicles are sometimes caught between the desire of the consumer for a reasonable cost conveyance that is a pleasure to operate and the mandates of regulation seeking societal objectives of energy conservation and preservation of air quality. The prospects for improving conventional vehicles in these areas by the year 2000 are considered. Alternative engines and fuels are reviewed for the same time frame. The status of the battery EV is assessed. Shifting attention to the mid 21st century, the possibility of global warming is channeling thought toward non fossil fuels, with hydrogen being added to the list of options.

American Association of State Highway and Transportation Officials (1990). AAHSTO Table X - 4, AAHSTO Table X-6. *A Policy on Geometric Design of Highway and Streets*, pages 986, 991

AAHSTO guidelines for minimum distances needed for design of highway entrance and exit terminals based on vehicle acceleration and deceleration rates.

Anderson, William M. and Cambler, Craig S. (1991). Integrated Electric Vehicle Drive. SAE Paper 910246

An advanced drive system for electric vehicles is described. The extremely compact and lightweight design features a high efficiency, high power density permanent magnet brushless dc motor with an integral gear reduction and differential. The electronic controller features full four quadrant operation with regeneration capable to zero speed.

Ashley, Steven (1993). Flywheels Put a New Spin on Electric Vehicles. *Mechanical Engineering*, October, pages 44 - 51

Advances in high-strength composite materials, frictionless magnetic bearings, high-efficiency motors / generators, and lower-cost miniaturized power conditioning and control electronics have resurrected the possibility that the venerable flywheel could be used to power pollution-free electric and hybrid vehicles.

AUS Consultants (1993). AUS Electric Vehicle Infrastructure Analysis. Technical Paper LM-001. September 9

This study examines the infrastructure costs associated with EV charger installations at residential homes. Infrastructure in this context is defined as electrical components needed to provide power to an EV charger, including, but not limited to, the weatherhead, entrance conductor, panel, circuit breakers, wiring, conduit, elbows, and receptacles.

Bates, B. and Patil, P. B. (1986). ETX - A Second Generation Advanced AC Propulsion System. CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 396 - 400

This paper discusses the characteristics of the concept that is being developed and includes the discussion of the system constraints, including traction battery constraints, and brief descriptions of the major subsystems being developed. The controller, dc to ac inverter, an internal permanent magnet type motor and a two - speed automatic transmission with an integral final drive and differential. The motor and transmission are on a common axis and are integrated into one compact unit that is integral with the rear axle of the vehicle.

Bechtel Corporation (1994). Summary of Electromagnetic Field Standards and Guidelines. Roadway Powered Electric Vehicle Project. TM-RPEV-094-041, May

This report will examine the existing standards and guidelines that may be relevant to this technology. There are few, if any, studies at the precise field levels and form associated with the RPEV Project and even fewer standards in place. Therefore, standards for nearby frequencies are also given in this report to indicate where further standards might fall. Best efforts were made to identify and cite relevant standards and guidelines available at the time of writing. This report cannot, however, be guaranteed to be fully inclusive since new standards and guidelines regarding electric and magnetic field exposures are being proposed almost daily whose jurisdictions and applicabilities vary widely. Before planning or constructing any RPEV, an extensive search of standards in effect for the particular proposed location of the system must be conducted.

Bedard, Patrick (1992). What's the Deal on Electric Cars. *Car and Driver*, May, pages 133 - 141

Discussion of driving forces behind renewed interest in EVs, and the current drawbacks to this technology. This article looks at the air pollution and emissions regulations issues along with the energy sources that will be used to produce the electricity required for electric vehicles. The battery problem is discussed along with the current performance of EVs.

Bentley, Teagan, Walls, Balles, and Parish (1993). The Impact of Electric Vehicles on CO_2 Emissions. EGG-EP-10296 DE93 003719. Arthur D. Little, Cambridge, MA, 02140

This report summaries the results of a study which builds on previous efforts with a particular emphasis on:

1. A detailed analysis of ICEV, FCV, and EV technology and electric power generation technology. Most previous transportation greenhouse studies have focused on the characterization of fuel chains that have relatively high efficiency (65-85 percent) when compared to power generation (30-40 percent) and vehicle (13-16 percent) efficiencies.
2. A direct comparison of EVs, FCVs with gasoline and dedicated alternative fuel, ICEVs using equivalent vehicle technology improvements in both types of vehicles.
3. Consideration of fuel cell vehicles and associated hydrogen infrastructure.
4. Extension of analyses for several decades to assess the prospects for EVs with a longer term prospective.

Birch, Yamaguchi, Demmler, and Jost (1993). Second Generation BMW E1. *Automotive Engineering*, Global Viewpoints, November, page 27

News clip on second generation BMW E1 gasoline / electric / hybrid electric vehicle and its associated power plants, performances and specifications.

Birch, Yamaguchi, Demmler, and Jost (1993). Mercedes Benz Vision A 93. *Automotive Engineering*, Global Viewpoints, November, pages 29 - 30

This article reviews the Mercedes Benz Vision A 93 design study electric / hybrid electric vehicle. The studies unique design elements are discussed along with its specifications and performance measures. A news clip on the Mercedes C-electro is included as well.

Booth, F. H. K. and Patterson Jr., Dr. Philip D. Projected Costs and Benefits of Accelerating Federally - Sponsored Vehicle Technology R&D, pages 262 - 267

The Department of Energy (DOE) Office of Transportation Technologies (OTT) supports a broad spectrum of advanced vehicle technology R&D, as well as, R&D programs focused on basic research supportive of programs of many different vehicle technologies. The analysis focuses on estimating the magnitude of private and societal benefits and costs expected to occur as a result of two alternative funding levels for highway vehicle technology R&D sponsored by DOE.

Braess, Hans-Hermann and Regar, Karl-Nikolaus (1991). Electrically Propelled Vehicles at BMW-Experience to Date and Development Trends. SAE Paper 910245.

Back in the first two decades of automobile development, electric propulsion was a serious competitor for the internal combustion engine.

Electrically propelled vehicles, however, soon proved unable to satisfy users' increasing performance demands in terms of range, acceleration, top speed and hill climbing, together with such factors as operating life, initial purchase price, running costs and reliability.

Engineers investigating electric propulsion today face precisely the same unwelcome legacy as their predecessors, despite many varied attempts in the meantime to improve the components of the electric vehicles drive system.

Progress in battery development, particularly in the case of the NaS system, has nevertheless enabled us at least to partly overcome the previous problems associated with electric drive systems, though it cannot be claimed that all obstacles to its commercial application have been eliminated as yet.

This is a report on the experience gained at BMW to date, the current state of work and development trends.

Brogan, John J. and Venkateswaran, Sek R. (1992). Diverse Choices for Electric and Hybrid Motor Vehicles: Implications for National Planners. *The Urban Electric Vehicle*. Presented at International Conference on the Urban Electric Vehicle: Policy Options, Technology Trends, and Market Prospects (Stockholm, Sweden). Paris: Organisation for Economic Cooperation and Development, pages 77 - 88

The US Department of Energy is undertaking a balanced program or research, development, and testing of propulsion technologies to improve the efficiency and fuel flexibility of highway vehicles and reduce vehicle emissions. For light duty vehicles, a range of electric and hybrid approaches based on advanced batteries, fuel cells, and heat engines are currently being developed.

In planning and implementing its R&D programs, the Department recognizes that multiple propulsion systems and fuel alternatives are potentially available to achieve the program goals. Decisions ion which technologies to support are based on extensive analyses and understandings of the alternatives in terms of primary resource utilization and overall environmental and economic impacts over the fuel chain (from primary energy resource extraction through vehicle end-use). This paper presents the results of one such analysis to estimate the fuel chain energy and emissions performance of electric, battery/heat engine hybrid, and fuel cell vehicles as compared to gasoline and alternative fueled internal combustion engine vehicles. The analysis confirms that the advanced alternatives offer the potential for significant energy efficiency improvements, better utilization of primary energy resources, and lower emissions as compared to conventional gasoline vehicles.

Brooke Lindsay (1994). Patriot Games. *Automotive Industries*, February, pages 114 - 116, 174

Chrysler and its aerospace allies aim their advanced hybrid power train towards LeMans, hoping to prove that hybrids hold the key to clean, efficient, passenger vehicles.

Brooke, Kobe, and Sawyer (1993). Supercar Technology Now ! *Automotive Industries*, December, pages 25 - 30

While president Clinton's Clean Car program searches for the 80 mpg passenger car, an advanced platform team at GM has already built, tested, and driven much of its technology. The platform of the GM Impact represents the technology that could be applied to build the Clean Car today.

Brown, Stuart F. (1992). California Dreaming. *Popular Science*, April, page 39

News clip on introduction of new BMW E2 electric vehicle prototype at the Los Angeles Auto Show in the winter of 1992. The article includes an overview of the vehicle specifications, dimensions, design elements, range projections, and battery technology.

Brusaglino, G. (1991). Electric Vehicle Development in Fiat. SAE Paper 910244

Discussion of impact, features and issues for the new technologies currently being developed at Fiat. The Fiat Panda Elettra is presented along with a multimode hybrid bus.

Burke, A. F. Electric Vehicle Propulsion and Battery Technology 1975 - 1995, pages 119 - 135

General overviews of current battery, EV controllers, electric and hybrid vehicle technology. Comparison of current EV batteries as well as future alternatives. Overview of current motor and controller progress for EVs. Characteristics of electric and hybrid vehicles.

Burke, A. F. (1992). Hybrid / Electric Vehicle Design Options and Evaluations. SAE Paper 920447

Various aspects of the design and evaluation of hybrid / electric vehicles are considered with emphasis on the consequences of utilizing advanced electric driveline components such as AC motors / electronics and ultracapacitors. Simulation results for series hybrid vehicles on the FUDS and the Federal Highway cycles indicate that their fuel economy operating in the hybrid mode will be 25 - 50 percent greater than conventional ICE vehicles of comparable interior size. Hybrid / Electric vehicles using ultracapacitors to load level the engine in the driveline showed even a greater potential improvement in fuel economy.

Burke, A. F. and Cole, G. H. (1991). Simulation of Electric Vehicles with Hybrid Power Systems. CONF 901207 - 3. Idaho National Engineering Laboratory

Computer programs for the simulation of the operation of electric vehicles with hybrid power systems are described. These programs treat cases in which high energy density ultracapacitors or high power density pulse batteries are used to load level the main energy storage battery in the vehicle. A generalized control strategy for splitting the power between the main battery and the pulse power devices is implemented such that the user can specify the nominal battery power as a function of the state of charge of the ultracapacitor or pulse power battery. The programs display graphically on the screen as they run, the power form both the main battery and the pulse power device and the state of charge of the pulse power device. after each run is completed a summary is printed out from which the effects of load leveling the battery on vehicle range and energy consumption can be determined. Default input files are provided with the programs so various combinations of vehicles, driveline components, and batteries of special current interest to the EV community can be run with either type of pulse power device. Typical simulation results are shown including cases in which the pulse power devices are connected in parallel with the main battery without interface electronics.

Burke, A. F. and Henriksen, G. L. (1989). Electric Vehicle Design and Performance Using Advanced Batteries. SAE Paper 891663

Series of designs of compact and full-size passenger cars and minivans were formulated using state of the art driveline components and battery modules / cells. The performance of each of the designs was simulated using the ELVEC. Computer runs were

made for constant speeds between 40 and 88.5 km/h and the J227D and FUDS driving cycles as well as maximum effort accelerations. The simulations indicated for the three vehicle types the target ranges and acceleration times could be met for both the near production and advanced batteries. The targets were consistent with those established for the various batteries by the DOE Battery Goals Task Force in 1988. The energy consumption values calculated for vehicles utilizing DC drivelines were consistently lower by 15 - 25 percent than those vehicles using AC drivelines, primarily due to the higher efficiency of the transmission in the DC power train system. The attractive performance of the formulated electric vehicle designs emphasizes the need to give greater attention in the future to battery cost, life, and maintenance issues than they have often received in the past. Successful marketing of the electric vehicles now depends to a large extent on these issues about which there is presently considerable uncertainty.

Burke, A. F. and MacDowall R. D. (1991). Track and Dynamometer Testing of the Eaton DSEP Minivan and Comparisons with Other Electric Minivans. SAE Paper 910243

Track and dynamometer testing of the Eaton Dual Shaft Electric Propulsion minvan has been performed by the Idaho National Engineering Laboratory. The dynamometer testing included constant speed tests up to 88 km/h and driving cycle tests on the J227a C and D driving cycle and the Federal Urban Driving Schedule as well as maximum effort acceleration tests. The dynamometer data were analyzed to determine the energy consumption (Wh/km) of the DSEP vehicle for the various driving modes and to project the range of the vehicle if the Nif170 nickel-iron battery had been at its rated capacity. Ranges of 90 - 125 miles at constant speeds and about 70 miles on the driving cycles were projected.

Comparisons were made of the DSEP vehicle and the ETX-II and the TEVan minivans, which have been developed on other DOE and EPRI programs using lead-acid, nickel-iron, nickel-cadmium, and sodium-sulfur batteries. The comparisons utilized test data when available, but were based primarily on computer simulation results obtained using the SIMPLEV program.

Burke, Dowgiallo, and Hardin, (1990). Application of Ultracapacitors in Electric Vehicle Propulsion Systems. *IEEE*, pages 328 - 333

Simulations of electric vehicles utilizing hybrid power sources showed that load leveling the main storage battery is a promising approach for reducing the design power requirements for the battery and increasing battery life. Significantly increased vehicle range should also result for batteries, which have been optimized for energy density for lower peak power requirements made possible by load leveling. Consideration of he characteristics of ultracapacitors and bi-polar lead-acid pulse batteries for the pulse power device indicate either device could be used, but the efficiency of the system would be greater by about ten percent using the ultracapacitors.

Burke, Andrew F. (1986). The Effect of Track Grades on Electric Vehicle Range and Energy Requirement. Presented at VIII International EV Symposium USDOE Washington, DC, pages 521 - 526

The effect of track grade on the range and energy requirement of an electric vehicle tested on a track having significant grades is studied. The analytical approach taken includes the effect of grade on the road load and battery power required and then determines the effect of battery depletion using the fractional utilization model to describe the battery. The analytical expressions obtained are applied to the Bedford Van for grades up to ± two percent. It is found that effect of grade on the energy requirement (kWh/mi) is relatively small, but the effect on vehicle range can be significant. For example, at 50 mph and an undulating grade of two percent, the effect of grade on the energy requirement is less than five percent while the range is reduced 25 percent.

Calfee, John F. (1985). Estimating the Demand for Electric Vehicles Using Fully Desegregated Probabilistic Choice Analysis. *Transportation Res.-B*, Vol. 19B, No. 4, pages 287 - 301

This study uses probabilistic choice models to predict potential demand for electric cars. Survey data are employed to estimate separate utility functions for each of 51 subjects. This provides a sample distribution of consumer preferences for vehicle attributes including price, operating cost, and range. The results indicate great diversity in individual trade-offs among attributes, with range and top speed generally being highly valued. The sample of utility functions is then used to predict potential market shares for various kinds of electric vehicles as second cars. Demand is quite limited, except when (a) electric cars are considerably more advanced than anything likely to be available in the near future, and (b) consumers fear massive gasoline shortages. The latter effect derives from an observed "bias" in favor of electric autos, which is plausibly interpreted as a hedge against disruptions in the gasoline market.

California Department of Transportation. Highway Electrification and Automation. Report Under Section 164 of 1987 STURAA, pages 1 - 33

The US surface transportation systems are over-stressed. Worse, the problems have not responded to conventional solutions. These problems include:

- limited capacity and productivity of infrastructure
- traffic congestion and stressful travel conditions
- accidents involving injuries, fatalities and property damage
- limited mobility, especially for the disadvantaged
- air and noise pollution
- excessive energy consumption
- high capital and operating costs

The first four problems can be addressed primarily by IVHS and particularly by highway automation technologies. Air, noise and excessive energy consumption can be overcome through the use of electric vehicle technologies. However, current electric vehicle battery technologies suffer from energy storage limitations, thereby limiting the range of these vehicles. Highway electrification is one method that addresses this limited energy storage problem to extend the range of electric vehicles.

This report addresses how Caltrans and PATH have applied the resources allocated in Section 164 of the 1987 Surface Transportation and Uniform Relocation Assistance Act (STURAA), with much larger matching state and private resources, to evaluate the feasibility and applicability of highway electrification and automation technologies. Chapter II describes how the work was conducted. Chapters III, IV and V describe the findings on highway electrification with experimental results, design study results, and a region wide application impact study for Los Angeles. Chapters VI, VII and VIII describe the highway automation findings, beginning with the concept definition and analysis work, followed by the experimental results and the region wide application impact study results for Los Angeles. The overall conclusions are summarized in Chapter IX.

California Energy Commission (1992). Analysis of the Potential Electricity Demand, Electricity Supply and Emissions Impacts of Electric Vehicles. Staff Report, February 10

This report provides detailed documentation of the California Energy Commission Staff's assessment of the potential effects of electric vehicles on electricity demand; electricity supply, or the amounts, types, and operation of resources required to meet demand; and on the total air pollution emissions.

Caruana, Claudia M. (1993). Electric Vehicle Research Draws Batteries of ChEs. *Chemical Engineering Progress*, February, pages 11 - 18

By the turn of the century, an electric car may be in your garage, but before that, millions of government and private research dollars must be spent to optimize one of its critical components: the battery. A review of the currently available EV battery sources and those proposed for after the year 2000 follows.

Chan, C. (1993). An Overview of Electronic Vehicle Technology. *Proceedings of the IEEE*. Vol. 81. No. 9. September, pages 1201 - 1213

In a world where energy conservation and environmental protection are growing concerns, the development of electric vehicle technology has taken on an accelerated pace. The 1990's are likely to be the decade in which the long - sought practical, economical electric vehicles will begin to be realized. The paper provides an overview of presents an overview of present status and future trends in electric vehicle technology, with emphasis on the impact of rapid development of electric motors, power electronics, microelectronics, and new materials. Comparisons are made among electronic drive systems and various battery systems. The market size of electric vehicles in the coming years and the potential electric vehicle impacts are discussed.

Cheiky, Danczyk, and Wehrey (1990). Rechargeable Zinc-Air Batteries in Electric Vehicle Applications. SAE Paper 901516

Dreisbach ElectroMotive Inc. is developing a maintenance free rechargeable Zinc-Air Battery that operates at room temperature. This new battery has an energy density of 200 Wh/kg or about eight times conventional Nickel-Cadmium or Lead-Acid technology now used in electric vehicle applications.

This paper will cover the performance characteristics of DEMI's Zinc-Air Batteries to date and the results of a 48 cell test in a Chrysler minivan which was converted to electric drive under the sponsorship of Southern California Edision. In addition, work in progress on a 168 cell long range vehicle configuration will be presented.

Cheiky, Mike C., Danczyk, Len G., and Scheffler, Robert L. (1991). Zinc-Air Powered Electric Vehicle Systems Integration Issues. SAE Paper 910249

Dreisbach ElectroMotive, Inc. (DEMI) is developing and testing a maintenance - free wall plug rechargeable Zinc - Air Battery to power Electric Vehicles. This new battery

technology offers over 200 mile range capability from very low cost, commonly available raw materials.

This paper will focus on the preliminary systems integration needed by an electric vehicle to operate these air breathing batteries in various common environments. Air cooling and reaction air requirements will be covered as well as the actual systems used to implement these requirements in a Chrysler minivan which is sponsored by Southern California Edison. In addition, the projected system implementations of Zinc - Air batteries in automobiles and multi-use vans will be presented.

Cherry, Timothy R. (1992). The LA301 Hybrid Electric Vehicle. SAE Paper 921540

The development of the LA301 hybrid-electric vehicle was the result of a unique public / private partnership between the city of Los Angeles, the LA Department of Water and Power, and Clean Air Transport AB. From the research and development funds provided by LADWP to Clean Air, to the production of two semi-engineered prototypes by Clean Air and the City of Los Angeles' commitment to make LA the first "EV - Ready" city, the stage has been set for the successful introduction of the LA301 vehicle.

Clemens, Kevin (1994). General Motors Impact. *Automobile Magazine*, February, pages 96 - 97

With the upcoming 1998 CARB mandates, automobile manufacturers must have viable electric vehicle designs available for purchase, the General Motors Impact is one vehicle that may be on the road in the near future. This article describes consumer relevant aspects of the GM Impact electric vehicle; performance parameters, technology, design, and specifications.

Cogan, Ron (1993). Volvo ECC: A Hybrid Electric Family Sedan Goes the Distance. *Motor Trend*, April, pages 62 - 63

Current EV battery technology suffers from poor energy storage capabilities translating into limited range for electric vehicles. Therefore, auto makers have looked into hybrid electric vehicles to extend the range and performance of EVs. HEVs utilize a fossil fuel burning power plant in series or parallel configuration to provide power for highway use or act as a generator to charge the batteries or provide instantaneous power needed for hill climbing and passing. Volvo’s approach to EV technology is the Environmental Concept Car, or Volvo ECC. The ECC is a series hybrid vehicle that uses a turbine motor to generate electricity to charge the vehicle’s NiCd batteries. The vehicle meets ULEV emissions standards in hybrid mode and can be operated in all electric mode in cities where ZEV standards exist.

Cogan, Ron (1991). Electric Cars The Silence of the Cams. *Motor Trend*, August, pages 71 - 77

Review of several electric vehicles including conversions and ground up designs. Current vehicle performances are discussed as well as the future directions EV producers are taking. High inflation, low rolling resistance tires are discussed and a brief review of current EV battery technology is provided as well.

Coghlan, Andy (1993). Electric dreams take to the road. *New Scientist*, October 2, page 38

With the pressure on to limit carbon emissions, manufactures are finally making electric cars that are more than just interesting prototypes. Article reviews the Tokyo Electric IZA.

Considine, Douglas M. and Considine, Glenn D. (1984). *Van Nostrand Reinhold Encyclopedia of Chemistry*. Fourth Edition. Van Nostrand Reinhold Company. New York, pages 108 - 114; 410 - 413

Excerpts from the encyclopedia on batteries and fuel cells. The aforementioned subjects were described in detail. Their operating concepts, history and present and future technology and applications are mentioned. Full definitions of batteries and fuel cells are given.

Cook, K. (1993). Electric Drive Motor and Controller Technology in Detail. *Automotive Engineer*, Vol. 18, No. 2, April / May, pages 28 - 31, 60

Description of basic information on motors, characteristics and performance, controllers and systems, batteries and drive train, together with a look at what car makers are doing.

Creasey, William A. and Goldberg, Robert B. (1993). Safety of High Speed Guided Ground Transportation Systems: Potential Health Effects of Low Frequency Electromagnetic Fields Due to Maglev and Other Electric Rail Systems. DOT/FRA/ORD-93/31. United States Department of Transportation Final Report. August. pages 1 - 84

The safety of magnetically-levitated (maglev) and high-speed rail (HSR) trains proposed for use in the United States is the responsibility of the Federal Railroad Administration. There are concerns for physical safety associated with equipment operation and high-voltage currents, and for potential adverse health effects on transportation workers and the public from the electric and magnetic fields (EMF) produced in the Extremely Low Frequency (ELF) range (3-3000 Hz). This report outlines research on the biological and health effects mot relevant to fields generated by maglev and HSR systems. Among the conclusions are: epidemiological results suggest a low-level health risk for power-line frequency ELF EMF which is, at present, the most relevant risk to ascribe maglev systems; bioeffects may occur at specific window frequencies and intensities; of effects ascribed to EMF, the most convincing are altered circadian rhythms of melatonin secretion, modulation of transmembrane transport, slight increases in the risks for some rare cancers, and mild behavioral disturbances; occupational categories used as the basis for epidiologic studies need better definition in terms of the characteristics of EMF exposure ; and, there is need to improve bioassay systems and test maglev-type fields on them.

Dabels, John. (1992). Environmental Requirements and the Impact Prototype Vehicle. *The Urban Electric Vehicle*. Presented at International Conference on the Urban Electric Vehicle: Policy Options, Technology Trends, and Market Prospects (Stockholm, Sweden). Paris: Organisation for Economic Cooperation and Development, pages 331 - 345

The first main topic of this paper is the driving forces behind Electric Vehicle (EV) deployment in the United States which are:

(1) Public concern for the environment;
(2) Government Legislation;

(3) Energy Independence;
(4) Cost of operation.

My second subject is the development of the Impact Prototype vehicle, its subsystems and the resulting vehicle configuration. I will concentrate on the propulsion system and other areas of significant difference.

Lastly, I will address possible differences between Europe and the United States.

DeCicco, John M. and Gordon, Deborah (1992). The Environmentally Friendly Vehicle. *EPA Journal*. September / October, pages 24 - 25

What would the “green car” be like ? A oxymoron to some and an environmentally safe, personal mobility machine to others. Think of a green car as an ideal toward which the nation must strive if it is to achieve an ecologically sustainable transportation system. Production, use, and disposal of such a car would consume no fossil fuels and generate no pollution.

Delarue, C. (1992). The Renault Approach to Cleaner European City Cars. *The Urban Electric Vehicle*. Presented at International Conference on the Urban Electric Vehicle: Policy Options, Technology Trends, and Market Prospects (Stockholm, Sweden). Paris: Organisation for Economic Cooperation and Development, pages 271 - 282

There is increasing evidence that EVs can reduce the burden of local pollution in cities. It makes it possible to leave the investigation era to come to production; however, vehicle production level is linked to equipment manufacturers capacities and existence of customers. It is the reason why the approach of Renault is progressive so that all involved partners can grow in harmony.

The first possible market is small commercial vehicles, and as the leading European manufacturer in this field, Renault develops EVs derived from its best sellers Express/Rapid and Master; this is the cheapest and simplest way to go. Simultaneously, Renault prepares an electrified small passenger car and a specific urban EV to be ready when many customers will consider EVs as viable products.

We think we have to be realistic and to aim at niches where the use of cars is compatible with the present battery technology and the usual power output of electric outlets for recharge; that means that range is not much in excess of 100 km, but that covers already a significant portion of urban traffic needs in Europe, fortunately different from those in the US.

Although progress in batteries will improve EV performance, we should not make the public believe that EVs will have the same range and refueling time of their conventional counterparts: recharge power requirements of hundreds of kWs are only affordable for show cars or fleet companies; megawatt recharging capabilities are impractical.

Before fuel cells will be ready for car applications, Renault thinks that the need for clean cars in city use with highway capability and longer range is another niche satisfied by CNG or better LPG cars and HEVs. Renault works in all these areas for real world solutions.

DeLuca, Tummillo, Kulaga, Webster, Gillie, and Hogrefe (1990). Performance Evaluation of Advanced Battery Technologies for Electric Vehicle Applications. CONF - 900801 -21 E1.99: DE90 013895. In *Proceedings of the 25th IECEC*, Volume 3, Reno, Nevada, August 12 - 17

At the Argonne Analysis and Diagnostics Laboratory, advanced battery technology evaluations are performed under simulated electric vehicle driving conditions. During 1989 and the first quarter of 1990, single cell and multicell modules from seven developers were examined for the Department of Energy and Electric Power Research Institute. The results provide battery users, developers, and program managers with an interim measure of the progress being made in battery R&D programs, a comparison of battery technologies, and a source of basic data for modeling and continuing R&D. The paper summarizes the performance and life characterizations of two single cells and seven 3 - to 960 - cell modules that encompass six technologies (Na/S, Ni/Fe, Ni/Cd, Ni - metal hydride, Lead - acid, and Zn/Br).

DeLuchi, Wang, and Sperling (1989). Electric Vehicles: Performance, Life-Cycle Costs, Emissions, and Recharging Requirements. *Transportation Res. - A*. Vol. 23A. No. 3, pages 255 - 278

EVs are periodically promoted as quiet, pollution-free alternatives to ICEVs. They have failed each time because of inferior performance and high costs. In this paper, we conduct an updated and detailed evaluation of the performance, costs, environmental impacts, and recharging requirements of EVs. We find that considerable progress has been made in EV battery and power train technology since the last surge of interest in EVs in the 1970s.

Demmler, Al (1993). Design Study Uses Under Floor Drivetrain. *Automotive Engineering*, Tech Briefs, October, page 15

This news clip includes a discussion of the Mercedes Benz Vision A 93 concept car and its unique underfloor drivetrain which features an engine and transmission located beneath the passenger compartment of the vehicle. Vehicle specifications, performance and power plants being studied are also included

Dieckmann, John and Mollory, David (1991). Climate Control for Electric Vehicles. SAE Paper 910250

The vast majority of cars and small trucks are sold with factory installed air conditioning (approximately 80 percent in 1989). For electric vehicles to succeed in the marketplace, air conditioning will need to be offered as optional equipment, along with adequate heating and defrosting systems. While providing the level of cooling performance expected by vehicle operators, it is important that the power consumption of the air conditioning systems used in electric vehicle be minimized, to minimize penalties to vehicle range and performance.

This paper summarizes the design and performance of several air conditioning systems that have been developed for electric vans over the past two years, including systems based largely on standard automobile air conditioning components and more advanced systems using high performance heat transfer components and a variable speed refrigerant compressor. The feasibility of using a heat pump cycle for vehicle heating functions (instead of a fuel fired heater), and the feasibility of applying measures to control vehicle thermal loads is discussed.

Diem, William R. (1994). GM Impact Ready for Lead - Acid Test. *Automotive News*, January 3, page 6

This article describes the GM Impact electric vehicle; performance parameters, technology, design, and specifications. And discusses the nationwide 2 year test drive program that GM is providing selected customers to get their opinion of the vehicle after a one to two week test drive period.

Dietrich, Fred M., Feero, William E., and Jacobs, William L. (1993). Safety of High Speed Guided Ground Transportation Systems: Comparison of Magnetic and Electric Fields of Conventional and Advanced Electrified Transportation Systems. DOT/FRA/ORD-93/07. United States Department of Transportation Final Report. August. pages 1 - 70

The safety of magnetically levitated (maglev) and high speed rail (HSR) passenger trains proposed for application in the United States is in the responsibility of the Federal Railroad Administration (FRA). Plans for near future US applications include maglev projects (e.g. in Orlando, FL and Pittsburgh, PA) and high speed rail (the French Train a Grande Vitesse (TGV) in the Texas Triangle).

Concerns exist regarding the potential safety, environmental and health effects on the public and on transportation workers due to electrification along new or existing rail corridors, and to proposed maglev and high speed rail operations. Therefore, the characterization of electric and magnetic fields (EMF) produced by both steady (dc) and alternating currents (ac) at power frequency (50 Hz in Europe and 60 Hz in the US) and above, in the Extreme Low Frequency (ELF) range (3-3000 Hz) is of interest.

This report summarizes and compares the results of a survey of EMF characteristics (spatial, temporal, and frequency bands) for representative conventional railroad and transit and advanced high-speed systems including: the German TR-07 maglev system; the Amtrak Northeast Corridor (NEC) and New Jersey Transit (NJT) trains; the Washington, DC Metrorail (WMATA) and the Boston, MA (MBTA) transit systems; and the French TGV-A high speed rail system.

This comprehensive comparative EMF survey produced both detailed data and statistical summaries of EMF profiles, and their variability in time and space, characterizing a range of electrotechnologies. EMF data represent a range of train or transit system operating conditions and locations (in vehicles, stations and waysides), as well as in traffic control and electrical power supply facilities.

EMF ELF levels for WMATA are also compared to those produced by common environmental sources at home, work, and under power lines, but have specific frequency signatures.

Dooling, Dave (1993). Transportation. *IEEE Spectrum*, January, pages 68 - 71

Contained in the Technology 1993 section, this article discusses the new technologies on the horizon for reducing traffic congestion and decreasing pollution and environmental impacts of today’s transportation systems. The article includes brief reviews of IVHS, the Green Motor Cars dealership that specializes in electric vehicle sales only, the Horizon lead cloth battery, MAGLEV, other high speed rail systems, and magnetohydrodynamic (MHD) propulsion.

Dowgiallo, Edward J. and Kevala, Russ J. (1986). Development of a Simplified Driving Cycle Based on Actual EV Operations. CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 166 - 171

The standard EV test procedures in use today are of value for comparisons between EVs on the same basis. The are not suitable for predicting the EV performance or range under actual field conditions. An important finding from this study is that for the actual EV operations tested, times spent in acceleration and deceleration are significantly longer than in cruise in all velocity bands. This is not the case for the SAE J227a test procedure. Due to the difference, the urban commuter mission required 21 percent less energy per mile than the SAE J227a Schedule C. This paper presents preliminary efforts at defining the important parameters of actual missions and their relationship to standard EV test procedures.

Dowgiallo, Edward J., Jr. and Kevala, Russ J. (1986). Examination of Battery-Related Electric Vehicle Track and Field Measurements. *Journal of Power Sources*, Vol. 17, No. 1-3, January - April, pages 248 - 256

The US Department of Energy (DOE) Electric and Hybrid Vehicle Program activities include on - the - road evaluation of electric vehicles by site operators at several locations throughout the United States. Daily vehicle operation, and maintenance logs and energy input data are recorded by these site operators, which provide useful operating information about the EV fleet of more than 500 vehicles.

Dunne, Jim (1992). Concept Internationale. Popular Mechanics, May, page 39 - 41

The world's top designers forecast the shapes and systems of tomorrow. News clips on the Volkswagen Chico 4 seat hybrid electric vehicle and Nissan FEV electric vehicle are included in this review of the Frankfurt and Tokyo auto shows, as well as the North American International Auto show in Detroit.

Electronic Power Technology, Inc. (1994). EPTI Battery Charging Technology. Brochure. Available from Electronic Power Technology, Inc., 6400 Atlantic Blvd, Suite 130, Norcross, GA 30071, (404) 449 - 0588

Information regarding Electronic Power Technology, Inc., its technology and battery charger products.

Electrosource, Inc. (1994). The Horizon Battery. Brochure. Available form Electrosource, Inc., 3800 B Drosset Drive, Austin, Texas 78744 - 1131 USA, (512) 445 - 6606

This brochure describes the Horizon lead cloth battery. Its design, performance characteristics, manufacturing processes. Included is a company description and the history of lead cloth battery technology.

Energy Information Administration (1991). Annual Outlook for US Electric Power 1991: Projections Through 2010. DOE/EIA-0474 91) DE91 016023. Energy

Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, United States Department of Energy, Washington, DC 20585, pages 1-91

The report contains three chapters. Chapter 1 presents 1990 data and highlights major events affecting the electric power industry in 1990. Chapter 2 provides national and regional level projections of sources and uses of electricity through the year 2010 and comparisons with other projections. Chapter 3 provides information about provisions of the Clean Air Act Amendments of 1990 that affect emissions of nitrogen oxide and sulfur dioxide and provides provisions on the electric utility industry. The appendices to this report provide detailed assumptions (Appendix A), and regional projections of this year's forecasts (Appendix B).

The report is intended for the general audience. It should be of particular interest to public utility analysts, investment firms, trade associations, Federal and State regulators, and legislators.

Erickson, Deborah (1991). Cadmium Charges. *Scientific American*, May, page 122

The environmental costs of batteries are stacking up. Environmentalists intent on keeping toxic materials out of landfills promoted the message "Get the Lead Out !" to battery manufacturers. Next came mercury, laws were passed so that by 1992 poisonous metals will contribute no more than .025 percent of a battery cell's weight. Now cadmium, a toxic, carcinogenic metal, is on the line. Cadmium waste does not meet EPA safe disposal requirements and must be placed in specially lined landfills with dumping fees of up to $1000 / ton. As a result, states such as Minnesota and Connecticut have passed legislation mandating NiCd battery recycling, some thirty states more are considering enacting such legislation. Manufacturers are concerned that their product lines will be ruined, but they do not want to destroy the environment either. They want local governments to be responsible for the collection and sorting of these batteries so that they can avoid the costs, environmentalists so no way.

Faust, Goubeau, and Scheuerer (1992). Introduction to the BMW - E1. SAE Paper 920443

At the IAA '91 in Frankfurt (Germany), BMW presented its E1, the first specially designed electric car for urban traffic. This paper gives a survey of the development goals. Further details will be presented describing the concept of the car including the safety system, the concept of the drive train and the heating system. The selection of material is presented which gives the high potential for recycling and for the use of recycled materials. Additionally, the effects on energy consumption and environmental impacts are described and compared with conventional cars and EVs of older design.

Fenton, J.E. and Patil, P. B. (1986). Advanced Electric Vehicle Powertrain (ETX - 1) Performance: Vehicle Testing. CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 496 - 502

The ETX-I power train represents the most advanced electric vehicle technology in operation today. This power train was developed by the Ford Motor Company and General Electric Company as a major element of the U. S. Department of Energy's Electronic and Hybrid Vehicle program. During the final phase of this program , a vehicle test plan was developed, test requirements defined, and procedures carefully followed to measure the acceleration, gradability, and energy consumption performance of the power train and to characterize component efficiencies. An electric chassis dynamometer was used for the majority of the tests to minimize test variability.

Fisher, Diane C., Ph.D. (1992). How an Environmentalist Views Electric Vehicles. *The Urban Electric Vehicle*. Presented at International Conference on the Urban Electric Vehicle: Policy Options, Technology Trends, and Market Prospects (Stockholm, Sweden). Paris: Organisation for Economic Cooperation and Development, pages 171 - 177

Achieving air quality standards in many regions will require major reductions in NOx, HC and CO emissions. For instance, in the Los Angeles Basin, reductions of 62 percent in NOx, 83 percent in HC and 51 percent in CO will be needed to attain Federal clean air standards by 2010. Even this will not be enough to attain the more stringent California standards. Furthermore we must reduce carbon dioxide emissions to avoid harmful Greenhouse effects. These conditions imply that we must begin to wean ourselves from the use of fossil fuels to sustain life on Earth.

Fitz, Frank A. and Pires, Paul B. (1991). A High Torque, High Efficiency CVT for Electric Vehicles. SAE Paper 910251

Epilogics, a young engineering firm in Los Gatos, CA, has developed the first fully geared, high torque, high efficiency, infinitely variable transmission suitable for automotive applications. The IVT has particular significance to electric vehicles because it can provide a highly efficient, yet exceptionally controllable means to regenerate power throughout the normal braking cycle (allowing regeneration even at near-zero vehicle speeds). Under normal operating conditions, the efficiency of the Epilogics transmission exceeds 90 percent as derived mathematically and corroborated experimentally. The device does not rely on traction to transmit torque and can therefore match the torque capacity of any typical gear drive. The size, weight, and cost of the device closely approximated that of a four-speed transmission suitable for the application. A recent development allows a bi-directional transmission which greatly enhances its attractiveness as an electric vehicle transmission by providing for a highly desirable (albeit, unnecessary in itself) means to regulate vehicle speed independently of motor speed, in addition to a means to a highly practicable regenerative barking system.

Flanagan, R. C. and Keating, M. Evaluation of a Flywheel Hybrid Electric Vehicle, pages 205 - 210

Alcan International Limited, in association with Unique Mobility Inc. and the University of Ottawa, have a program to develop an advanced concept electric vehicle that will use a flywheel / electric surge power unit. The applications model and analysis presented simulates a minivan operating on the Federal Urban Driving Schedule with an all electric power train. With the flywheel / electric surge power unit, it was shown that both battery and load leveling (constant current or power) and the FUDS cycle performance requirements could be easily met. The Powell multidimensional algorithm was used to optimize and size power train components. Based on the optimization results together with component size sensitivity, overall costs and cooling requirements, the following components were selected: (i) flywheel energy storage = 500 Wh; (ii) flywheel motor / alternator = 40 kW rated; (iii) drive motor/alternator = 100 kW rated and (iv) battery mass = 1000 kg. With these components, the average battery power required to operate over the FUDS cycle is only 8.5 kW and the vehicle range was estimated at 182 km.

Ford, Andrew (1991). Utility Impacts of Electric and Natural Gas Vehicles: The Impact of Electric Vehicles on The Southern California Edison System. Draft Report. September

The analysis of scenarios with two million EVs in the SCE area suggest that EVs could be extensively used in Southern California without the need for extra generating resources in the long term plan. This finding depends, in part, on the adoption of a “smart control” communication system which would allow the utility to control night time battery charging loads. It also assumes EVs operating on NaS batteries whose long ranges would lead to minimal opportunity charging during day time hours.

Freedman, David H. (1992). Batteries Included. *Discover*, March, pages 90 - 98

Designed by a team of visionary engineers, a unique new car is fast, sexy, and - with zero emissions - environmentally correct for the nineties. This article contains an overview of the people involved with the design of the GM Impact, their though processes, design hurdles and technological breakthroughs.

Fukino, Irie, and Ito (1992). Development of an Electric Concept Vehicle with a Super Quick Charging System. SAE Paper 920442

Recent environmental concerns such as atmospheric pollution and energy conservation have intensified the need to develop pollution - free, energy - efficient vehicles. One such solution is the electric automobile which draws its power from rechargeable batteries. There are few vehicles on the road today because present batteries can store very little energy compared with that of a tank of gasoline. To obtain adequate range, this concept vehicle adopts a new battery which can be recharged to 40 percent capacity in six minutes. This super quick charging system makes it possible to recharge the batteries at an electric recharging station just as gasoline - powered vehicles are refilled at service station. The electric concept vehicle also has improved aerodynamics, reduced rolling resistance, and a lighter curb weight, which help to assure adequate range.

Georgia Tech Research Institute (1994). Roadway Powered Electric Bus System for Olympics Village. Proposal for 1996 Olympics Demonstration Project. June 15, pages 1 - 6

An advanced technology demonstration project for the Olympics using a specially designed roadway powered electric bus within the Olympics Village at the Georgia Tech Campus is proposed. The demonstration will entail 3 all electric buses of advanced design operations on about a 10 km route on the Georgia Tech Campus.

Gilbert, Alan T. and Gunn, Richard (1991). Natural Gas Hybrid Electric Bus. SAE Paper 910248

The design and predicted performance of a hybrid electric powered transit bus is described. The bus is a 7.6 meter, 24 passenger vehicle that incorporates a low floor design and rear door accessible to handicap passengers. The low floor and rear door are made possible by the use of individual high power density permanent magnet motors driving the rear wheels. The hybrid electric drive system consists of a compressed natural gas fueled internal combustion engine that drives a generator which in conjunction with the storage batteries supply power to the two traction motors.

GM Electric Vehicle Resource Center (1994). General Motors Electric Vehicles Program. Available from GM Electric Vehicle Resource Center, 432 North Saginaw Street, Suite 801, Flint, MI 48502

Overview of PrEView Drive Program and specifications on the GM Impact 3 electric vehicle prototype.

Gratt, Lawerence B. and Layton, David W. (1988). Health and Environmental Impacts of Future Aluminum - Air Powered Electric Vehicles. *Energy*, Volume 13, Number 4, pages 343 - 356

Aluminum could serve as a fuel source for vehicles using an innovative aluminum-air battery. This paper includes analyses of the major health and environmental consequences of operating a fleet of 10 million vehicles using such a transportation fuel. The principal environmental wastes associated with such a scenario are from the production of aluminum and the generation of electricity from a mix of energy sources. The primary contaminants of concern in the fuel cycle supporting the operation of the vehicles are fluoride, sulfur dioxide, carbon dioxide, and carbon monoxide. However, control technologies can reduce these emissions to safe levels. Occupational exposures to gases in potrooms of aluminum reduction plants are also identified as a potential problem. Finally, operation of the vehicles could expose occupants to sodium hydroxide, a battery reagent, in the event of an accident.

Gromer, Cliff (1994). New Age of the Electric Car. *Popular Mechanics*, February, pages 38 - 40, 103

GM's hard charging Impact is practical, fun to drive and a master stroke of engineering. This article describes the GM Impact electric vehicle and its associated performance parameters, technology, design, and specifications.

Harmon, Robert (1992). Alternate Vehicle - Propulsion Systems. *Mechanical Engineering*, March, pages 58 - 65

Tighter emissions standards are forcing the automotive industry to develop and adopt new technologies for engine design and operation. Three promising alternative propulsion systems are electric or electric-hybrid systems, gas turbine, and fuel cells.

Henriksen, G.L. and Embry, J. (1991). Lithium / Metal Sulfide Technology Status. In *P-256, Proceedings of the Annual Automotive Technology Development Contractor's Meeting*, pages 95 - 100

The US Department of Energy sponsors the development of lithium / iron sulfide batteries for electric vehicle applications at SAFT R&D Center and Argonne National Laboratory (ANL). SAFT is conducting the engineering development of the first generation prismatic LiAl/FeS battery for electric van applications, while ANL provides technology transfer and R&D support to SAFT. Also, ANL conducts a low level R&D project on the second generation bipolar $LiAl/FeS_2$ battery for high performance EV applications. SAFT is building and testing 200 Ah prismatic cells and a 12 V module. ANL is evaluating SAFT cells and is building and testing its own 25 Ah 13 cm diameter bipolar $LiAl/FeS_2$ cells. The prismatic LiAl/FeS cells provide a peak power of 375 W/L (166 W/kg) and a delivered energy of 217 Wh/L (96 Wh/kg), while the bipolar $LiAl/FeS_2$ cells provide 1120 W/L (400 W/kg) peak power at

80 percent depth of discharge (DOD) and 500 Wh/L (180 Wh/kg) at the 85 W/L rate. Batteries based on prismatic LiAl/FeS cells should satisfy the performance requirements of an electric van, while batteries based on LiAl/FeS_2 cells are projected to fulfill the performance requirements of a whole range of electric vehicle applications, including those of high-performance commuter and hybrid vehicles.

Hornstra, Mulcahey, Biwer, Christianson, Carothers, Hogrefe, Kulaga, and Webster (1986). A Methodology to Assess the Impact of Driving Schedules and Drive Train Characteristics on Electric Vehicle Range. CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 202 - 208

A methodology is described that combines the use of the battery Ragone (average power) and peak power characteristics, in a simple manner, to show which batteries and which drive train characteristics favor any one driving schedule over another, including the Federal Urban Driving Schedule (FUDS) and the SAE J227aD Urban Driving Schedule (SUDS). The methodology also reveals the energy remaining unused in the batter at the end of a discharge cycle when the vehicle fails the requirements of the driving schedule. The additional range achievable by relaxing the discharge terminating requirements of the driving schedule for a 'limp home' can be determined. The methodology shows why batteries that have high peak power capability, while giving greater range, generally have less 'limp home' ability.

HR Ross Industries, Inc. (1994). Case Study on Highway Electrification for the San Diego Region: Economics of Ownership & Operation. Roadway Powered Electric Vehicle Project. TM-RPEV-094-041. Draft. August 1

This analysis suggests that for a utility, or other owner / operator, the electrified roadway could provide an extremely valuable private sector investment opportunity, where the user fee revenues are more than four times the electricity charges alone. For the State of California it could be a new source of revenue for highway improvements, as it could be double that of gas tax revenues displaced; it could permanently solve the problem of underfunding for the highway. On a statewide basis in 2015, with full market penetration, a state system of electrification could provide total revenue for the state of 9 x 10^9 / year, of which 50 percent is new. For the individual driver recoverable benefits of around $ 800 / year / vehicle could be realized, or over $ 2.6 billion annually in the San Diego Region in 2015. The widespread financial benefits that are realized accrue solely because of the introduction of new technology on a large scale.

HR Ross Industries, Inc. (1991). Playa Vista Final Report on Phase I R & D Program. Roadway Powered Electric Vehicle Project. RPEV-091-007. August 31

This report describes the process of redefining the R&D mission of the project, the definition of new design points, the redesign necessary to match the new design points, the prototyping of major system elements, and the accomplishments in terms of proof of technological concept. The plans for Playa Vista, which are now deferred until Phase II are aimed at a test facility for the site, and not public demonstration.

HR Ross Industries, Inc. (1994). Roadway Powered Electric Vehicle Development Program. Highway Electrification & Automation Development Program. April 30

The roadway powered electric vehicle provides a means of resolving the inherent limitations of the battery as an energy storage system for the EV. Development of the RPEV system has been underway in California since 1979, with total funding in an amount of approximately $10 million. Current focus of the development effort is in San Diego, where one vehicle and a test facility will be built to test the charging concept for the buses. Planning for a cold-weather test facility and experimental highways in New York State, is already underway.

Commercialization of the technology is focused initially on a number of small scale field test and demonstration projects around the country, which will involve a small, all-seated low floor bus. A joint venture to manufacture these advanced vehicles is being arranged. Full size and articulated electric transit buses that are competitive with diesel buses will be developed, and overseas industrial partners will be sought for manufacturing.

Development of a commercially viable electric automobile utilizing these technologies is being planned for the longer term.

HR Ross Industries, Inc. (1991). Summary Report on Phase I R&D Program. Roadway Powered Electric Vehicle Project. RPV-091-088. July 15, pages 1- 21

The Playa Vista roadway powered electric vehicle project, launched in January 1990 with funding from Southern California Edison and the City of Los Angeles, Department of Water and Power, has centered on advancement of the technology that was developed under PATH at UC, Berkeley. A 1000 ft powered roadway and test facility were laid out on the Playa Vista site for the purpose of adapting RPEV technology.

In June 1990, the project was redirected to investigate EMF induced noise in conventional vehicles traveling over the roadway. Construction plans were set aside, and a one year R&D redesign and prototype program was initiated.

HR Ross Industries, Inc. (1994). USCD Field Test & Demonstration Project. Highway Electrification & Automation Development Program, FTDP-RPEV-094-001. May 1, pages 1 - 38

The roadway powered electric vehicle encompasses distributed power in the roadway, a non-contacting inductive energy transfer technique, a high specific-power energy storage system on the vehicle, and power electronics onboard the vehicle for control and management of the energy. Development of the system has been underway in the US since 1979, centered principally in California. Over 10 million dollars of R&D has been provided by federal, state, and local governments as well as the private sector. A midsize bus and electric van have been built, and short sections of powered roadway built for test and demonstration purposes.

Current focus of the development effort is in San Diego, with a project funded by FHWA totaling 1.5 million dollars. A vehicle and test facility were built in 1994. The works has been carried out by HR Ross Industries, Inc. under contract form Caltrans.

The purpose of this document is to propose a field test and demonstration project for the University of California, San Diego (USCD) campus, which will entail three electric busses, a wayside power supply charging station, and two charging pads at pull out areas at the southern end of the campus. These vehicles will operate in conjunction with conventional ICE buses which will also operate along the route.

Johnsee Lee, Tummillo, Miller, Hornstra, and Christianson (1986). Capacity and Peak Power Degradation of Lead - Acid Battery Under Simulated Electric Vehicle Operations. CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 151 - 156

In the program supported by the Electric Power Research Institute, controlled laboratory tests were conducted at Argonne to evaluate the effects of selected EV application factors on the performance and life of the EV - 2300 lead - acid battery. These application factors include simulated driving profile discharges with different levels of peak power demands for vehicle acceleration, long rest times after charge or discharge, and different methods of recharging. The performance and life variations among cells and modules in a full scale battery pack were also examined. Statistical methods were used to analyze the laboratory test data. The key factors affecting the performance and life of the battery were identified, and the rates of capacity and power degradation were quantified using multiple regression techniques. The analyses show that the most significant factors were peak power demand levels and cell location within the six - cell modules. The effects of charge method and rest times were found to be small.

Kacher, Georg (1994). Mercedes - Benz Vision A 93. *Automobile*, March, pages 66 - 67

Even for the maker of the mighty S-class, small is suddenly beautiful. This article is a brief review and test drive of the Mercedes - Benz Vision A 93 developmental electric car which is intended for production.

Kaiser, R. and Graver, C. (1980). Analysis of the Infrastructure for Recharging Electric Vehicles. SAE Paper 800112

Three infrastructure alternatives are examined: (1) transient recharging stations, where the EV recharged while the owner is at work; (2) battery swapping stations, which replace discharged with fully charged batteries; and (3), hybrid vehicles, which have a small internal combustion engine (ICE) in addition to the electric engine, for range extension.

Kalberlah, A. (1991). Electric Hybrid Drive Systems for Passenger Cars and Taxis. SAE Paper 910247

Various hybrid drive configurations are described and their advantages and disadvantages for application in passenger cars are discussed; specifically, these are the series hybrid, the parallel hybrid, hybrid drives with added torque and speed, single and two shaft hybrids.

The Volkswagen and Audi group has developed different vehicles with hybrid drive for various applications. These vehicles are described and test results are presented on their energy consumption, emissions and driving performance. In conclusion, some considerations are pursued concerning their chances on the market in different scenarios.

Kobe, Gerry (1993). EVs Unplugged ? *Automotive Industries*, March, page 38

Domestic EV purchasing programs are on "hold." The question is: Will they ever come back ? Automobile manufacturers have decided that they can not produce viable electric vehicles to compete with internal combustion engine vehicles until a suitable power source

exists. Current battery technology has lagged behind vehicle development, and manufacturers have spent billions on their EV programs without suitable results.

Kobe, Gerry (1993). What if Electric Vehicles Don't Sell ? *Automotive Industries*, April, pages 33 - 35

The California Air Resources Board say EVs will sell if the price is right. Auto makers fear they may not sell at all. Current electric vehicle technology does not compete with their ICE vehicle counterparts. Battery technology has limited EVs from becoming viable alternatives to today’s cars. Auto makers have spent billions to develop EV technology and they must have these vehicles for sale in 1998, but their biggest fear is that the expense, limited performance, and lack of an associated electric vehicle infrastructure will chase the consumer away.

Kobe, Gerry (1992). Point of Impact. *Automotive Industries*, July, pages 40 - 43

GM explodes the myths surrounding its electric vehicle program. This article discusses the GM electric vehicle program and uncovers the myths about electric vehicles. Issues of electric vehicle conversions, the DC motor as opposed to the AC motor and its inverter losses, the lead acid battery, utilities and power supply limitations, and infrastructure problems associated with electric vehicle technology.

Lashkari, K., et al. (1986). Inductive Power Transfer to an Electric Vehicle . CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 256 - 265

This paper explains the technology of the RPEV system, in which energy is transferred inductively from an inductor buried just beneath the road surface, across an air gap, to a vehicle which can be stationary or moving. The electrical characteristics of this unique EV system are explained in terms of an equivalent circuit model and phasor plots. The trade-offs inherent in the design of the system are explained , and the performance of the system is described on the basis of both analytical predictions and results of testing the full - scale equipment. The ability of the system to transfer power from the roadway to vehicle without mechanical contact is also demonstrated.

Lechner and Shaldover (1986). The Roadway Powered EV An All - Electric Hybrid System. CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 248 - 255

This Paper describes the design and development of the roadway powered electric vehicle (RPEV), a hybrid system that includes an onboard energy storage device and a system for inductively transferring energy to the vehicle. The paper explains how the RPEV system can provide a battery vehicle with essentially unlimited range, using as an example the design, development, and testing of a prototype electric bus system for Santa Barbara, CA. The system design issues and trade-offs are explained, with particular emphasis on the energy budget that ensures a full day of vehicle operation. Results of testing of the prototype vehicle are used to demonstrate the feasibility of the technology, and future directions for the development of the RPEV technology are indicated.

Lipkin, Richard (1993). Firing Up Fuel Cells: Has a space-age technology finally come of age for civilians ? *Science News.* Vol. 144, November 13, pages 314 - 318

The fuel cell - which generates electricity, heat, and water by combining hydrogen and oxygen has been around conceptually for more than 150 years. Fuel cell technology, first used in the 1960s, is finally branching out from space and defense missions and into the public sector. The future holds fuel cell powered power plants, transportation systems, and individual homes. Phosphoric acid fuel cells are the furthest developed for commercial use, but engineering hurdles like hydrogen storage and high cost has held fuel cells back. New advancements have led to lower costs and hydrogen storage problems are being resolved to silence skeptics.

Lyman, Jane W. and Palmer, Glenn R. (1993). Investigating the Recycling of Nickel Hydride Battery Scrap. *JOM*, May, pages 32 - 35

New nickel hydride alloys have been developed to replace the cadmium containing negative electrodes of nickel cadmium batteries. The new, cadmium-free alloys promise enhanced electrochemical properties as well as reduced environmental toxicity. Rechargeable batteries using nickel hydride electrodes are strong candidates for electric vehicle applications. The US Bureau of Mines is investigating hydrometallurgical technology that separates and recovers purified metallic components present in nickel hydride battery scrap. A preliminary investigation of acid dissolution and metal recovery techniques using whole batteries and electrode rolls has shown potential options that will allow the successful recycling of much of the battery fabrication scrap.

Markus, Frank (1994). The Electric Tropica. Car and Driver, March, pages 95 - 97

Finally a battery powered car that promises little, and delivers more. This article describes the features of Renaissance Cars Inc. of Florida electric Tropica roadster. The article includes a full road test of the vehicle.

McCosh, Dan (1991). BMW's Electric Debut. *Popular Science*, Automotive Newsfront, December, page 27

News clip on new BMW E1 electric vehicle prototype introduced at the Frankfurt Auto Show in the fall of 1991. The article includes vehicle specifications, dimensions, design features and performance and range projections.

McGee, Daniel W. (1992). Electric Turbine Drives HEVs into the Future. *Electrical Manufacturing*, January / February, pages 8 - 10

Recent innovations in electromechanical design have resulted in the electric turbine, which offers the advantages of DC brushless servo motors and a traction torque curve similar to DC brush series motors, but is produced with the low fabrication costs associated with induction motors. The electric turbine offers a prospect for direct drive in an automotive power system.

Mead, John T. (1994). The Impact of Electric Vehicle Battery Charging on the PG&E Distribution System. Report 008.1-93.20. April

The load level requirements for EV charging can either be a positive or negative contribution to the distribution asset question. If charging occurs during peak hours, negative contributions result; if charging occurs during off peak hours, a positive contribution would

result. the objective of this study is to investigate the potential impacts of EV charging on PG&E ‘s electrical distribution systems. A brief discussion on EV use and EV charging profiles is also included.

Miller, Mark A., Dato, Victor, and Chira-Chavala T. (1992). Emissions Impact of Roadway-Powered Electric Buses, Light-Duty Vehicles, and Automobiles. In *Transportation Research Board 71st Annual Meeting*, pages 1 - 46

Changes in pollutant emissions as a results of adopting roadway powered electric busses, Light Duty Vehicles, and automobiles in California are analyzed. The analysis involves comparing emissions of hydrocarbons, carbon monoxide, oxides of nitrogen, oxides of sulfur, and particulate matter in grams per vehicle mile of travel, between RPEVs and ICEVs. The comparison is based on the assumption that RPEVs and ICEVs are operated under identical conditions. Findings indicate that significant reductions in emissions of HC and CO can be expected from the adoption of RPEVs, while fluctuations between emission increases and reductions are likely for NOx, SOx, and PM depending on energy consumption by vehicle type, the split between roadway / battery power usage, and proper flow efficiencies from the power plant to the roadway.

Moore, Taylor (1991). The Push for Advanced Batteries. *EPRI Journal*, April / May, pages 16 - 19

The widespread success of electric vehicles depends primarily on the development of advanced batteries that can deliver improved driving range and performance. While the earliest EVs on the road are likely to operate on large packs of conventional lead acid batteries, researchers are exploring advanced batteries based on sodium sulfur, lithium-metal sulfide, and even more exotic electrochemical combinations; the goal is to commercialize the most successful of these later in the decade.

Moore, Taylor (1994). Producing the Near - Term EV Battery, *EPRI Journal*. April / May, pages 7 - 13

Advanced, affordable batteries will be essential for making electric vehicles practical, and the utility industry, through EPRI, is a participant in the US Advanced Battery Consortium, which is pursuing mid - and long-term battery technologies. For the near term, EPRI is in a strategic alliance with a recently formed joint venture to manufacture an advanced lead-acid battery that could be the first on the market. Expected to be in commercial production by next year, the Horizon® battery promises to deliver substantially greater range and acceleration than today’s lead-acid batteries and to offer the capability for quick charges.

Moore, Taylor (1993). Battery Charging for Electric Vehicles. *EPRI Journal*, June, pages 6 - 17

With significant numbers of electric vehicles expected to hit the road before the end of the decade, the push is on to develop the infrastructure-especially battery-charging systems- that will allow EVs to become a major part of the nation’s transportation picture. The vision calls for simple, convenient recharging not only at home but on the road and perhaps right in your daily parking space. Smart charging systems now in development will improve on currently available plug-and-cord chargers, and a number of utilities are conducting recharge demonstration projects to gain experience before large numbers of EVs roll of the production lines. While the need for safety, common standards, and equipment capability is clear, load

growth and the impact of charging vehicles during peak demand periods will also become issues as the population increases.

Morcheoine, Alain and Chaumain, Gerard (1992). Energy Efficiency, Emissions and Costs; What are the Advantages of Electric Vehicles ? *The Urban Electric Vehicle*. Presented at International Conference on the Urban Electric Vehicle: Policy Options, Technology Trends, and Market Prospects (Stockholm, Sweden). Paris: Organisation for Economic Cooperation and Development, pages 115 - 124

Are electric vehicles an attractive solution to the acute problems of energy consumption and pollution engendered by transport in our cities ? In order to try and answer this question, this article compares electric vehicles and their internal combustion engine counterparts in several areas.

Energy efficiency and emissions of pollutants are compared. The influence of the structure of electricity generation is examined, as well as pending changes in the quality of diesel fuels. The article looks at the problems of acquisition and operating costs. We outline the philosophy which has determined French public action in support of the penetration of electric vehicles. A brief general conclusion points our the main technical, economic and political problems.

New York State Thruway Authority (1993). New York State 2 Year R&D Program Highway Electrification and Automation Development Program. New York State Technical Prospectus - Draft, September 30

Technical prospectus on NYS plan to adapt a test roadway to provide RPEVs and determine design strategies, environmental impacts, power requirements, and safety hazards.

O'Connell, Lawrence G. (1992). Infrastructure Considerations for Electric Vehicles . SAE Paper 921539

The potential benefits of EVs have prompted legislation mandating EV use in areas with air quality problems. For example, California's legislation requires auto makers to begin selling EVs in the state in 1998. In response, the utility industry is working to establish a national recharging infrastructure to provide the elements necessary to make EV use safe and convenient. Infrastructure components include connecting standards and hardware, convenient residential and public charging stations, safety standards and procedures, utility load management controls, and educational material. This paper discusses infrastructure issues and describes the work being conducted under the Electric Power Research Institute's research program.

Ovshinsky, S. R., Fetcenko, M. A., and Ross, J. (1993). A Nickel Metal Hydride Battery for Electric Vehicles. *Science*. Vol. 260. No. 9, April, pages 176 - 181

Widespread use of electric vehicles can have significant impact on urban air quality, national energy independence, and international balance of trade. An efficient battery is the key technological element to the development of practical electric vehicles. The science and technology of a nickel metal hydride batter, which stores hydrogen in the solid hydride phase and has high energy density, high power, long life, tolerance to abuse, a wide range of operating temperature, quick charge capability, and totally sealed maintenance free operation, is described. A broad range of multi-element metal hydride materials that use structural and compositional disorder on several scales of length has been engineered for use as the negative electrode in this battery. The battery operates at ambient temperature, is made from nontoxic materials, and is recyclable. Demonstration of the manufacturing technology has been achieved.

Porter, David F. (1986). The Role of Electricity Supply Industry in the Market Development of Advanced Battery Electric Commercial Vehicles. CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 301 - 305

This paper reviews the development of advanced electronic commercial vehicles and the support being given by the electricity supply industry for their market and development. Already 300 production vehicles have been purchased by Electricity Boards and a further 200 will be purchased in the coming year. A comprehensive marketing program is aimed at generating vehicle sales to fleet operators and a wide variety of promotional activities are undertaken. The industry is continuing its investment in the development of the NaS (Beta) battery with a view to further substantial market expansion.

Prans, G. and Chaya Jr., H. (1986). The Characteristic Warm-up Distance of an EV in City Driving and Its Dependence on Air Temperature. CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 467 - 471

A 1980 Ford Fairmont station wagon EV was tested on a 1.104 - mile city street "track " in NYC. Data acquired during each lap was used to calculate the battery electrical energy expended per lap, EB/LAP, of the track. It was found that EB/LAP varied with distance driven , x (in laps), as EB/LAP (x) = A + B[exp(-x/L)] (Wh/lap). For each day's data , values of A, B, and L could be found such that the function fit all data to within three percent. EB/LAP(x) varied with controller type, tire type, and air temperature. The overall decrease in EB/LAP(x) from the first lap to the 20 th lap was as much 15 percent on any one day.

Pratt, Gill Andrews (1992). EVs On the Road Again. *Technology Review*, Vol. 95, No. 6, August / September, pages 50 - 59

Electric vehicles have failed before. But they're making a come back and this time the prospects are better. In 1976, the gas crises initiated the US Department of Energy to enact the Near Term Electric Vehicle Program to quickly develop a practical electric car. Concepts were developed, but gasoline prices began to fall and automobile manufactures started designing smaller, more efficient vehicles, the electric car programs were abandoned.

Recently, however, growing air pollution has renewed interest in electric vehicle technology as a way to improve air quality standards in urban areas of the US. In addition, the California Air Resources Board (CARB) has mandated that by 1998, two percent of all the light duty vehicles sold in California be zero-emissions vehicles. Several Northeastern states have adopted CARB standards as well, making it essential that major auto-makers have viable ZEVs on the road. This article describes current electric vehicle and battery technologies along with the emissions and energy consumption problems that we face in this country.

Rahman, S. and Shrestha, G. B. (1993). An Investigation into the Impact of Electric Vehicle Load on the Electric Utility Distribution System. *IEEE Transactions on Power Delivery*. Vol. 8. No. 2. April, pages 591 - 597

The electric utilities interest in electric vehicles lies in the anticipated / expected benefits beyond the simple increase in energy sales. It is expected that the EV load will be contained within system off-peak hours without affecting the peak demand, thus increasing the sale of low cost electricity. However, the impact of electric vehicle charging on the energy and power demand is determined not only by the number of EVs in use and their usage pattern, but also by the number of EVs being charged at an instant and the charging profile of the battery module. The daily energy consumption by an EV will be limited by the range / cycle and the charging time, while its impact on the system demand will depend on the hour and pattern of charging. The case studies in this paper have revealed several important issues regarding the impacts EV load may have on utility distribution systems. Firstly, it is not adequate to have only sufficient generation capacity during off-peak hours to assure a system’s ability to absorb EV loads without adverse effects. The constraints at the distribution level must be studied properly. Secondly, a sizable EV load can introduce a new peak in the early off-peak period. It may have scheduling implications, and completely throw any load management programs off balance. Thirdly, at the present state of EV technology, including those of battery modules and chargers, a typical distribution system may not be able to supply EV loads beyond 20 percent penetration level. This constraint is created by the long (up to 12 hours) charging cycle of batteries.

Rajan, Arvind, V. (1993). Do Electric Vehicles Really Provide a Solution to the Urban Pollution Crises ? Brochure, Solectria Corporation, June

Electric vehicles are being cited with increasing regularity as the answer to the air pollution problems that are plaguing the urban areas of the United States. California, Massachusetts and other states have already mandated that by 1998, two percent of vehicles sold will have to be zero-emissions vehicles; other states are on the verge of adopting similar legislation. The only vehicles that meet this criteria are electric vehicles.

Rajan, Arvind, V. (1993). Electric Vehicles and Energy Consumption. Brochure, Solectria Corporation, June

Electric vehicles have been touted in recent years as a solution to the air quality problems of America's cities. They also offer other important benefits. A shift to electric power will allow the country to diversify its energy mix; currently, 95 percent of the energy consumed by the transportation sector comes from oil. Recent evidence gathered by the Southern California Edison, the Electric Power Research Institute, and others has demonstrated that electric vehicles are also considerably more efficient than gasoline powered vehicles, and hold the promise of significantly decreasing the nation's energy consumption.

Reynolds, Kim (1992). AC Propulsion CRX: Harbinger of things electric. *Road & Track*, October, pages 126 - 129

Description and road test of an AC Propulsion, Inc. converted Honda CRX electric car that is not intended for production but rather to showcase their know how. This article includes vehicle specifications, acceleration measures, braking requirements, and range capabilities of the AC CRX.

Riezenman, Michael, J. (1992). Electric Vehicles: The Great Battery Barrier. *IEEE Spectrum*, November, pages 97 - 101

The biggest obstacle by far to the success of electric vehicles - inadequate energy storage capacity - is under attack. Comparison of current battery technologies and roadblocks. Discussion of current level of EV battery research and the possible battery alternatives for the future.

Riezenman, Michael, J. (1992). Electric Vehicles: Why Now ? Pursuing Efficiency. *IEEE Spectrum*, November, pages 18 - 24,93

The California Air Resources Board (CARB) has brought a renewed interest in EVs by mandating automobile manufacturers to produce zero emissions vehicles (electric vehicles) in the state of California ranging from two percent of the vehicle fleet in 1998 to ten percent by 2003. The adaptation of California emissions standards by nine Northeastern states has manufacturers scrambling to get EVs on the road. Current limitations of EVs, poor acceleration, limited range, high initial cost, and recharge time, have thus far prevented EVs from being a viable alternative to internal combustion engine vehicles. Recent advancements in electric vehicle design - aerodynamics, lower tire rolling resistance, new AC motors and motor control technology, regenerative braking, and climate control advances - have brought them closer to production, but battery technology has been the limiting factor.

Riezenman, Michael, J. (1992). Electric Vehicles: Architecting the System. *IEEE Spectrum*, November, pages 94 - 96

Standardized charging hardware and procedures must be put in place before the first electric vehicles go on sale in the mid - '90s. The infrastructure exists today for the ICE vehicle, at the dawn of the automobile, this was not the case. For EVs to be accepted, it is essential that a similar infrastructure be established. The responsibility rests with the government and localized utility companies as well as private organizations and home owners.

Roan, Vernon P. (1992). A Study of Potential Attributes of Various Fuel Cell - Powered Surface Transportation Vehicles. SAE Paper 929134

A parametric study was made to compare the potential benefits and liabilities of powering various surface transportation systems with fuel cells. It was found that while the potential fuel savings are greatest for automobiles and light trucks, economics and packaging considerations favor initial applications in locomotives, long distance trucks, and buses. It was further shown that for the alternative fuels likely to be used, infrastructure requirements also favor the commercial vehicles over the personal vehicle. However, the potential benefits to energy conservation and atmospheric pollution reduction are so great that major efforts should continue to adapt fuel cells and alternative fuels to personal vehicles as well as commercial vehicles.

Rudd, E. J. (1989). The Development of Aluminum - Air Batteries for Electric Vehicles. SAE Paper 891660

The aluminum - air battery has unique features that make it an attractive candidate as a power source in an electric vehicle. The energy and power densities of the battery can provide driving ranges comparable to those of the internal combustion engine. The battery is a multi-component system as will be described and any development program must face several challenges: (a) the need for high performance electrodes (b) a cell design that allows rapid replacement of an anode and (c) separation of the solid product from the electrolyte.

Saints Road Project (1993). Husky Bus Shuttle Project Development Program. Brochure, Saints Road Project

Description of Saints Road Husky Bus Shuttle Project in Minnesota and the E-TRAN electric "trolley" technology that is being developed for it.

Samuel, Sir John (1992). The Clean Air LA 301 Electric Vehicle for the Los Angeles Vehicle Initiative. *The Urban Electric Vehicle*. Presented at International Conference on the Urban Electric Vehicle: Policy Options, Technology Trends, and Market Prospects (Stockholm, Sweden). Paris: Organisation for Economic Cooperation and Development, pages 317 - 330

A number of mule test vehicles and two semi-engineered prototype four seater electric hybrid passenger cars - code named LA 301 - have been built and are now under development for Clean Air by International Automotive Design of Worthing, England. Features of the LA 301 are described together with some performance and energy efficiency forecasts.

Schrieber, Shaltens, and Beremand (1992). Electric and Hybrid Vehicle Study Utilizing a Time-Stepping Simulation. SAE Paper 929136

This paper describes a study performed to assess the applicability of NASA's advanced power technologies to electric and hybrid vehicles. In support of this study, a time-stepping computer simulation was developed to model electric and hybrid vehicles operating over the Federal Urban Driving Schedule (FUDS). Variations in vehicle configuration and subsystem specifications are possible. By the nature of a time-stepping simulation, both the energy and power demands of FUDS are taken into consideration, consequently vehicle economy, range and performance are addressed simultaneously. Features of the LeRC simulation include options to evaluate abrupt power requirements such as 0 - 30 mph and 0 - 60 mph acceleration times, and for the user to create, store and edit alternate driving cycles. A description of the simulation is presented along with initial results of the study.

Simanaitis, Dennis (1993). Volvo ECC: A brief drive into a turbine / electric future. *Road & Track* , June, pages 120 - 123

The ECC represents Volvo's attempt at a series hybrid EV using a turbine engine to generate power for the battery to drive the electric motor. This vehicle offers good performance and range (in hybrid mode) while exceeding CARBs upcoming ULEV emissions standards. In electric mode, the vehicle performance is poor by ICE standards with rage limited to 50 to 90 miles.

Simanaitis, Dennis (1992). Electric Vehicles. *Road & Track*, May, pages 126 - 136

Overview of current electric vehicles and battery technology. Performance measures of batteries and EVs given. Discussion of CARB mandated EVs in California by 1998.

Simanaitis, Dennis (1992). California Dreamin': Can car enthusiasts find happiness in a world of TLEVs, LEVs, ULEVs, and ZEVs. *Road & Track*, March, pages 91 - 95

Discusses upcoming emissions standards in California and the Northeastern states that have adopted CARB standards and how automotive engineers and designers will cope with these changes, and how car enthusiasts will have to deal with them.

Simanaitis, Dennis (1993). Ford Ecostar Electric. *Road & Track*, February, page 39

The first EV you're likely to see is the most transparent we've driven so far. This article features a brief test drive review of Ford Ecostar converted electric vehicle. The reviewer finds that the vehicle performance is similar to the European Escort van on which its based until it comes time for refueling. The prototype driven had led acid batteries while Ford intend to use sodium sulfur batteries for production due to their high energy densities which will extend the range of the vehicle.

Simanaitis, Dennis and Reynolds, Kim (1994). Ford Ecostar Electric. *Road & Track*. August, pages 96 - 100

Plug in, turn on - if we can afford it. Road & Track evaluated a Ford Ecostar electric van for five weeks. What follows is a combination of a technology update, road test, and a semi-long-term wrap up of the vehicle. Ecostar mechanicals and performance parameters are discussed along with a driving impression of the vehicle.

Siuru, Bill (1991). Electric Vehicles: Getting the Lead Out. *Mechanical Engineering*, December, pages 36 - 41

Purpose built EVs have improved safety, performance, and creature comforts compared to cars that have been converted to electric power. However, they cannot become viable competition until their economics are more in line with internal combustion cars.

Small, Charles H. (1992). Nickel-Hydride Cells Avert Environmental Headaches. *EDN*, December 10, pages 156 - 161

After 20 years as the reigning king of rechargeable cells, nickel cadmium may be deposed by nickel-metal hydride because of environmental concerns and the need for greater energy density. This article includes a review of nickel-hydride battery technology and comparisons with other popular secondary battery systems including, NiCd, lead-acid, and lithium batteries. The main driving forces behind NiMH technology are its excellent energy density and cycling performance characteristics and its safe, reliable, environmentally friendly operation.

Smith, Kevin (1993). Electric Aesop. *Car and Driver*, March, pages 100 - 103

Welcome to the world of electric cars. If speed kills, we'll live forever in these things. Road test of a Toyota Paseo converted to a lead acid battery powered electric vehicle by Solar Electric Engineering of Santa Rosa, California. This article contains a complete review of the SEE Electric Aesop including, acceleration parameters, braking distances, and range measures.

Smith, Kevin (1994). Life With an Electric Ford. *Car and Driver*. September, pages 147 - 155

We find that good electric vehicles might actually have a place in this world. But precisely where, we're not quite sure. The article reviews the performance, driveability and practicality of the Ford Ecostar. The vehicle is found to work as advertised: a 70 mph freeway speed, a 100 mile plus operating range, and a six to seven hour recharge time on a 240 volt circuit, along with refinement and user-friendliness. The main problem is cost. The Ecostar currently costs $100000 dollars for a 30 month lease, and the sodium sulfur battery pack requires replacement about every two years with the current cost estimate being $46000. To meet California mandates, Ford assumes that $1500 would have to be added to the price of every vehicle it sells in California to bring the Ecostar's price to $20000. A brief overview of the sodium sulfur battery technology used in this vehicle is also presented.

Society of Automotive Engineers (1992). Battery and Electric Vehicle Technology Update. *Automotive Engineering*, September, pages 17 - 25

Overview of current electric vehicles and battery technology. Performance measures of batteries and EVs given. Discussion of CARB mandated EVs in California by 1998.

Society of Automotive Engineers (1994). SP-1023, Advancements in Electric and Hybrid Electric Vehicle Technology. SAE Papers 940293-940298, 940336-94340, 94510, 940556-940557. Available from Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096-001, USA, February

A series of papers collected at SP-1023, Advancements in Electric and Hybrid Electric Vehicle Technology.

Society of Automotive Engineers (1993). SAE J227a Electric Vehicle Test Procedure. SAE Handbook, Vol. 4, Sections 27 - 43, *On Highway Vehicles & Off - Highway Machinery*, pages 28.01 - 28.06

Standard Electric Vehicle Test Procedure as defined by the SAE

Solectria Corporation (1994). Solectria E-10 Fleet Pickup. Brochure Available from Solectria Corporation, 27 Jason Street, Arlington, MA 02174, (508) 658 - 2231

Brochure on Solectria E-10 electric pickup conversion.

Solectria Corporation (1994). Solectria Force. Brochure. Available from Solectria Corporation, 27 Jason Street, Arlington, MA 02174, (508) 658 - 2231

Brochure on Solectria Force electric car conversion.

Stix, Gary (1992). Electric Car Pool. *Scientific American*. May, page 126 - 127

Automakers consort on advanced batteries. With the passage the CARB mandates requiring automobile manufacturers to produce viable electric vehicles for sale by the year 1998 and the adoption of California mandates by several northeastern states, a push has begun for the development of advanced batteries to power these EVs. Currently, electric vehicle performance has been limited by battery technology. To combat this issue, Chrysler, Ford, and General Motors along with the Electric Power Research Institute formed the United States Advanced Battery Consortium to quickly develop battery technology for use in electric vehicles. This article goes on to describe the goals and battery technologies currently being funded by the USABC.

Stodolsky, Frank (1989). Safety Considerations for Sodium-Sulfur Batteries for Electric Vehicles. SAE Paper 891693

Safety issues and current transport (shipment and in vehicle use) and environmental regulations applicable to sodium-sulfur batteries for electric vehicles are summarized, and an assessment technique is suggested for evaluating potential hazards relative to commonly accepted risks. It s found that shipment regulations do not directly apply to sodium-sulfur batteries. Disposal hazards need to be quantified and decommissioning procedures need to be developed to comply with the environmental regulations. The risk assessment could be used to help commercialize sodium-sulfur and other advanced batteries in electric vehicles.

Swan, D.H. (1989). Fuel Cell Powered Electric Vehicles. SAE Paper 891724

Fuel cell powered electric vehicles have the potential of replacing internal combustion powered vehicles if the problem of low power density and high cost can be overcome. Future cost and performance estimates for proton exchange membrane fuel cell power systems are compared with internal combustion power systems. Specific areas of research for fuel cell power systems are suggested.

Takehara, Zen-Ichiro and Kanamura, Kiyoshi (1993). Historical Development of Rechargeable Lithium Batteries in Japan. *Electrochemica Acta*. Vol. 38. No. 9, pages 1169 - 1177

The rechargeable lithium battery is very attractive for new applications, such as power supply for the electric vehicle and energy storage in the home. In this paper, the technology of the rechargeable lithium battery, which has been developed in japan, is reviewed in the following terms: (1) the electrochemical characteristics of various cathode materials, especially metallic oxide cathodes; (2) lithium metal and graphite as anode materials; (3) the problems of the liquid and solid electrolytes were considered.

Tanaka, Norimasa (1989). The Important Role of Electric Vehicles in Reducing Air Pollution. Vol. 8, No. 1, February, pages 17 - 18

In Japan, air quality has been generally improved over the past decade or two. In large cities, however, trends in nitrogen dioxide have shown only slight decline and air quality does not meet the environmental standards at a considerable portion of roadside monitoring stations. The Environmental Agency conducted an analysis of the reasons for the delay in improving air quality and concluded that it was largely attributable to failure in reducing air pollution from vehicle exhaust emissions sufficiently to achieve their goal. Encouraging the use of electric - powered and other low - pollution vehicles is important from a long - term point of view.

Tikkanen, H. and Oy, N. (1986). On-Road Performance of an AC - Drive Passenger EV. CONF - 8610122 E1.99:DE87 010697. Presented at VIII International EV Symposium USDOE Washington, DC, pages 527 - 528

An AC - Drive passenger EV has been developed by a group of Finnish companies. The design and technology of this car is described and the results of the on-road performance measurements are presented and discussed.

US Electricar (1994). US Electricar Sedan. Brochure. Available from US Electricar

Brochure on US Electricar Sedan conversion.

US Electricar (1994). US Electricar Pickup. Brochure. Available from US Electricar

Brochure on US Electricar Pickup conversion.

US Electricar (1994). US Electricar Sport Coupe. Brochure. Available from US Electricar

Brochure on US Electricar Sport Coupe conversion.

Vaughn, Mark (1994). The Silence is Shocking. *Autoweek*, April 11, pages 41 - 42

Backers of solar and electric motorsports hope for a quiet revolution on the racetrack. This article reviews the fourth annual APS Solar Electric 500 at Phoenix International Raceway.

Wallace, John R. (1992). Government Policies to Ease Market Introduction of Electric Vehicles. *The Urban Electric Vehicle*. Presented at International Conference on the Urban Electric Vehicle: Policy Options, Technology Trends, and Market Prospects (Stockholm, Sweden). Paris: Organisation for Economic Cooperation and Development, pages 387 - 398

The electric vehicle is viewed as a desirable addition to the transportation fleet throughout the world because it is the most environmentally benign choice of fuel, especially for urban areas. The technology of the vehicles and the infrastructure to support them, however, are new to the marketplace, and new technologies almost always carry the burden of higher cost and uncertain market demand.

Widespread acceptance of the electric vehicle will progress faster if appropriate polices are implemented to enhance their value for the customer. Governments throughout the world have an opportunity to support this emerging technology by playing a vital role in the development of EV standards, including new building codes, safety requirements, and uniformity for measurement of performance. They can also help formulate friendly laws and regulations to encourage electric vehicle ownership. Not only are purchase incentives needed, but the supporting infrastructure for recharging and service must be visible as well.

Wang, DeLuchi, and Sperling (1990). Emissions Impacts of Electric Vehicles. *Journal of the Air and Waste Management Association*, Vol. 40, pages 1275 - 1284

Alternative vehicular fuels are proposed as a strategy to reduce air pollution. In this paper, we analyze the emission impacts of EVs in CA for two target years, 1995 and 2010. We consider range assumptions regarding electricity consumption of EVs, emission control technologies for power plants, and the mix of primary energy sources for electricity generation. We find that, relative to continued use of ICE vehicles, the use of EVs would dramatically reduce CO and HC. Under most conditions, NO_x emissions would decrease moderately. Sulfur oxide and particulate emissions would increase or slightly decrease. Because other areas of the US tend to use more coal in electricity generation and have less stringent emissions controls on power plants, EVs may have less emission reduction outside California.

Wang, Quanlu and Santini, Danilo L. (1993). Magnitude and Value of Electric Vehicle Emissions Reductions for Six Driving Cycles in Four US Cities with Varying Air Quality Problems. ANL/ES/CP-77429 DE93 006417. Presented at the 72nd Annual Meeting of Transportation Research Board, January 10-14, Washington, DC, pages 1-28

The emissions of logically competing mid 1990 gasoline vehicles and electric vehicles are estimated as if the vehicles were driven in the same pattern of driving. Six different driving cycles are evaluated, ranging in speed from 7 to 49 miles per hour. These steps are repeated using specifics of fuel consumption, electric power mix, and environmental conditions applicable to Chicago, Denver, Los Angeles, and New York in the month of July. The year 2000 emissions differences for each of four regulated pollutants - HC, CO, NO_x, SO_x - are estimated. CO_2 emissions are also estimated. With the use of EVs, HC and CO emissions are consistently lowered by 98 percent or more. Across metro areas, CO_2 emissions reductions are uniformly large at low speed, but variable at high speed. It is found that initially introduced EVs could achieve 100 percent emissions reductions in Chicago by using off peak power from nuclear power plants for EV electricity generation. Emissions reductions occur for all combinations in Los Angeles, and for most combinations in New York, excepting SO_x. NO_x emissions are reduced for all four cities.

An “avoided cost” value in $/ton/year of emissions reductions for each regulated pollutant is estimated for each of the cities. The values for each city depend on severity of air quality violations. An estimate of annual emissions reductions over the vehicle lifetime as a function of year 2000 values is developed. The annual emissions reduction value of substituting a mid 1990s EV for a GV for each speed in each city is estimated. Depending on the driving conditions assumed and emissions speed correction factor used, it is estimated that the emissions reduction value of EVs driven an average of one and one half hours per day in Los Angeles ranges from $1050 to $3900; $590 to $2100 in New York; $270 to $1200 in Chicago; and $330 to $1250 in Denver (1989$). Assuming a range of about 100 miles in congested conditions with speeds of 10 mph or less, commercial use EVs driven 7.5 hours/day 200 weekdays per year would realize emissions reduction values 3.42 times greater for low speed driving conditions. In this case, assuming a New York City driving cycle averaging 7.1 mph, the estimates range from $3600 to $13300 for Los Angeles; $2004 to $7200 for New York; $930 to $2930 for Chicago; and $1120 to $4290 for Denver. Low estimates are obtained using EPAs draft Mobile5 model for GV emissions, high values using California’s EMFAC7EP-SCF1 model. These two emissions models are preliminary. The dollar value benefit estimates include no economic value for changes in CO_2 emissions. The sensitivity of emissions dollar value versus vehicle hours of operation estimates to $/ton/yr. values is not evaluated.

Watson, Gyenes, and Armstrong (1986). A Refueling Infrastructure for an All-Electric Car Fleet. Transport and road Research Laboratory. Department of Transport. Research Report 66

The refueling infrastructure required if Great Britain’s 14 million cars were replaced by battery-electric cars has been estimated, using computer simulation, for three advanced battery types. The calculations used electric car designs with approximately the performances of today’s cars and carrying out today’s journey patterns.

The infrastructure consisted of changing points at own premises, at other parking locations (opportunity charging), and battery exchange stations on motorways, trunk and principal roads. Its main characteristics were found to be that 80-85 per cent of the energy would be obtained at own premises, 10 per cent by opportunity charging, and 5 - 10 per cent by battery exchange; the use of own premises and opportunity charging would reduce total infrastructure costs substantially; considerable latitude in the opportunity charging infrastructure would be possible without altering effectiveness or total cost.

Its annual cost would be 270- 630 million depending on battery type. This would be less than 5 per cent of the electric car system costs.

Whitehead, Gerald D. and Keller, A. Scott (1991). Performance Testing of the Vehma G Van Electric Vehicle. SAE Paper 910242

This paper presents the results of performance characterization testing of two prototype Vehma G Van electric vehicles. Testing was performed at the Electrotek Electric Vehicle Test Facility as part of the Electric Power Research Institute / Electrotek EV Program. The G Van is a GMC full sized van converted to electric propulsion by Vehma International of Toronto, Ontario. One of the vans tested at the EVTF was a five passenger model, the other was a two seat cargo van. These vehicles utilize tubular plate lead acid batteries and dc power train system components produced by chloride EV Systems of Redditch, England. Performance testing was conducted according to the EPRI/ Electrotek EV Test Plan and included measurement of driving range at 56 kmh, on the SAE J227a C cycle, and the Electrotek defined Urban route. Vehicle top speed, maximum acceleration, dc and ac energy consumption, hill climbing, and braking capabilities were also measured. A series of product improvement tests were then conducted. These tests compared driving between the original equipment passenger van and the same van that was modified by changing tire type and pressure, and rear axle type. additional tests were performed to determine the power consumption and driving range effects of the vehicles power steering / power brake unit and the air conditioner.

Wicks, Frank E. and Marichonne, Darryl (1992). Development of a Model to Predict Electric Vehicle Performance Over a Variety of Driving Conditions. SAE Paper 929135

This paper develops a mathematical model of an electric vehicle in terms of power and energy requirements and conversion components, and presents an equivalent circuit model of the batteries as a function of the charge condition, with the battery parameters obtained from charge-discharge testing, and demonstrates the use of this model to predict vehicle performance over a variety of driving and battery conditions.

Wisconsin (1985). Wisconsin Electric and Hybrid Vehicle Demonstration Project. Microfiche

Final report of demonstration project undertaken by the Wisconsin Board of Vocational, Technical, and Adult Education program in 1981. Converted EVs and hybrid vehicles were evaluated for 4 years to determine the feasibility of EVs and collect data on their performance and emissions in a cold weather climate.

Wyczalek, Floyd A. (1991). GM Electric Vehicle Technology in the 1990's, pages 317 - 322

This is an assessment of General Motors electric propulsion instrumentation policy, vision, goals , and vehicle development and commercialization strategy. It includes a historical review of key GM electric vehicle developments, a summary of the specifications for the new 1990 GM Impact electric vehicle, and an outline of a future vision for battery electric propulsion in America.

Wyczalek, Floyd A. and Wang, Tsih C. (1992). Electric Vehicle Regenerative Braking. SAE Paper 929139

This paper illustrates the application of a generalized mathematical model of the regenerative braking system and shows how some design choices for regenerative braking systems can be affected by the newly disclosed high performance high power level battery electric vehicles and the type of driving schedules encountered. Also examined, as a function of two hypothetical driving schedules, are alternative regenerative braking control concepts for optimizing energy recovery and battery life. The scope of this review is limited to illustrating some effects of design parameters for battery electric vehicles and regenerative braking systems.

Yau, T.S., Zaininger, Bernard, M.J., Heitner, K., Singh, M.K., and Saricks, C.L. (1993). Utility Emissions Associated with Electric and Hybrid Vehicle (EHV) Charging. US Department of Energy Interim Report. April

The report was prepared by the Electric Power Research Institute (EPRI) at the request of the USDOE. The USDOE developed several scenarios of potential EHV use through the year 2010. The EHVs were distributed by geographical region. These scenarios included assumptions regarding daily travel by EHVs and daily electricity requirements. EPRI agreed to develop estimates of the utility emissions associated with these scenarios.

Zorpette, Glenn (1990). The Sodium Sulfur Battery. *IEEE Spectrum*, February, page 19

Of the dozens of batteries proposed as replacements for the lead acid storage battery, none can match the impressive potential of the advanced sodium sulfur battery first developed by Joseph T. Kummer at Ford Motor Company more than 25 years ago. At the time of this article, researchers had nearly abandoned this technology leaving only Asea Brown Boveri of Heidelberg, Germany and Chloride Silent Power, Ltd. in Runcorn, England as the largest developers of this technology. Recently, however, research has began to pay off and this battery technology is once again on the rise. A discussion of the batteries operating and design principals is also discussed.

APPENDIX B. ALTERNATIVE PROPULSION VEHICLE INFORMATION

Table B1. Alternative Propulsion Vehicle Descriptions

Production Electric Vehicles				
Vehicle Description	**Vehicle Dimensions**	**Capacities**	**Motor Description**	**Battery Description**
Chrysler TEVan[1] Chrysler T115 Minivan conversion	Curb Weight: 2681 kg Length: 4524 mm Width: 1829 mm Height: 1676 mm Wheel Base: 2582 mm	8 passenger 545 kg payload	One 54 kW Permanent Magnet DC	40 kW-h Nickel-Iron weight: 800 kg
Electricar GTP Sport Coupe[2] Consulier GTP conversion	Curb Weight: 1360 kg	2 passenger	AC	Sealed Lead-Acid
Electricar Pick-up[3] Chevrolet S-10 Pick-up Truck conversion	Curb Weight: 1995 kg Length: 5184 mm Wheel Base: 2995 mm	2 passenger 363 kg payload	One 50 kW AC	21 kW-h Sealed Lead-Acid weight: 907 kg
Electricar Sedan[4] Toyota Corolla conversion	Curb Weight: 1560 kg Length: 4394 mm Width: 1684 mm Height: 1354 mm Wheel Base: 2464 mm	5 passenger	One 50 kW AC	13 kW-h Sealed Lead-Acid
Ford Ecostar[5,6,7] European Escort van conversion	Curb Weight: 1420 kg Length: 4300 mm Width: 1694 mm Height: 1704 mm Wheel Base: 2596 mm	2 passenger 454 kg payload	One 57 kW AC	50 kW-h Sodium Sulfur weight: 350 kg
Solectria E-10 High[8] Chevrolet S-10 Pick-up Truck conversion	Curb Weight: 1565 kg	2 passenger 204 kg payload	One 56 kW AC	Sealed Lead-Acid
Solectria E-10 Medium[8] Chevrolet S-10 Pick-up Truck conversion	Curb Weight: 1678 kg	2 passenger 91 kg payload	One 42 kW AC	Sealed Lead-Acid
Solectria Force 2-Seat Auto[9] GEO Metro conversion	Curb Weight: 968 kg Length: 3708 mm Width: 1575 mm Height: 1334 mm Wheel Base: 2273 mm	2 passenger	One 20.9 kW AC	12.6 kW-h Sealed Lead-Acid
Solectria Force 2-Seat NiCd GT[9] GEO Metro conversion	Curb Weight: 1030 kg Length: 3708 mm Width: 1575 mm Height: 1334 mm Wheel Base: 2273 mm	2 passenger 385 kg payload	One 42 kW AC	16.8 kW-h Nickel-Cadmium
Solectria Force 4-Seat Auto[9] GEO Metro conversion	Curb Weight: 933 kg Length: 3708 mm Width: 1575 mm Height: 1334 mm Wheel Base: 2273 mm	4 passenger	One 19.6 kW AC	10.4 kW-h Sealed Lead-Acid

Table B1. Alternative Propulsion Vehicle Descriptions (continued)

Current Electric Vehicle Prototypes				
Vehicle Description	**Vehicle Dimensions**	**Capacities**	**Motor Description**	**Battery Description**
BMW E1[10]	Curb Weight: 880 kg Length: 3460 mm Width: 1648 mm Height: 1500 mm Wheel Base: 2325 mm	4 passenger	One 32 kW Permanent Magnet DC	19 kW-h Sodium Sulfur weight: 200 kg
BMW E2[1]	Curb Weight: 1000 kg Length: 3800 mm Width: 1600 mm Height: 1500 mm	4 passenger	One 34 kW Permanent Magnet DC	Sodium Sulfur
Citroen Citela[1]	Curb Weight: 790 kg Length: 2960 mm Width: 1550 mm	Not Available	One 20 kW	Nickel-Cadmium
General Motors Impact[11,12,13]	Curb Weight: 1319 kg Length: 3827 mm Width: 1760 mm Height: 1283 mm Wheel Base: 2512 mm	2 passenger 158 kg payload	One 103 kW AC	13.6 kW-h Sealed Lead-Acid weight: 499 kg
Mercedes Benz Vision A93[14]	Curb Weight: 1005 kg Length: 3348 mm Width: 1659 mm Height: 1570 mm Wheel Base: 2286 mm	4 passenger	One 40 kW AC	Sodium Nickel Chloride
Opel Twin[1]	Curb Weight: 740 kg Length: 3470 mm Width: 1630 mm Height: 1360 mm	Not Available	Not Available	Lithium Carbon weight: 250 kg
Electric Vehicle Technology Demonstrators				
Vehicle Description	**Vehicle Dimensions**	**Capacities**	**Motor Description**	**Battery Description**
Nissan FEV [15]	Curb Weight: 900 kg Length: 3995 mm Width: 1698 mm Height: 1290 mm Wheel Base: 2436 mm	4 passenger	Two 25 kW AC	Nickel-Cadmium weight: 200 kg
Tokyo Electric IZA[16]	Curb Weight: 1573 kg	4 passenger	Four 25 kW Permanent Magnet DC	Nickel-Cadmium weight: 530 kg
Toyota Town Ace Van[1]	Curb Weight: 1300 kg	4 passenger	AC	Not Available weight: 670 kg
AC Propulsion CRX Honda Civic CRX HF conversion[17]	Curb Weight: 1243 kg Length: 3772 mm Width: 1674 mm Height: 1273 mm Wheel Base: 2301 mm	2 passenger	One 90 kW AC	Sealed Lead-Acid weight: 503 kg
DEMI / APS Saturn[1] Saturn SC Coupe conversion	Curb Weight: 950 kg	2 passenger	Not Available	Zinc Oxide

Table B1. Alternative Propulsion Vehicle Descriptions (continued)

Hybrid Vehicles				
Vehicle Description	**Vehicle Dimensions**	**Capacities**	**Motor Description**	**Battery Description**
LA 301[18] Parallel Hybrid design concept	Curb Weight: 1765 kg Length: 4166 mm Wheel Base: 2770 mm	4 passenger 340 kg payload 17.6 L fuel tank	One 43 kW DC brush, One 25 kW 4 cyl 650 cc	Sealed Lead-Acid weight: 453 kg
Volkswagen Chico[1] Parallel Hybrid design concept	Curb Weight: 785 kg Length: 3150 mm Width: 1600 mm Height: 1473 mm	4 passenger	One 6 kW AC, One 25 kW 2 cyl 636 cc	Nickel-Cadmium
Volvo ECC[19.20] Series Hybrid technology demonstrator	Curb Weight: 1568 kg Length: 4488 mm Width: 1803 mm Height: 2700 mm Wheel Base: 2700 mm	5 passenger 34.8 L fuel tank	One 70 kW AC, One 41 kW Single radial compressor / turbine	16.8 kW-h Nickel-Cadmium weight: 349 kg

Table B2. Alternative Propulsion Vehicle Performance Measures

Production Electric Vehicles			
Vehicle Description	**Acceleration (s)**	**Top Speed (kmh)**	**Range**
Chrysler TEVan[1] Chrysler T115 Minivan conversion	0 - 48 kmh: 9.0 0 - 80 kmh: 14.0 0 - 96 kmh: 25.0	104.7	193 km
Electricar GTP Sport Coupe[2] Consulier GTP conversion	Not Available	128.8	72 - 112 km
Electricar Pick-up[3] Chevrolet S-10 Pick-up Truck conversion	0 - 48 kmh: 6.0 0 - 80 kmh: 15.0	120.8	80 - 144 km
Electricar Sedan[4] Toyota Corolla conversion	0 - 48 kmh: 4.5 0 - 80 kmh: 12.0	128.8	80 - 128 km
Ford Ecostar[5,6,7] European Escort van conversion	0 - 48 kmh: 4.2 0 - 64 kmh: 7.1 0 - 80 kmh: 11.1 0 - 96 kmh: 16.4 0 - 30 m: 3.8 0 - 150 m: 10.6 0 - 400 m: 20.3	112.8	161 km FUDS (average speed = 32 kmh maximum speed 92 kmh, 19 % stationary) 322 km at 40 kmh
Solectria E-10 High[8] Chevrolet S-10 Pick-up Truck conversion	0 - 48 kmh: 7.0	112.8	96 km @ 80 kmh 160 km with NiCd batteries
Solectria E-10 Medium[8] Chevrolet S-10 Pick-up Truck conversion	0 - 48 kmh: 9.0	96.6	112 km @ 80 kmh 160 km with NiCd batteries
Solectria Force 2-Seat Auto[9] GEO Metro conversion	0 - 48 kmh: 8.5	96.6	112 km
Solectria Force 2-Seat NiCd GT[9] GEO Metro conversion	0 - 48 kmh: 4.5	112.7	192 km
Solectria Force 4-Seat Auto[9] GEO Metro conversion	0 - 48 kmh: 8.0	96.6	96 km

Table B2. Alternative Propulsion Vehicle Performance Measures (continued)

Current Electric Vehicle Prototypes			
Vehicle Description	**Acceleration (s)**	**Top Speed (kmh)**	**Range**
BMW E1[10]	0 - 48 kmh: 6.0 0 - 80 kmh: 18.0	120	215 km @ 50 kmh 155 km @ 80 kmh 143 km on FTP75-cycle
BMW E2[1]	0 - 48 kmh: 6.5 0 - 80 kmh: 15.6	121	430 km
Citroen Citela[1]	0 - 48 kmh: 8.5	110	210 km @ 40 kmh
General Motors Impact [11,12,13]	0 - 96 kmh: 8.5 0 - 400 m: 16.7	128.8	With two people and luggage using 80 % of the battery: 112 km city, 144 km highway 160 km @ 88 kmh 400 km @ 40 kmh City driving Energy equivalent is 47 mpg
Mercedes Benz Vision A93[14]	0 - 100 kmh: 17.2	120.8	150 km city, 150 km highway @ 80 kmh
Opel Twin[1]	0 - 48 kmh: 7.0	120	
Electric Vehicle Technology Demonstrators			
Vehicle Description	**Acceleration (s)**	**Top Speed (kmh)**	**Range**
Nissan FEV[15]	0 - 40 kmh : 3.6 0 - 400 m: 20	130	250 km @ 40 kmh 160 km @ 72 kmh City driving with A.C. on, less than 80 km
Tokyo Electric IZA[16]	Not Available	176	548 km @ 40 kmh
Toyota Town Ace Van[1]	0 - 48 kmh: 10.0	85	140 km @ 25 kmh
AC Propulsion CRX[17] Honda Civic CRX HF conversion	0 - 48 kmh: 3.5 0 - 80 kmh: 6.2 0 - 96 kmh: 7.8 0 - 400 m: 16.3	128.8	210 km @ 88 kmh 177 km @ 96 kmh
DEMI / APS Saturn[1] Saturn SC Coupe conversion	0 - 140 kmh: 10.0	200	350 km @ 60 kmh
Hybrid Vehicles			
Vehicle Description	**Acceleration (s)**	**Top Speed (kmh)**	**Range**
LA 301[18] Parallel Hybrid design concept	0 - 48 kmh: 7.0 0 - 80 kmh: 17.0	120.8	Electric Mode: 80 to 96 km, Hybrid Mode: More than 240 km is possible. (Meets California's ULEV emissions standards)
Volkswagen Chico[1] Parallel Hybrid design concept	0 - 80 kmh: 19.0 0- 96 kmh: 30.0	131	400 km
Volvo ECC[19,20] Series Hybrid technology demonstrator	0 - 100 kmh: 13 (ULEV mode) 23 (EV mode)		Pure electric, 80 % discharge: 144 km at 48 kmh, 85 km city cycle. Turbine / generator mode: more than 640 km. (Meets California's ULEV emissions standards)

Table B3. Alternative Propulsion Vehicle Battery Charging Requirements

Production Electric Vehicles		
Vehicle Description	**Battery Description**	**Recharge Requirements**
Chrysler TEVan[1] Chrysler T115 Minivan conversion	40 kW-h Nickel-Iron weight: 800 kg	Not Available
Electricar GTP Sport Coupe[2] Consulier GTP conversion	Sealed Lead-Acid	4 - 6 hours with 220 V source 8 - 10 hours with 110 V source
Electricar Pick-up[3] Chevrolet S-10 Pick-up Truck conversion	21 kW-h Sealed Lead-Acid weight: 907 kg	6 - 8 hours with 220 V source 12 - 14 hours with 110 V source
Electricar Sedan[4] Toyota Corolla conversion	13 kW-h Sealed Lead-Acid	4 - 6 hours with 220V source 8 - 10 hours with 110V source
Ford Ecostar[5,6,7] European Escort van conversion	50 kW-h Sodium Sulfur weight: 350 kg	6 - 7 hours with 240 V, 30 A source 18 - 24 hours with 110 V, 15 A source
Solectria E-10 High[8] Chevrolet S-10 Pick-up Truck conversion	Sealed Lead-Acid	Not Available
Solectria E-10 Medium[8] Chevrolet S-10 Pick-up Truck conversion	Sealed Lead-Acid	Not Available
Solectria Force 2-Seat Auto[9] GEO Metro conversion	12.6 kW-h Sealed Lead-Acid	8 hours with 120 V source 4 hours with 110 V fast charge source
Solectria Force 2-Seat NiCd GT[9] GEO Metro conversion	16.8 kW-h Nickel-Cadmium	4 hours with 220 V fast charge source
Solectria Force 4-Seat Auto[9] GEO Metro conversion	10.4 kW-h Sealed Lead-Acid	8 hours with 120 V source 4 hours with 110 V fast charge source
Current Electric Vehicle Prototypes		
Vehicle Description	**Battery Description**	**Recharge Requirements**
BMW E1[10]	19 kW-h Sodium Sulfur weight: 200 kg	Not Available
BMW E2[1]	Sodium Sulfur	Not Available
Citroen Citela[1]	Nickel-Cadmium	Rate 2 km range / minute
General Motors Impact [11,12,13]	13.6 kW-h Sealed Lead-Acid weight: 499 kg	2 - 3 hrs with 220 V source 8 - 10 hrs with 110 V source 10 - 15 min with 50 kW source
Mercedes Benz Vision A93[14]	Sodium Nickel Chloride	Not Available
Opel Twin[1]	Lithium Carbon weight: 250 kg	Not Available

Table B3. Alternative Propulsion Vehicle Battery Charging Requirements (continued)

Electric Vehicle Technology Demonstrators		
Vehicle Description	**Battery Description**	**Recharge Requirements**
Nissan FEV [15]	Nickel-Cadmium weight: 200 kg	40 % in 6 min, 100 % in < 15 min with 440 V source 8 hrs with 100 V, 15 A source
Tokyo Electric IZA[16]	Nickel-Cadmium weight: 530 kg	8 hours from a conventional power supply
Toyota Town Ace Van[1]	Not Available weight: 670 kg	8 hours
AC Propulsion CRX[17] Honda Civic CRX HF conversion	Sealed Lead-Acid weight: 503 kg	2 hrs with 240 V, 40 A source 10 - 14 hrs with 110 V source
DEMI / APS Saturn[1] Saturn SC Coupe conversion	Zinc Oxide	low/med/fast charge between 100 and 240 V
Hybrid Vehicles		
Vehicle Description	**Battery Description**	**Recharge Requirements**
LA 301[18] Parallel Hybrid design concept	Sealed Lead-Acid weight: 453 kg	On board 110 / 220 V charger Charge for 60 mile range cost $1.00 in off peak Southern California hours
Volkswagen Chico[1] Parallel Hybrid design concept	Nickel-Cadmium	Not Available
Volvo ECC[19,20] Series Hybrid technology demonstrator	16.8 kW-h Nickel-Cadmium weight: 349 kg	Not Available

Legend:

[1] Society of Automotive Engineers, 1992
[2] US Electricar Sport Coupe Brochure, 1994
[3] US Electricar Pick-up Brochure, 1994
[4] US Electricar Sedan Brochure, 1994
[5] Simanaitis and Reynolds, 1994
[6] Simanaitis. Ford Ecostar Electric, 1993
[7] Cook, 1993
[8] Solectria E-10 Pick-up Brochure, 1994
[9] Solectria Force Brochure, 1994
[10] Faust, Goubeau, and Scheuerer, 1992
[11] GM Electric Vehicle Resource Center, 1994
[12] Clemens, 1994
[13] Gromer, 1994
[14] Kacher, 1994
[15] Fukino, Irie, and Ito, 1992
[16] Coghlan, 1993
[17] Reynolds, 1992
[18] Cherry, 1992
[19] Simanaitis. Volvo ECC, 1993
[20] Cogan, 1993

APPENDIX C. ELECTROCHEMICAL BATTERY INFORMATION FOR APV USE

Table C1. Electrochemical Battery Performance Measures for APVs

Battery Type	Specific Energy (Wh/kg)	Peak Power (W/kg)	Cycle Life	Recyclable	Notes
Nickel Iron					
EPI NIF-200[2]	51	112 @ 50 % DOD	> 258	Yes	NiFe batteries are currently available technology used in production EVs made from environmentally benign materials. The high residual values of Ni and Fe ensures recycleability.
EPI NIF-200[1]	51 @ C/3 rate	99 @ 80 % DOD	918 with 80 % DOD - J227aC	Yes	
Zinc - Air					
DEMI[5]	200 - 300	52 @ 80 % DOD	30 - 75 @ 80 % DOD	Yes	Zn-Air batteries are in development, meet USABC mid term goals, and are environmentally benign. If Zn-Air batteries enter high volume production, they can be recycled.
Aluminum - Air					
LLL[3]	320	140		Yes	Al-Air batteries, which are still under development, meet USABC mid term goals and are mechanically rechargeable,
Nickel Metal Hydride (Ovionic)					
OBC Laboratory Prototype[7]	80 @ C/3 rate	175 @ 80 % DOD	1000 @ 80 % DOD	Yes	NiMH batteries, which are ambient temperature, nontoxic, and meet USABC mid term goals, can be safely disposed of in landfills or recycled into additives for cast iron, stainless steel, or new NiMH batteries using existing technology.
OBC C-cell[1]	54 @ C/3 rate	158 @ 80 % DOD	333 to 100 % DOD - SFUDS	Yes	
OBC Ext. C-cell[1]	57 @ C/3 rate	105 @ 80 % DOD	108 @ 100 % DOD - SFUDS	Yes	
OBC H-cell[1]	55 @ C/3 rate	175 @ 80 % DOD	380 with 80 % DOD	Yes	

Table C1. Electrochemical Battery Performance Measures for APVs (continued)

Battery Type	Specific Energy (Wh/kg)	Peak Power (W/kg)	Cycle Life	Recyclable	Notes
Sodium Sulfur					
ABB B11[1]	81 @ C/3 rate	152 @ 80 % DOD	592 on SFUDS to 100% DOD	Unknown	NaS batteries, which are being tested in current production EVs, meet USABC mid term goals. The low cost, highly abundant materials used may preclude NaS battery recycling. However, sodium is considered a hazardous waste and must be properly disposed of in landfills.
CSPL PB-MK3[1]	79 @ C/3 rate	90 @ 80 % DOD	795 on SFUDS to 100% DOD	Unknown	
Nickel Cadmium					
SAFT STM5-200[2]	55	191 @ 50 % DOD	> 44, still in testing at time of article	Yes	NiCd is a viable technology used in current production EVs. The toxicity of cadmium is an issue. A NiCd recycling infrastructure is currently in place and economically viable.
Zinc Bromine					
SEA 2BB-5/48[1]	79 @ C/3 rate	40 @ 80 % DOD	334 to 100 % DOD - SFUDS	Yes	ZnBr batteries are currently under development and have been tested in vehicles. One drawback is that bromine is noxious and highly reactive. However, the bromine electrolyte is separated in the design allowing for recycling.
Lead-Acid					
GM Impact[6]	35 @ C/2 rate	280 @ 50 % SOC	> 500	Yes	Pb-acid batteries, considered a near term solution, are used in current production EVs. The infrastructure for lead acid battery recycling is already in place and economically viable..
(Chloride) CEVS 3ET205[2]	33@ C/3 rate	93 @ 50 % DOD	715	Yes	
Sonnenschein 6V160[2]	32	127 @ 50 % DOD	> 152	Yes	
Horizon® Lead Cloth Battery[8]	> 50 @ C/3 rate	> 500 @ 0 % DOD, > 300 @ 80 % DOD	600 to 80 % cap., > 900 to 64% cap.	Yes	Horizon® batteries which meet USABC mid term goals, are seen as an available technology for current production EVs and can be recycled using the current lead acid methods.

Table C1. Electrochemical Battery Performance Measures for APVs (continued)

Battery Type	Specific Energy (Wh/kg)	Peak Power (W/kg)	Cycle Life	Recyclable	Notes
Lithium Metal Sulfide					
SAFT R&D Cells[4]	66 @ C/3 rate	83 @ 50 % DOD		Yes	Still under development, lithium-metal /sulfide batteries meet USABC long term goals and are seen as a viable technology for 2000 and beyond. These batteries are environmentally benign and are being developed with recycleability issues in mind.
SAFT Prismatic[1]	66 @ C/3 rate	64 @ 80 % DOD	163 with 80 % DOD	Yes	
Lithium Polymer					
R&D Cell[6]	100 @ C/2 rate	200 @ 50 % SOC	< 500	Yes	Lithium polymer batteries are seen as a year 2000 and beyond battery alternative. These batteries are environmentally benign and being designed with environmental issues in mind

Legend:

[1] Riezenman, 1992
[2] DeLuca, et al., 1990
[3] DeLuchi, et al., 1989
[4] Society of Automotive Engineers, 1992
[5] Chieky, et al., 1990
[6] Dabels, 1992
[7] Ovshinsky, et al., 1993
[8] Electrosource Brochure, 1994

APPENDIX D. APV AND RPEV FAULT HAZARD AND SAFETY ANALYSIS

Safety analysis assumptions for alternate propulsion vehicles (APVs) used on the Automated Highway System (AHS):

- General vehicle hazard categories as described by the safety task apply to APVs.
- APVs will be designed to the same safety criteria as today's internal combustion engine vehicles (ICEVs).

Notes:

- In the case of a battery electrolyte spill, hazardous material (HAZMAT) and emergency response teams must know what they are dealing with and taking the proper safety precautions to avoid further injury.
- Electric vehicle drivetrains are more reliable, simpler, and easier to maintain than today's ICEVs.

Table D1. APV Safety

	Component Failure	**System**	**Hazard Description**			
No.	**Identity**	**Event Phase**	**Local Effect**	**System Effect**	**Risk**	**Remarks**
1.0	Storage Battery					
1.1	Battery Discharge	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Charge is below 20% capacity Vehicle longitudinal control affected Vehicle moves to breakdown lane or off AHS at the next available exit	Vehicle gives no go for AHS engage Possible vehicle slowdown or stoppage could result in collision and traffic slowdown and delays Surrounding traffic notified and adjusted so vehicle can move out of traffic	3A - 4C IV	At least 20% total battery capacity is required for AHS engage A vehicle collision could result in battery damage and a possible fire and / or explosion
1.2	Battery Damage:	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle could pose a hazard to surrounding AHS traffic Vehicle could lose power Vehicle moves to breakdown lane if possible	Vehicle must disengage AHS Possible traffic slowdown, collisions, fire, vehicle damage Roadway debris must be cleared to lessen traffic impacts	2 - 4D IV	Initial detection would prevent AHS access HAZMAT teams may need to be dispatched to clean up hazardous debris, spills Occupants could be overcome by fumes affecting manual control and decisions

Table D1. APV Safety (continued)

No.	Component Failure Identity	System Event Phase	Hazard Description Local Effect	System Effect	Risk	Remarks
1.0	Storage Battery continued					
1.3.1	Liquid Sodium Leak	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle is a hazard to AHS, traffic, and vehicle occupants Vehicle power is lost Vehicle occupants notified Vehicle directed to breakdown lane if possible	AHS disengage required since a fire hazard is created Surrounding traffic notified and directed around incident or stopped HAZMAT teams and emergency crews dispatched	2E II - IV	Initial detection would prevent AHS access Liquid sodium produces a violent reaction when exposed to either air or water - possible fire Vehicle occupants at risk if vehicle catches fire
1.3.2	Liquid Sulfur Leak	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle is a hazard to both AHS traffic and occupants Vehicle loses power Driver / occupants may be incapacitated and unable to resume control of the vehicle	Battery damage resulting in loss of power and poisonous fumes Vehicle occupants could be overcome by fumes, manual control / driver decisions could be affected HAZMAT teams and emergency response teams dispatched to incident to treat affected persons and clean up spill	2E II - IV	Poses an environmental hazard since poisonous fumes are emitted.

Table D1. APV Safety (continued)

	Component Failure	System	Hazard Description			
No.	**Identity**	**Event Phase**	**Local Effect**	**System Effect**	**Risk**	**Remarks**
1.0	Storage Battery continued					
1.3.4	Sulfuric Acid Leak	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle poses a hazard to roadway and surrounding traffic Vehicle loses power Vehicle directed to breakdown lane if possible	AHS engage denied, initial detection prevents system access Traffic slowdown, possible damage to vehicles and roadway with prolonged exposure Surrounding traffic notified and adjusted HAZMAT team dispatched to clean up spill	3E III - IV	Sulfuric acid can corrode vehicle and roadway components with prolonged exposure In most cases the acid is stored in a gel form so that it will not flow in event of battery damage An H_2SO_4 spill can be easily neutralized using sodium bicarbonate (baking soda) A sulfuric acid spill is less hazardous than an equivalent gasoline spill
1.3.5	Potassium Hydroxide Leak Nickel Iron Batteries Zinc - Air Batteries	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle poses a hazard to roadway and surrounding traffic Vehicle loses power Vehicle directed to breakdown lane if possible	AHS engage denied, initial detection prevents system access Traffic slowdown, possible damage to vehicles and roadway with prolonged exposure Surrounding traffic notified and adjusted HAZMAT team may need to dispatched to clean up spill	3E III - IV	Potassium hydroxide breaks down into a baking soda equivalent with prolonged exposure to air. Vehicle occupant exposure is reduced if the electrolyte can be rinsed off within several minutes of exposure Zinc - air batteries have a short circuit proof chemistry that prevents fire or explosion when the battery is damaged

Table D1. APV Safety (continued)

	Component Failure	System	Hazard Description			
No.	**Identity**	**Event Phase**	**Local Effect**	**System Effect**	**Risk**	**Remarks**
1.0	Storage Battery continued					
1.3.6	Sodium Hydroxide Leak Aluminum - Air Batteries	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle poses a hazard to roadway and surrounding traffic Vehicle loses power Vehicle directed to breakdown lane if possible	AHS engage denied, initial detection prevents system access Traffic slowdown, possible damage to vehicles and roadway with prolonged exposure Surrounding traffic notified and adjusted	3E III - IV	Sodium hydroxide can cause serious burns as well as eye, nose, throat, and lung irritation HAZMAT team dispatched to clean up spill
1.3.7	Liquid Bromine Leak Zinc Bromine Batteries	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle poses a hazard to surrounding traffic Vehicle loses power Vehicle directed to breakdown lane if possible	AHS engage denied, initial detection prevents system access Traffic slowdown, noxious vapors harmful to people Surrounding traffic notified and adjusted HAZMAT team dispatched to clean spill	2E III - IV	Bromine is a noxious gas which is difficult to seal in pumps and piping Bromine volitalizes at room temperature forming a red gas which causes eye and throat irritation In liquid form, contact with bromine causes painful skin lesions
2.0	Fuel Cell System					
2.1	Fuel Cell Hydrogen Supply Depleted	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Supply is below 20% capacity Vehicle longitudinal control affected Vehicle moves to breakdown lane or off AHS at the next available exit	Vehicle gives no go for AHS engage Possible vehicle slowdown or stoppage could result in collision or traffic slowdown and delays Surrounding traffic notified and adjusted so vehicle can move out of traffic	3B - 4D IV	At least 20% total fuel cell capacity is required for AHS engage A vehicle collision could result in fuel cell damage and a possible fire or explosion

Table D1. APV Safety (continued)

	Component Failure	System	Hazard Description			
No.	Identity	Event Phase	Local Effect	System Effect	Risk	Remarks
2.0	Fuel Cell System continued					
2.2	Fuel Cell Damage	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Possible roadway hazard, vehicle performance is degraded Ability to maintain speed may be lost, occupants at risk to explosion Vehicle directed to breakdown lane or off of AHS if possible	AHS engage is denied Possible traffic slowdown or collision. fire and explosion are possible Surrounding traffic is notified and adjusted so vehicle can exit from AHS	2 - 4D IV	Fuel cell hydrogen storage compartment damage could result in a fire or possible explosion A worse case scenario could require a traffic shutdown to avoid serious injury until situation is resolved
3.0	Flywheel Damage Flywheel Can Not Maintain Rotation Speed Flywheel Disconnects Flywheel Breaks Vacuum is Damaged	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle performance is degraded Ability to maintain speed may be lost Vehicle directed to breakdown lane or off of AHS if possible	AHS engage is denied Possible traffic slowdown or collision Surrounding traffic is notified and adjusted so vehicle can exit from AHS	2 - 4D IV	Initial detection prevents AHS engage Vehicle damage could result Flying debris may damage surrounding vehicles or injure vehicle occupants
3.1	Ultracapacitor Damage	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle performance degradation to loss of power Vehicle could slowdown or stop or acceleration could be impaired Vehicle directed to breakdown lane or off of AHS if possible	Vehicle might be denied AHS access or disengage system Possible traffic slowdown or collision Surrounding traffic is notified and adjusted so vehicle can exit from AHS	3 - 4D IV	Depending on ultra-capacitor performance, vehicle could experience acceleration and range problems (using battery alone) or lose all power (pure ultracapacitor and no battery)

Table D1. APV Safety (continued)

No.	Component Failure Identity	System Event Phase	Hazard Description Local Effect	System Effect	Risk	Remarks
4.0	Hybrid Vehicles					
4.1	Series Hybrid: IC Engine Failure	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Limited to no vehicle power Vehicle could slowdown or stop depending on remaining battery charge Vehicle would move to breakdown lane or off the AHS if possible	Vehicle gives no go for AHS Could result in a traffic slowdown or possible collision Surrounding traffic is notified and adjusted so vehicle can exit from AHS	4D IV	Initial detection would prevent AHS access Severity depends on remaining battery charge, an exit within reasonable proximity may allow time for vehicle to continue AHS travel until the next exit and avoid traffic impacts
4.2	Parallel Hybrid: IC Engine Failure Electric Motor Failure	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Reduced vehicle performance Vehicle acceleration capability and range reduced Vehicle might need to exit AHS or move to breakdown lane	Vehicle gives no go for AHS Could result in a traffic slowdown Surrounding traffic is notified and adjusted so vehicle can exit from AHS	4D III - IV	Initial detection would prevent AHS access Could be a more serious problem if battery charge is low and IC engine fails, vehicle might need to exit AHS quickly

Safety analysis assumptions for roadway powered electric vehicles (RPEVs) used on the Automated Highway System (AHS):

- I3C3 configuration used.
- Roadway power is inductive: 12-foot modular segments spaced at 6-foot supply. Power as vehicle passes over them.
- Power segments are provided for one out of every 10 highway miles.
- Power segments, supplied by a central source, are powered up only if the passing vehicle requires a charge.
- Magnetic field given off by roadway provides a lateral guidance source.

Table D2. RPEV Safety

	Component Failure	System	Hazard Description			
No.	**Identity**	**Event Phase**	**Local Effect**	**System Effect**	**Risk**	**Remarks**
1.0	Environmental : Deep Snow Ice	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle inductor pick-up height must be adjusted to conditions to avoid damage If inductor pick-up height varies greatly from optimal length, roadway power supply capability could be degraded	Severe conditions might require system shutdown Roadway guided lateral control capabilities could be degraded	2B - 4D I - IV	Possible inductor pick-up damage could occur which would prevent vehicle from accepting roadway charge, reducing range capabilities
2.0	Roadway					
2.1	Debris	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Possible debris could damage vehicle or its inductor pick-up Vehicle could lose roadway power source if inductor pick-up damaged Vehicle could continue AHS travel until battery depleted enough for vehicle to exit system	AHS could still be engaged Possible traffic slowdown or vehicle damage	3B - 4C III - IV	Roadway might direct vehicle around object or adjust inductor pick-up length to avoid damage Roadway debris must be cleared to avoid damage Possibility to inductive heat transfer to roadway debris might pose a hazard to clean up crews
2.2	Power Degraded Or Lost	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle may be unable to gain recharge or lateral control from roadway power source Vehicle with critical battery discharge level could be directed off of the AHS	Roadway power supply might be lost, lateral control could be affected Vehicle could safely continue AHS travel until next power source is reached (10 miles)	2C - 4E II - IV	Would require system shutdown only if multiple failures occur Redundant lateral control systems would be activated

Table D2. RPEV Safety (continued)

	Component Failure	System	Hazard Description			
No.	**Identity**	**Event Phase**	**Local Effect**	**System Effect**	**Risk**	**Remarks**
3.0	Vehicle Inductor Pick-Up Damaged	Check - In AHS Entry Lat / Long Check - Out AHS Exit	Vehicle unable to accept roadway charge Vehicle range could be degraded when compared to surrounding traffic	Vehicle might be denied AHS access if a long trip is required Roadway lateral guidance is unaffected	4B - D IV	Vehicle inductor pick-up is needed only to accept charge form the roadway.

APPENDIX E. MISCELLANEOUS

Table E1. Emissions Standards set by the California Air Resources Board (CARB)[1]

Category	Vehicle Definition	Emission Level, g/mi (g/km)		
		NMOG	NO_X	CO
TLEV	Transitional low-emission	0.125 (0.078)	0.4 (0.25)	3.4 (2.11)
LEV	Low-emission	0.075 (0.047)	0.2 (0.12)	3.4 (2.11)
ULEV	Ultra-low-emission	0.040 (0.025)	0.2 (0.12)	1.7 (1.06)
ZEV	Zero-emission	0.00	0.00	0.00

Table E2. CARB Implementation Dates[1]

Model Year	Percentage of new vehicles mandated by emission standards			
	TLEV	LEV	ULEV	ZEV
1994	10	-	-	-
1995	15	-	-	-
1996	20	-	-	-
1997	-	25	2	-
1998	-	48	2	2
1999	-	73	2	2
2000	0	96	2	2
2001	0	90	5	5
2002	0	85	10	5
2003	0	75	15	10

Table E3. USABC Battery Goals[1]

	Mid-Term	Long Term
Specific Energy, Wh/kg (at C/3 discharge rate)	80 (100)	200
Energy Density, Wh/L (at C/3 discharge rate)	135	300
Specific Power, W/kg (80% DOD per 30 seconds)	150 (200)	400
Power Density, W/L	250	600
Life, Years	5	10
Life, Cycles (80% DOD)	600	1000
Cost, $/kWh	> $150	> $100
Operating Environment	-30° to 65°C	-40° to 85°C
Recharge Time	> 6 hours	3 to 6 hours
Continuous Discharge in One Hour (no failure)	75% of rated energy capacity	
Power and Capacity Degradation	20% of rated specification	

[1] Source: Electric Transportation Coalition. Taken from Riezenman, 1992.

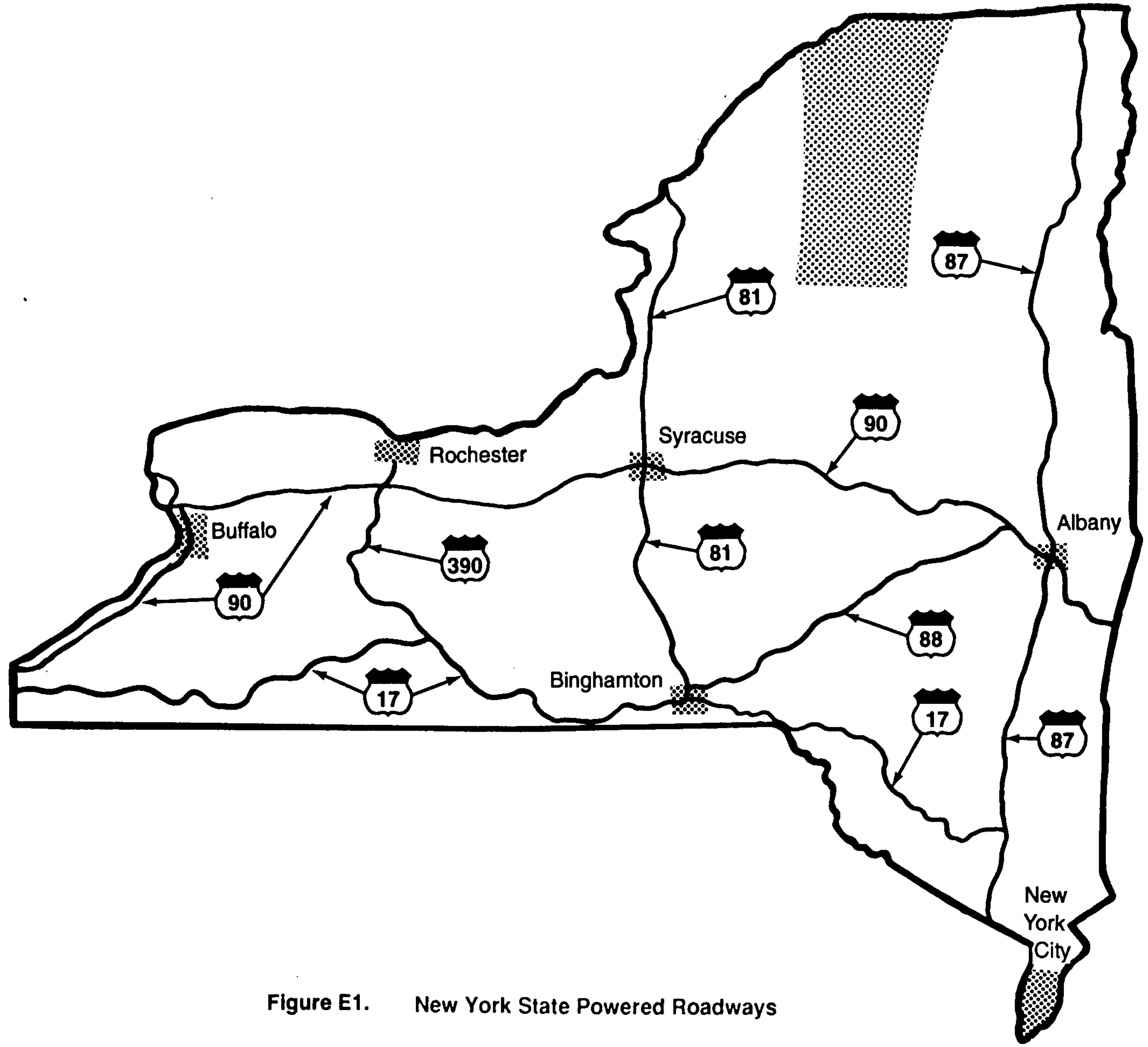

Figure E1. New York State Powered Roadways

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