ZERO-EMISSION VEHICLE TECHNOLOGY ASSESSMENT

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**ZERO-EMISSION VEHICLE
TECHNOLOGY ASSESSMENT**

Final Report

Prepared for

**THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY**

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ABSTRACT

This is the final report in the Zero-Emission Vehicle (ZEV) Technology Assessment, performed for NYSERDA by Booz-Allen & Hamilton Inc. Booz-Allen wrote the final report, and performed the following tasks as part of the assessment: assembled a database of key ZEV organizations, their products or services, and plans; described the current state of ZEV technologies; identified barriers to widespread ZEV deployment and projected future ZEV technical capabilities; and estimated the cost of ZEVs from 1998 to 2004.

Data for the ZEV Technology Assessment were obtained from several sources, including the following: existing ZEV industry publications and Booz-Allen files; major automotive original equipment manufacturers; independent electric vehicle manufacturers; battery developers and manufacturers; infrastructure and component developers and manufacturers; the U.S. Department of Energy, the California Air Resources Board, and other concerned government agencies; trade associations such as the Electric Power Research Institute and the Electric Transportation Coalition; and public and private consortia. These sources were contacted by phone, mail, or in person. Some site visits of manufacturers also were conducted. Where possible, raw data were analyzed by Booz-Allen staff and/or verified by independent sources. Performance data from standardized test cycles were used as much as possible.

Key Words: Electric Vehicle, Zero-Emission Vehicle, Air Quality, Emissions, Mobile Source, Transportation, Automotive

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FOREWORD

by the New York State Energy Research and Development Authority

New York State adopted the California Low Emission Vehicle (LEV) program that includes a sales mandate for ZEVs starting in 1998. The New York State Department of Environmental Conservation (NYSDEC) was required to perform a technology review of zero-emission vehicles (ZEVs) in 1994, and examine technology developments and issues relating to ZEV performance in New York State, by the amendments to 6NYCRR Part 218, February 1992. The New York State Energy Research and Development Authority (NYSERDA) entered into a cooperative agreement (2000-ERER-ER-93) with NYSDCE on September 3, 1992, to carry out this study.

NYSERDA, following its standard practice, established a Technical Evaluation Panel (TEP) to help develop a detailed Statement of Work that would be used in a competitive Request for Proposals (RFP). The TEP consisted of representatives from NYSERDA, NYSDCE, the Greater New York Auto Dealer's Association, an Albany-area automobile dealership service department, the NYS Energy Office, the NYS Thruway Authority, the NYS Office of General Services Division of Vehicle Management, and the NYS Department of Transportation. Following a review of the proposals submitted in response to the RFP, the TEP selected Booz-Allen & Hamilton to perform the study. Throughout the project, NYSERDA, assisted by the TEP, reviewed draft results from Booz-Allen & Hamilton, providing comments on methodology and information sources.

The Final Report presents an overview of technology as of the spring of 1995, and a projection of technology status over the next 10 years. Recent developments such as the change in business plans announced by U.S. Electric Car and the controversy over the degree of environmental impact associated with lead-acid battery manufacturing were evolving at the time and therefore are not addressed in the report.

Limitations

This report does not provide policy recommendations, but rather is intended to provide technical information that will be useful to New York State policy makers. In addition, market surveys were beyond the scope of this study. Therefore, this report does not predict whether EVs that cost and perform as projected for 1998 will meet the needs of the consumers.

EXECUTIVE SUMMARY

This is the final report in the Zero-Emission Vehicle (ZEV) Technology Assessment, performed for NYSERDA by Booz-Allen & Hamilton Inc. Booz-Allen wrote the final report, and performed the following tasks as part of the assessment: assembled a database of key ZEV organizations, their products or services, and plans; described the current state of ZEV technologies; identified barriers to widespread ZEV deployment and projected future ZEV technical capabilities; and estimated the cost of ZEVs from 1998 to 2004.

Data for the ZEV Technology Assessment were obtained from several sources, including the following: existing ZEV industry publications and Booz-Allen files; major automotive original equipment manufacturers; independent electric vehicle manufacturers; battery developers and manufacturers; infrastructure and component developers and manufacturers; the U.S. Department of Energy, the California Air Resources Board, and other concerned government agencies; trade associations such as the Electric Power Research Institute and the Electric Transportation Coalition; and public and private consortia. These sources were contacted by phone, mail, or in person. Some site visits of manufacturers also were conducted. Where possible, raw data were analyzed by Booz-Allen staff and/or verified by independent sources. Performance data from standardized test cycles were used as much as possible.

Findings and conclusions are presented in Section 9 of the report. The findings and conclusions are summarized as follows:

Vehicle range and cost, associated primarily with battery performance, will most likely continue to be an impediment to EV competitiveness with gasoline-powered vehicles through the study period (1994–2004). Although incremental improvements in battery performance are occurring, significant breakthroughs will be required to fully mitigate the cost and range issues.

Cold-weather effects on vehicle performance can likely be minimized through appropriate design using existing technologies. However, such measures will require that EVs operated in New York be different than those operated in California.

Infrastructure to support EV use in New York State is currently inadequate. Infrastructure issues include recharging facilities, standards for plugs and cords, public education, battery recycling, safety training, vehicle registration, insurance coverage, and the cost of infrastructure development and implementation.

Adequate lead time is required to provide the necessary infrastructure and vehicle production volume. Major vehicle manufacturers have stated that decisions for the 1998 model year must be made now. Likewise, small vehicle conversion facilities and motor/controller manufacturers must establish or expand production facilities to meet production volume goals for 1998.

Section 1

INTRODUCTION

BACKGROUND

With the adoption of 6NYCRR Part 218, the State of New York set into motion a requirement for the production and delivery for sale of zero-emission vehicles (ZEVs). ZEVs are vehicles that have no direct exhaust or evaporative emissions of any regulated pollutant. For the 1998 model year, two percent of new passenger cars and light-duty trucks produced for sale in New York State must be certified as ZEVs. The requirement increases to five percent in 2001 and 10 percent in 2003. The ZEV regulations are part of the State's overall low-emission vehicle (LEV) strategy, a vehicular emissions reduction program initially adopted in 1990 by the State of California.

In the near term, battery-powered electric vehicles (EVs) are the most viable technology for meeting the ZEV mandate. However, EVs have different performance capabilities, infrastructure requirements, and costs than the gasoline-powered vehicles that now dominate the light-duty fleet. Successful integration of EVs into the general vehicle population will depend on whether and how these differences are accommodated.

To reevaluate and affirm the feasibility of ZEVs for New York State, Part 218 of 6NYCRR requires periodic review of ZEV technology developments. As part of this review process, the New York State Energy Research and Development Authority (NYSERDA) awarded a contract to Booz-Allen & Hamilton Inc. (Booz-Allen) to perform a technology assessment of ZEVs. Specifically, Booz-Allen performed the following tasks:

- Assembled a database of information about key ZEV manufacturers and other organizations, their products or services, and plans;
- Described the current state of ZEV technologies;
- Identified barriers to widespread ZEV deployment and projected future ZEV technical capabilities; and
- Estimated the cost of ZEVs from 1994 to 2004.

The data collected, and the analyses performed by Booz-Allen, will be considered by policy makers in evaluating New York State's ZEV policies.

DEFINITION OF A ZEV

The definition of ZEV used is based upon Title 13, California Code of Regulations, part 1900, as modified by the California Air Resources Board (CARB), and has been approved for this study by NYSERDA:

"A Zero Emission Vehicle (ZEV) is a vehicle which produces zero emission of any criteria pollutant (carbon monoxide, oxides of nitrogen, nonmethane hydrocarbons, and particulate matter [PM-10]) under any and all possible operational modes and conditions, with the exception of emissions from fuel-fired heaters. Fuel-fired heaters are allowed on ZEVs provided that the fuel system is completely sealed and leak-free, and that the heater cannot be operated when the ambient temperature is above 40°F."

DATA COLLECTION METHODS AND SOURCES

During this study, every effort was made to obtain the most unbiased and objective data. This was often difficult, because much of the available data came from stakeholders with vested interests in the outcome of the study. Where possible, raw data were analyzed by Booz-Allen staff and/or verified by independent sources. Performance data from standardized test cycles were used as much as possible. In some cases, it was necessary to maintain the anonymity of the data source.

As a matter of business policy, Booz-Allen maintains the highest possible levels of objectivity in studies such as the ZEV Technology Assessment. The firm holds no manufacturing or other proprietary interests that would be affected by the outcome of this study.

Data for the ZEV Technology Assessment were obtained from several sources, including the following:

- ZEV industry publications and Booz-Allen files;
- Major automotive original equipment manufacturers (OEMs);
- Independent electric vehicle manufacturers;
- Battery developers and manufacturers;
- Infrastructure and component developers and manufacturers;
- The U.S. Department of Energy (DOE), the California Air Resources Board (CARB), and other government agencies;
- Trade associations, such as the Electric Power Research Institute (EPRI) and the Electric Transportation Coalition; and
- Public and private consortia.

These sources were contacted by telephone, mail, or in person. Some site visits of manufacturers also were conducted. In obtaining data for the ZEV database, a data collection guide was used to structure the personal interviews.

The authors of this report have attempted to make the information contained herein as current as possible. However, the status of ZEV technology and related events is changing rapidly, and some of the information in this report may quickly become outdated. Any relevant developments that occurred since April 1995 may not be included.

Section 2

THE ZEV DATABASE

DATABASE PURPOSE AND OBJECTIVES

The ZEV Database contains information about organizations and products in the ZEV marketplace. The database focuses on major players (primarily domestic) in the industry, as well as New York State manufacturers and other organizations. Point-of-contact information (e.g., name and address) and product information are included. Products include vehicles, batteries and energy storage devices, and miscellaneous components (including charging stations).

The ZEV Database was developed to achieve several objectives:

- Provide basic information for the ZEV Technology Assessment;
- Provide input for solicitation bidders' lists, and assist New York State in contacting ZEV industry representatives;
- Assess employment and other economic activity related to ZEVs in New York State;
- Consolidate and augment existing ZEV databases belonging to other organizations;
- Ensure compatibility with the existing NYSERDA Outreach Database; and
- Create a user-friendly and easily expandable database system.

The primary users of the ZEV Database will be staff members of NYSERDA and the NYS Department of Environmental Conservation (DEC). The ZEV Database has been developed using Paradox®¹ relational database software for use on an IBM-compatible personal computer.

¹ The Paradox® software package is produced by Borland International, Scotts Valley, California.

DATABASE STRUCTURE

As shown in Figure 2-1, the ZEV Database consists of four main tables—Companies and Organizations, Vehicles, Batteries/Energy Storage Devices, and Component Manufacturers.

Figure 2-1. ZEV Database Structure

DATA COLLECTION

Data for the ZEV Database have been collected from existing databases and selected survey respondents. Data also were collected from Booz-Allen's in-house files and documents. Most of the data were collected by telephone, facsimile, or mail; and much of the data were self-reported. The accuracy of the data has been verified where possible.

Survey respondents were identified using Booz-Allen address lists, attendance lists from ZEV-related conferences, and industry literature. Judgments on whether to include particular organizations or products in the database were made on a case-by-case basis by Booz-Allen personnel. Criteria included the following:

- Level of specialization in the ZEV industry;
- Amount of yearly expenditures devoted to ZEVs or related products;
- Number of vehicles, batteries, or other major ZEV products developed or produced;

- Potential for entering the ZEV industry in the future;
- Location in New York State; and
- Location in the United States.

Vehicles were included in the database if at least five of a model have been made, or if the manufacturer has significant production plans. There are a number of one-of-a-kind stock conversion ZEVs in existence. However, most of these are not included in the database, unless they are located in New York State.

Component suppliers generally were not included if ZEVs represent a relatively small part of their existing or potential sales. For example, most electrical connector and instrumentation suppliers were not included. However, special consideration was given to firms located in New York State.

SYSTEM INTEGRITY

The integrity of the database was maintained by validating input, performing updates, and instituting configuration controls.

Database inputs were performed by Booz-Allen. In addition, hard-copy database reports were reviewed for accuracy and consistency by Booz-Allen personnel. Prior to final acceptance and delivery of the database, NYSERDA, and DEC staff were given the opportunity to review a complete set of hard-copy database reports.

Data concerning product performance (such as vehicle range) were entered into the database as stated by the manufacturer. For the purposes of the database, Booz-Allen did not make judgments regarding the accuracy of such claims. Concerns regarding the accuracy of the data are addressed in subsequent sections of this report. Footnotes included in the database hard-copy reports clarify this issue.

DOCUMENTATION

The following documents were submitted to NYSERDA:

- ZEV Database Design Document;
- User's Guide;
- Printout of table structures and source code; and
- Hard copies of all standard database reports.

Section 3

CURRENT STATE OF ELECTRIC VEHICLE TECHNOLOGIES

Currently, the only vehicles that qualify as ZEVs are electric vehicles (EVs). EVs are being built by a diverse group of manufacturers—ranging from hobbyists to the “Big Three” U.S. automakers and foreign automakers. EV performance capabilities and cost can vary substantially depending on component quality and manufacturer engineering expertise.

To review the status of EV technologies, it is necessary to understand basic EV components and subsystems. EVs use several components and subsystems that are very different from those used in conventional gasoline-powered vehicles. Therefore, we first discuss the developmental status of important EV components and subsystems. The primary focus of this discussion is on powertrain components—Section 4 discusses battery systems.

Next, we discuss features of pre-production or production EVs. This is followed by a review of manufacturers’ EV production plans to meet the 1998 ZEV sales mandate.

Finally, we present EV technology considerations for the State of New York. Most major manufacturers have done very little evaluation of EV operation in the Northeast. The colder ambient temperatures in New York State may significantly affect EV range and performance, therefore, we review these implications for the ZEV sales mandate.

EV COMPONENTS REVIEW

Electric vehicles contain several components and subsystems that are different from those used in conventional gasoline-powered vehicles. These unique components include the following:

- High-Voltage Battery system;
- AC or DC motor;
- Motor controller/inverter;
- DC to DC converter or battery for powering vehicle accessories;
- Onboard battery charging port (optional);
- Low rolling-resistance tires (optional);
- Electric or fuel-fired heaters (optional); and
- Electric air conditioners (optional).

Due to the importance of maximizing energy efficiency, some purpose-built EVs use lightweight body materials to reduce weight and incorporate sleek body styling to reduce aerodynamic drag. For example, the GM Impact has composite body panels surrounding an aluminum frame and magnesium-framed seats, and was designed to achieve a drag coefficient of 0.19¹ (compared to 0.3 for a typical gasoline-powered vehicle). The ability to minimize weight and optimize component placement will give efficiency advantages to an EV designed "from the ground up," compared to an EV converted from an existing vehicle chassis.

However, most EVs built by smaller manufacturers will continue to use existing gasoline vehicle chassis to avoid the cost of developing a purpose-built chassis. By using gliders—gasoline vehicle chassis with the engine, fuel system, and emission control system removed—EV manufacturers also can avoid performing physical crash testing to meet federal safety requirements, although engineering analysis of vehicle structural integrity still is required.²

In this section, the developmental status of important EV components and subsystems are reviewed. The primary focus here is on powertrain components. Advancements in battery systems are discussed separately in Section 4 of this report.

Electric Motors

Electric motors are used to convert electrical energy into mechanical energy. Both direct current (DC) and alternating current (AC) motor drives are available for providing traction power to EVs. Three types of motors are used for EVs—DC brush, AC induction and DC permanent-magnet.

The series motor is the most common type of DC brush motor used in EVs. A series motor consists of a field coil wired in series with the armature. As a result of the armature and field coil experiencing the same current, DC series motors exhibit certain distinct characteristics. They have a high starting torque, making them suitable for moving large loads from a complete standstill. When lightly loaded, the series motor runs at a relatively high speed. If the load increases, the motor slows down and produces more torque. At part-load conditions, the low motor speed leads to somewhat lower efficiency.

Brush DC series motors have a long history of use in industrial and on-road EVs. One of the main advantages of these motors is their ability to operate directly from the current provided by

¹ General Motors, *Impact 3 Specification Sheet*, 1994.

² Personal communications with EV conversion companies, 1994.

the battery, without having to use an inverter. Thus, controllers for DC brush motors are fairly simple and inexpensive, consisting of a "chopper" control. The disadvantages are somewhat low part-load efficiency, as previously mentioned, and generally lower maximum operating speeds (roughly 4,000 to 7,000 rpm). Peak efficiency for DC brush systems is 85 to 89 percent.³

Motor life depends on the condition of the brushes. The brush, actually a solid piece of carbon or other conductive material, is the contact through which electricity is transmitted to the armature. Brushes can wear out prematurely due to high temperatures, which can result from blocked air filters, or contamination due to poorly fitted air filters. Neglecting to replace worn brushes can damage the motor and shorten its life. Specifically, problems such as flash-over (electrical arcing across multiple commutator points) can occur. However, brush design and materials engineering have improved greatly over the last 10 years, so the brushes themselves are less prone to wear and damage. Under proper conditions, a normal brush life of 50,000 to 100,000 hours of motor operation can now be achieved.⁴ This is longer than the typical life of an EV.

Three-phase AC induction motors are now commonly used in EVs. An induction motor relies on magnetic flux to induce current in the armature rather than providing it directly. AC induction motors generally have "squirrel-cage" rotors, which require no commutators, slip rings, or brushes, thus making them less expensive to build and maintain.

AC induction motors used in EVs have the general torque and shaft power versus speed curves shown in Figure 3-1. AC induction motors are characterized by their high power and efficiency over wide ranges of torque and speeds. AC induction motors can operate up to 15,000 rpm and have a peak efficiency of about 95 percent.⁵

³ Ronald Martin, Presentation at the 1992 Solar and Electric Vehicle Conference, Boston, Massachusetts, 1992.

⁴ Product literature from General Electric (GE) and GE brush suppliers, 1994.

⁵ Ibid.

Figure 3-1. Illustrative Performance Curves for AC Induction Motors

Permanent-magnet DC motors are brushless and have peak operating speeds between brush DC series and AC induction motors. The input current actually has an alternating wave form, making them somewhat of a hybrid between AC and DC. Like AC motors, permanent-magnet DC motors require a complex controller, which adds significantly to total drivetrain system cost.

General performance curves for permanent-magnet DC motors are very similar to those for AC induction motors (see Figure 3-2). Compared to AC motors, brushless permanent-magnet motors have a lower maximum operating speed of about 6,000 to 7,000 rpm. Their peak system efficiency is 95 to 97 percent,⁶ and their part-load efficiency can be higher than AC induction motors under certain operating regimes.

Research also is being conducted on other types of motors for use in EVs, such as switched-reluctance and pancake-type motors. Switched-reluctance motors can operate at very high speeds of more than 15,000 rpm, and are potentially more efficient than AC induction motors. Although switched-reluctance motors have excellent durability, electronic component costs are high. Pancake-type motors rely on a series of pancake-like rotors to turn the drive shaft. Magnetic flux from the stator is transmitted in a longitudinal direction to the pancake surface of the rotor, allowing flux to be transmitted over a large area and small air gap. (A conventional motor transmits magnetic flux radially along the outside edge of the rotor.) The pancake motor offers the potential for lighter weight, higher torque, and more packaging flexibility than AC

⁶ Ibid.

induction motors.⁷ Both switched-reluctance and pancake motors are in the developmental stage and have not been considered for in-vehicle demonstrations until recently (late 1994).

It is unclear which type of propulsion system is superior overall. AC motors are generally lighter, more durable, more efficient, and cheaper to manufacture than brush DC motors. These advantages of AC motors are offset by the cost and weight of the complex electronics needed by the AC inverter/controller system. Also, liquid cooling is required for some AC propulsion systems, which further adds to their complexity. Recent advances in microelectronics, power electronics, and manufacturing technologies have made AC powertrains more practical than before for use in EVs. However, AC motor/controller systems still cost significantly more than brush DC systems.

Inverters/Controllers

The controller regulates the flow of electricity from the batteries to the motor by electronically turning the current on and off in response to driver commands and dynamic changes in the vehicle driveline. DC series motors use a relatively simple chopper-type controller. AC motors use a controller packaged with an inverter for converting the direct current from the battery pack to alternating current. DC permanent-magnet motors have controller requirements similar to those of AC induction motors. Inverter/controllers are about 95 percent efficient.

The controller also interfaces with and manages a number of other vehicle functions including battery charging, regenerative braking control, and driver display interfaces. Each of these functions is described briefly below:

- Battery charging. Many EVs are equipped with on-board chargers that convert AC power from an electrical outlet to DC power for charging the battery pack. Battery chargers are discussed in Section 5.
- Regenerative braking. Electric motors can generate energy when the vehicle is braking. The kinetic energy normally dissipated when braking can be converted to electrical energy by the motor, which acts as a generator/alternator. Energy is then transferred through the inverter/controller for storage in the battery pack. This is referred to as regenerative braking. In city driving, regenerative braking

⁷ Mr. S. Ohba, Soleq Corporation, 1994, personal communication.

can significantly increase driving range, and reduce wear on the vehicle's friction brakes.

- Driver display interfaces. The dashboard of an EV may include instruments such as an estimated state-of-charge indicator, a motor/controller over-temperature indicator, a brake light control during regenerative braking, a low-voltage indicator, and fault indicators.

Drive Systems

Electric motors can be coupled directly to the final drive of a vehicle without the need for a clutch or transmission. AC induction and DC permanent-magnet motors have much broader power ranges compared to brush DC series motors or conventional engines. The broad power range allows fixed-ratio gearing to be used and eliminates the need for a transmission. The advantages of fixed-ratio gearing include smoother acceleration, enhanced regenerative braking utilization, improved energy efficiency, reduced gearbox cost, and reduced size and weight of the driveline. If the motor is not able to provide the needed power levels and/or torque over the entire speed range, such as with some DC motors or heavier vehicles, 2- or 3-speed transmissions may be required to maintain acceptable acceleration and performance on grades.

Some EVs with AC propulsion systems have two motors, each mounted at a wheel. (AC motors are somewhat easier than DC motors to package into this configuration.) The motors are driven by two separate inverters, which are governed by a single controller. Speed reducers are used to translate the motor speed to the level needed by the wheels. This approach eliminates the need for a differential and associated components. However, concerns have been raised about the vulnerability of the motors to damage from road hazards. Work is continuing on this "wheel motor" driveline concept, particularly in the areas of motor packaging and improvement of motor speed range.

Propulsion Cooling Systems

With the motor spinning at high speeds and inverters/controllers handling massive amounts of power, the heat buildup within the motor and controller can be considerable (even though driveline efficiency is generally much greater for an EV than for a conventional internal combustion vehicle). There are several ways to provide the necessary cooling—natural air cooling, forced air cooling, or liquid cooling. Natural air cooling relies on natural ventilation, which is enhanced by the vehicle's motion. Forced-air cooling involves the use of fans and blowers. With liquid cooling, oil- or water-based solutions are used to carry excessive heat away

from the motor and controller. Most AC and DC permanent-magnet drivetrains available today use some type of liquid cooling system.

Lubrication oil for the final drive gearing can be circulated to cool motors mounted directly and sealed in the transaxle. Heat is either rejected through the axle housing and the oil pan (the oil pan would be finned to more quickly dissipate heat), or by adding a separate coolant circuit. The axle oil cannot be used to cool the inverter, since the operating temperature of the motor and axle is much higher than that of the inverter.

Climate Control Systems

Many EVs available today are equipped with resistive heaters and air conditioning. Due to the need to minimize energy use, it is especially important that climate control systems on EVs be optimized for very high efficiency.

EV motors generate little waste heat compared to combustion engines because electric motors are about 90 percent efficient, compared to about 25 percent for a gasoline engine. The waste heat from combustion engines is used to heat the passenger compartment and defrost windows, but EVs must rely on a separate heat source. EVs use resistive heaters, which operate on battery and/or regenerative current. Energy consumed by resistive heaters will have a detrimental impact on range. The OEMs estimate, and EV fleet operators confirm, that use of resistive heaters in very cold conditions can reduce overall vehicle range by more than 30 percent in urban driving.⁸ More efficient but complex and heavy heat pumps also can be used, although resistive heating will be needed at low temperatures. To avoid a loss in range, fuel-fired heaters with zero evaporative emissions are allowed under the ZEV regulations for use when the ambient temperature is below 40°F. (More information on the effect of heaters on EV range is presented in ZEV Technology Considerations for New York State, page 3-19.)

Air conditioners used for EVs operate in a similar manner to those on gasoline-powered vehicles. However, the energy comes from the battery pack rather than the fuel tank. Some manufacturers are working on developing more efficient, lighter-weight air conditioners for use in EVs and internal combustion vehicles. Other manufacturers are evaluating more effective cooling strategies such as providing cool air just to the passenger seat rather than the entire compartment,

⁸ Based on personal communications with fleet operators and vehicle manufacturers.

or using solar-powered fans to cool the vehicle while it is parked. Use of currently available air conditioners will reduce vehicle range by about 20 percent in typical city driving.⁹

GENERAL CHARACTERISTICS OF ZEVs AVAILABLE IN 1995

As of January 1995, more than 20 passenger car (PC) or light-duty truck (LDT) models have been certified as ZEVs. As shown in Table 3-1, this includes three models from major automobile OEMs. All these vehicles are battery-powered electrics. In addition, dozens of companies throughout the U.S. offer EV retrofit kits that can be used to convert gasoline-powered cars and trucks to electric propulsion. Retrofit EVs are not counted against the ZEV mandate, although they may qualify for tax credits and other financial incentives.

Most new EVs are purchased by government and electric utility fleets, which are subject to alternative-fuel vehicle purchase requirements. Research institutions are also major purchasers. In comparison to conventional vehicles, costs are high and vehicle optimization is still underway. Table 3-2 illustrates some important performance characteristics and costs of EVs that are for sale or are being tested in demonstration programs. These vehicles represent the current state of EV technology. It is important to note that many of these vehicles have not been formally certified as ZEVs by CARB.

**Table 3-1. ZEVs Certified by CARB as of January 1995
(Passenger Car and Light-Duty Truck Models Only)**

Source: Memorandum from Norman Kayne to Rod Summerfield, CARB, January 31, 1995

Manufacturer	ZEV Model(s)	
Advanced Electric Car Technology Inc.	Electric Hyundai Sonata Electric Hyundai Excel	Electric Hyundai Scoupe
Chrysler Corporation	TEVan (Dodge Caravan)	
Drive Electric	Calectric (Geo Prizm) Chevy S-1	Eagle Summit
Ford Motor Company	Ecostar (European Escort)	
General Motors Corporation	Impact 3 (purpose-built)	
Green Motorworks	Kewet El-Jet ("neighborhood EV")	
Renaissance	Tropica (purpose-built)	
Solar Electric/US Electricar (AC-motor equipped vehicles sold under Electricar nameplate)	Electron ECO (Geo Metro) Electron Sedan/Wagon (Ford Escort) Electron Truck (Chevy S-10) Electron Commuter Van (Consulier) Electron Truck (Ford Ranger) AESOP (Toyota Paseo)	Electricar ECO (Geo Metro) Electricar Sedan (Geo Prizm) Electricar Truck (Chevy S-10) Electricar Van (Consulier) Electricar GTP Sport (Consulier)
Solectria	Force (Geo Metro)	

⁹ Ibid.

Table 3-2. ZEVs Available for Sale or Demonstration in the U.S.—January 1995
Source: All data were obtained from manufacturers' product sheets unless indicated

Model Name	Base Vehicle/ Body Style	Battery Type	Curb Weight (lbs)	Motor Type (peak kW)	Mfr. Stated Range	Top Speed (mph)	Acceleration, 0 to 60 mph (sec)	Unit Base Price (\$)
AC Propulsion ELX	Honda CRX/Hatchback	Sealed recombinant lead-acid	2,740	AC induction (100 kW)	131 mi at 55 mph	80	7.8	~\$70,000 ^a
B.A.T. Int'l Geo Metro	Geo Metro/Hatchback	Deep-cycle lead-acid	N/A	DC brush (37 kW)	60 to 100 mi	N/A	N/A (0 to 35 in 10 sec)	\$16,000
B.A.T. Int'l Ford Ranger	Ford Ranger/Pick-up	Deep-cycle lead-acid	N/A	DC brush (48 kW)	50 to 80 mi	N/A	N/A	\$24,000
Chrysler TEVan	Dodge Caravan/ Plymouth Voyager	Nickel-iron or nickel-cadmium	5,150 ^b	DC brush (54 kW)	80 mi SAE C-Cycle	65	53.0	\$100,000 ^b
Ford Ecostar	European Escort / Mini-panel van	Sodium-sulfur	3,060 to 3,200	AC induction (56 kW)	100 mi EPA City	70	13.8	\$100,000 (lease only)
General Motors Impact 3	Purpose-built 2-door/ Sports coupe	Sealed recombinant lead-acid	2,910	AC induction (102 kW)	70 mi City 90 mi Hwy	75	8.5	Demonstration units only
Honda EVX	Modified Honda Civic/ Hatchback	Sealed lead-acid	3,417	Brushless DC P-M ^c (49 kW)	65 mi EPA City+Hwy	80	N/A	Demonstration units only
Renaissance Tropica	Purpose-built/ Convertible	Lead acid	2,160	DC brush ^d (18 kW)	60 to 80 mi	60	N/A (0 to 30 in 5.2 sec) ^d	\$15,200
Solar Car Corp Pickup Truck Kit	Chevy S-10/GMC S-15 conversion kit	Deep-cycle lead-acid	3,700	DC brush (21 kW)	40 to 70 mi	70 to 75	N/A	\$7,000 conversion kit only
Solectria Force	Geo Metro/Hatchback	Deep-cycle lead-acid	2,056 to 2,135	Brushless DC P-M (19-21 kW)	60 to 70 mi	60	N/A (0 to 30 in 8 sec)	\$26,000 to \$28,000
Solectria Force NiCd GT	Geo Metro/Hatchback	Nickel-cadmium	2,271	AC induction (42 kW)	120 mi	70	N/A (0 to 30 in 4.5 sec)	\$59,000
Solectria E-10 Fleet Pickup	Chevy S-10/Pick-up	Lead-acid (nickel-cadmium optional)	3,450 to 3,700	AC induction (42 to 56 kW)	60 to 70 mi (at 50 mph)	60 to 70	N/A (0 to 30 in 7-9 sec)	\$42,000 to \$43,000
U.S. Electricar Sedan	Geo Prizm/Sedan	Sealed recombinant lead-acid	3,440	AC induction (50 kW)	50 to 80 mi	80	N/A (0 to 50 in 12 sec)	\$38,000 ^e
U.S. Electricar Pick-up	Chevy S-10/Pick-up	Sealed recombinant lead-acid	4,400	AC induction (50 kW)	50 to 90 mi	75	N/A (0 to 50 in 15 sec)	\$43,000 ^e
U.S. Electricar GTP SportCoupe	Modified Consulier GT/ Racing chassis	Sealed recombinant lead-acid	3,000	AC induction (50 kW)	45 to 70 mi	80	N/A	~\$100,000 ^e

^a "AC Propulsion CRX," *Road & Track*, October 1992.

^b Personal communication, Chrysler, 1994.

^c "Honda EVs to LA," *Automotive Engineering*, January 1995.

^d "Preview Test: The Electric Tropica," *Car and Driver*, October 26, 1994.

^e Personal communication, U.S. Electricar, 1994.

One measure of the design maturity of an EV is its energy use rate (sometimes referred to as its efficiency). The energy use rate is a function of the weight of the vehicle, the efficiency of its drivetrain, and the aerodynamics of its body style.

In terms of energy use, the most advanced electric cars available today on a production or pre-production basis are the Solectria Force, the AC Propulsion ELX, and the GM Impact.

Table 3-3 lists available energy use data for these and other vehicles over the EPA City and Highway Cycles. These are standard test cycles used to measure the fuel economy of gasoline-powered vehicles and the energy efficiency of EVs. The EPA City Cycle, known as the Federal Urban Driving Schedule (FUDS), consists of about 7.5 miles of stop-and-go city driving for approximately 23 minutes (simulated on a dynamometer). The average speed over the FUDS is about 18 mph. The EPA Highway Cycle, known as the Federal Highway Fuel Economy Test (HWFET) Schedule, is approximately 10.5 miles in length and has an average speed of 48 mph.

Table 3-3. Energy Use Rates for Electric Vehicles

Source: Booz-Allen analysis of manufacturers' data

Vehicle	Body Type/ Test Weight (lbs)	Motor	Battery	Energy Usage	
				EPA City kWh/mi	EPA Hwy kWh/mi
GM Impact (1994)	Subcompact/ ~ 3,160	AC induction	Lead-acid	0.19 ^a	0.15 ^a
Solectria Force (1993)	Subcompact/ 2,260	AC induction	Nickel-metal- hydride	0.15 ^b	N/A
Solectria Force (1991)	Subcompact/ 2,300	Brushless DC permanent-magnet	Lead-acid	0.17 ^b	N/A
AC Propulsion ELX (1992)	Subcompact/ 2,940	AC induction	Lead-acid	0.17 ^b	0.155 ^c
Solar Car Corp. Festiva (1991)	Subcompact/ 2,280	DC brush	Lead-acid	0.32 ^b	N/A
Renaissance Tropica	Convertible/ 2,300	DC brush	Lead-acid	0.24 ^d	0.20 ^d
Ford Econstar	Small truck/ ~ 3,200	AC induction	Sodium- sulfur	0.30 ^a	N/A
Chrysler TEVan	Minivan/ 5,300	DC brush	Nickel-iron	0.48 ^e	N/A

N/A - Not available

a Booz-Allen calculation based on manufacturer's specification sheet.

b California Air Resources Board, *Electric Vehicle Test Program, Informal Report (Draft)*, May 1994.

c Idaho National Engineering Laboratory, *Performance Testing of the AC Propulsion ELX Electric Vehicle*, April 1994.

d Manufacturer's product sheet.

e Manufacturer's product sheet-test cycle not specified.

In terms of energy use, performance, and engineering design, the most advanced EV available today on a production or pre-production basis is probably the GM Impact. The Impact is a purpose-built, two-passenger sports coupe engineered to have a level of comfort and safety similar to a conventional vehicle. The GM Impact is equipped with an AC induction motor with regenerative braking; a sealed recombinant lead-acid battery system with inductively-coupled charging system; a purpose-built chassis that uses an aluminum frame with composite body panels; an electric heat pump climate control system; and low-rolling resistance, high-pressure tires. It also is equipped with dual air bags, anti-lock power brakes, cruise control, power door locks and windows and other features typically available on conventional gasoline-powered vehicles.

OEM PRODUCTION PLANS FOR ZEVs

The ZEV sales mandate applies initially only to automobile manufacturers that sell more than 35,000 passenger cars and small light-duty trucks per year in California. These same manufacturers will also be required to sell ZEVs in New York State and Massachusetts. Beginning in model year 2003, "intermediate volume" manufacturers that sell less than 35,000 vehicles per year in California also will be subject to the ZEV mandate. Small volume manufacturers that sell 3,000 or fewer vehicles are exempt from having to produce ZEVs.

Manufacturers claim that to produce EVs for the 1998 model year, vehicle designs must be "locked in" by early 1995 (concurrent with the publication of this report). A three-year lead time is needed to retool assembly plants, retrain workers, establish contracts with component suppliers, conduct federal certification testing (e.g., for safety), perform quality assurance testing, and launch a marketing campaign. At the present time, all major OEMs are planning to use advanced lead-acid batteries for their 1998 ZEV models, although nickel-metal-hydride and nickel-cadmium are still being considered. To meet 1998 production requirements, the OEMs have stated that a battery technology must be chosen at the same time that the vehicle designs are locked in.¹⁰ Because battery design is integral to the total vehicle design, especially thermal management, changing battery design at a later date could cause some problems. However, some independent EV developers claim that battery modularity can be achieved and that battery

¹⁰ Site visits and personal communications, EV engineering staff, General Motors, Ford, and Chrysler, 1994.

designs can be changed without extensive changes to the vehicle. Section 4 contains a more detailed discussion of the status of EV battery research and development.

This section summarizes the production plans of major vehicle manufacturers for meeting the 1998 ZEV mandate. Information in this section was obtained from on-site visits, personal interviews with company representatives, and press accounts of statements made by the various companies.

Large Volume Manufacturers

In the initial years of the ZEV sales mandate (from 1998 to 2003), seven large-volume OEMs will be required to produce ZEVs: General Motors, Ford, Chrysler Corporation, Toyota, Honda, Nissan, and Mazda. This section discusses each manufacturer's production plans.

General Motors. General Motors (GM) is planning to offer the two-seat Impact model for sale in 1998. GM also is developing other options in case there are problems with the Impact, such as its production cost or market-driven design changes. These other options include installing the Impact's propulsion system in a Geo Prizm or other existing chassis.¹¹

Intended as a commuter vehicle, the Impact is currently being demonstrated in GM's *PrEView Drive Program*—a program intended to gather market research on EV technology and infrastructure. Under this program, 30 Impact vehicles will be rotated among 1,000 drivers in 12 cities over a two-year period. GM plans to bring the Impacts in the program to New York City in spring 1995. The demonstration units are powered by 27, 12-volt AC/Delco, sealed recombinant lead-acid battery modules connected in series (nominally a 312-volt DC propulsion system, with one battery module dedicated for other loads).¹² The batteries have an expected life of 25,000 to 30,000 miles and will cost \$1,500 to \$2,000 to replace.¹³

Initial reaction from drivers participating in the PrEView Drive apparently has been very positive.¹⁴ A report in *Business Week* indicates that GM is planning to build as many as

¹¹ Site visit (July 1994) and personal communication (January 1995), EV staff, General Motors.

¹² "GM's PrEView Impact Electric Vehicle," *Automotive Engineering*, February 1995, pp. 85-89.

¹³ Kenneth Baker, vice president of GM R&D; as quoted in the *Chicago Tribune*, October 14, 1993.

¹⁴ *Investors Business Daily*, December 20, 1994; *Business Week*, January 23, 1995.

7,500 Impacts from 1995 to 1996, with the first models due out at the end of 1995.¹⁵ Current plans call for an initial run of 2,500 units. If these vehicles sell well, GM could build two more runs of 2,500 each for a total of 7,500 vehicles.¹⁶ To keep costs down, GM may contract assembly operations to a company that specializes in producing niche market/low-volume vehicles.¹⁷ The selling price for these early vehicles could be as high as \$40,000.¹⁸

Ford. Although Ford has gained substantial experience with the "Ecostar," the vehicle will not be offered for sale in 1998. Instead, Ford is considering five possible EV alternatives: a medium-duty delivery vehicle, a four-passenger vehicle on a truck chassis, a Ranger-based conversion, a purpose-built vehicle, or providing "gliders" to qualified EV conversion firms.¹⁹ (A "glider" is a conventional vehicle body without the gasoline engine, fuel tank, or emission control system installed.) When this report was published, none of the five alternatives had been eliminated.

Ford is actively working with conversion companies to establish specifications for a Qualified Vehicle Modifiers (QVM) Program. Under this program, Ford would provide gliders to preapproved conversion companies; the conversion companies would then install the electric drivetrain, battery, and other EV components. The Ford nameplate would remain on the vehicle and the vehicles would be sold through Ford dealerships. Ford has established a similar program for its compressed natural gas vehicles. For EVs, Ford has worked with U.S. Electricar and B.A.T. International to develop guidelines for its QVM Program.²⁰

Chrysler. Chrysler has announced that its EV product offering for 1998 will be a newly designed minivan called the "NS." The NS platform first will be introduced as a gasoline-powered vehicle in the 1996 model year. The electric version will be equipped with a Westinghouse AC drivetrain and will reportedly feature a more refined, consumer-ready design than the TEVan.²¹

¹⁵ "The Shocker at GM: People Like the Impact," *Business Week*, January 23, 1995.

¹⁶ Ibid.

¹⁷ Ibid.

¹⁸ Ibid.

¹⁹ Site visit (July 1994) and personal communication (January 1995), Ford Motor Company EV engineering staff.

²⁰ *Automotive News*, January 2, 1995.

²¹ *Electric Vehicle Progress*, April 15, 1994.

Chrysler has been testing both the Electrosource Horizon advanced lead-acid battery and the Ovonic nickel-metal-hydride battery as possible candidates for installation in its NS minivan.²² In October 1994, Electrosource announced it will package the Horizon battery in prototype versions of the electric NS, and develop tooling and manufacturing support equipment.²³ Chrysler has not formally made an announcement about the battery technology that will be used in the NS, but industry speculation is that the lead-acid Horizon battery will be selected for 1998.²⁴

Toyota. Toyota recently introduced its "EV-50" model, and it is likely that Toyota's 1998 EV product offering will closely resemble the EV-50. The EV-50 is a 2-door, 4-seat, monocoque commuter car with a curb weight of 3,200 pounds. It uses sealed, maintenance-free lead-acid batteries; an AC induction motor; and regenerative braking. The city driving range of the vehicle is about 68 miles per charge.²⁵ The concept vehicle features a heat pump air conditioner designed to achieve higher efficiency. When the vehicle is parked with the ignition off, a roof-mounted photovoltaic panel provides power to automatically-activated fans to provide forced ventilation in the passenger cabin, keeping the temperature down and reducing the load on the air conditioner.

Nissan. Nissan is currently evaluating two EV models in test programs in Japan: the "EV-1" and the "EV-2."²⁶ The vehicles are based on the Cedric and Gloria sedans sold by Nissan in Japan. Nissan's EV production plans for the United States are still uncertain. Although the "FEV" was prominently showcased at auto shows in 1991, Nissan has no plans to manufacture the 2-door coupe.

In February 1994, Nissan began selling its Cedric EV in the Japanese market. The Cedric EV is a 4-door sedan, mainly for use by government agencies.²⁷ The Cedric EV is equipped with a 60-kW (peak) AC induction drivetrain and weighs 3,900 pounds.²⁸ At a steady speed of 25 mph, the

²² Personal communication, Chrysler Motor Corporation, December 1994.

²³ "Horizon Battery to be Fitted for Chrysler Electric Vans," *Clean Fuels Report*, November 1994.

²⁴ "Giving Electric Vehicles a Charge," *Business Week*, February 6, 1995.

²⁵ Toyota product specifications.

²⁶ Personal communication, Nissan, January 1995.

²⁷ Shoji Tange and Akitoshi Itoh, "Motor and Controller Systems for EVs," Nissan Motor Co., SAE Paper 94C050.

²⁸ Ibid.

Cedric has a range of 75 miles.²⁹ The vehicle is equipped with a 336-volt, sealed lead-acid battery pack.³⁰

Honda. Honda currently is participating in a demonstration program with two California utilities to evaluate a Civic Hatchback-based EV, its likely ZEV offering for 1998. The Honda "EVX" is powered by sealed lead-acid batteries and a 49-kW brushless DC permanent-magnet motor.³¹ It has a range of about 70 miles in combined city and highway driving.³² The vehicle is equipped with driver and passenger airbags, regenerative braking, electric windshield defroster, and heat pump-driven air conditioning.³³

Mazda. Although Mazda has unveiled several prototype EVs in Japan, it has not announced its EV plans for the United States. A Mazda representative said that the company is looking at building an EV based on a small vehicle platform, such as the 323, or possibly purchasing EV credits or vehicles from another manufacturer.³⁴ Mazda has been developing hydrogen-powered internal combustion vehicles; however, hydrogen-burning vehicles do not qualify as ZEVs under the current regulatory language.

Intermediate-Volume Manufacturers

Although intermediate-volume manufacturers are not required to produce ZEVs until 2003, several of these manufacturers are actively working on EV development programs. In particular, the European manufacturers are readying EVs for the expanding ZEV market in Europe. It is possible that some of these vehicles may be introduced in the United States before the mandated 2003 introduction date.

Volkswagen. Volkswagen has developed an electric version of its Golf/Jetta model, equipped with lead-gel or sodium-sulfur batteries. In November 1994, Volkswagen announced plans to begin small-scale production of these "CityStromer" units in Germany; their near-term goal is to sell 100 units of the vehicle per year to fleet users.³⁵ In urban driving, the CityStromer has a

²⁹ Ibid.

³⁰ Ibid.

³¹ *Automotive Engineering*, January 1995.

³² Ibid.

³³ Ibid.

³⁴ Personal communication, Mazda, December 1994.

³⁵ Reuters Corporate World News, November 8, 1994.

range of 35 miles per charge on the lead-gel batteries, 90 miles on sodium-sulfur batteries.³⁶ The vehicle will be equipped with a 37 kW AC induction motor manufactured by Siemens.³⁷ Although it is not subject to the ZEV mandate until 2003, Volkswagen is considering marketing a Golf-based EV with sodium-nickel-chloride batteries in the United States in 1998.³⁸

Daimler Benz/Mercedes Benz. Daimler Benz, the parent company of Mercedes Benz, has developed several electric commuter cars intended primarily for the European market. Daimler Benz has introduced two electric models equipped with sodium-nickel-chloride batteries: the "C-Electro" based on its C-Class sedan, and the "Vision-A," a 5-door compact car.

The C-Electro is a 4-door sedan equipped with a 20-kW (continuous) AC induction motor and AEG Zebra sodium-nickel-chloride batteries.³⁹ (AEG is a corporate unit of the Daimler Benz Group.) The vehicle is reported to have a range of 75 miles, and the battery is expected to last for 60,000 miles.⁴⁰ Production plans for the C-Electro have not been made public.

Daimler Benz is planning to launch the Vision-A in Europe in late 1997.⁴¹ The ZEV version of the Vision-A is equipped with a 40-kW AC induction motor and has a range of 100 miles in city driving.⁴²

Mercedes Benz recently displayed the "Eco-Sprinter," the small city car it will produce in partnership with SMH Group, the manufacturer of Swatch watches. The Eco-Sprinter is equipped with an AEG Zebra sodium-nickel-chloride batteries and has roof-mounted solar panels that provide electricity to drive a ventilation blower that keeps the car cool when parked.⁴³

Daimler Benz has also unveiled an EV powered by a proton exchange membrane fuel cell that uses hydrogen fuel. The fuel cell has been installed in a Mercedes Benz MB 180 van called

³⁶ Volkswagen product brochure.

³⁷ *Advanced Transportation News Notes*, March 1994.

³⁸ Stuart Johnson, Volkswagen Environmental Staff, personal communication, 1994.

³⁹ *Automotive Engineering*, November 1993.

⁴⁰ *Ibid.*

⁴¹ *Clean Fuels Report*, September 1994.

⁴² *Automotive Engineering*, November 1993.

⁴³ *Clean Fuels Report*, September 1994.

"NECAR" and has been driven successfully several thousand miles in Germany.⁴⁴ According to Daimler Benz, the test vehicle is still experimental, and there are no plans for production.⁴⁵

BMW. BMW has introduced several electric prototypes in the past few years, including the "E1" and the "E2." The E1 is a compact, 2-door coupe that has a range of 75 miles when equipped with sodium-sulfur batteries. BMW recently introduced a second-generation version of the E2 that uses sodium-nickel-chloride batteries. This latter version reportedly achieves a range of 164 miles and accelerates from 0 to 80 mph in approximately 13 seconds.⁴⁶ The E2, also a 2-door coupe, is more spacious than the E1 and was developed specifically for the U.S. market.⁴⁷ With sodium-sulfur batteries, the E2 has a reported range of 160 miles in combined city and highway driving.⁴⁸ The BMW vehicles use a brushless DC permanent-magnet drivetrain developed by Unique Mobility, Inc.

Other Manufacturers

Manufacturers that sell 3,000 or fewer gasoline-powered cars and light-duty trucks in California are not required to produce and sell ZEVs. However, some of these small-volume manufacturers see a market opportunity selling ZEVs in the U.S. This section summarizes the product plans of some of these manufacturers. Conversion companies, such as U.S. Electricar and B.A.T. International, can earn ZEV credits if the gasoline-powered vehicles converted are new (never driven on gasoline) and are certified as ZEVs. These credits, or the EVs themselves, can be sold to OEMs to help them meet the state ZEV mandates.

PSA Peugeot-Citroën. Because no Peugeot cars have been sold in the U.S. since 1991, PSA is not subject to ZEV production requirements. In the spring of 1995, PSA will begin volume production in France of an electric version of its "AX" subcompact car. The vehicles will be built on the same production lines as their gasoline counterparts. PSA hopes to build 4,000 EVs in 1995.⁴⁹ The EVs are priced at about US\$13,000, roughly \$6,000 more than the internal combustion version. A 120-volt nickel-cadmium battery pack is leased separately by the driver

⁴⁴ Ibid.

⁴⁵ *Daimler Benz News*, April 13, 1994

⁴⁶ BMW product brochures.

⁴⁷ Ibid.

⁴⁸ Ibid.

⁴⁹ *Ward's Auto World*, January 1995.

for \$120 per month.⁵⁰ PSA believes when production approaches 40,000 to 50,000 units, the prices of electric AXs may reach parity with conventional versions.⁵¹

Kia. Kia Motors, based in Korea, has developed an EV conversion of its "Pride" passenger car. The EV is claimed to have a range of 60 miles per charge and a maximum speed of 70 mph.⁵² The vehicle is equipped with lead-acid batteries and uses solar panels to provide supplemental battery charging.⁵³ The EV sells for approximately US\$22,800 (compared to a base price of about \$6,000 for the gasoline-powered Pride).⁵⁴ According to Korean press reports, Kia is considering exporting the electric model Pride to the U.S. in anticipation of the ZEV mandate.⁵⁵

Renaissance Cars. Renaissance Cars is a start-up company headed by Bob Beaumont, who popularized the "Citicar" in the 1970s. Renaissance plans to manufacture a number of low-tech, low-cost EVs. Renaissance recently unveiled the "Tropica," a 2-seat convertible intended for sale in warm weather states. At a retail price of \$15,200, including options, the Tropica has a reported range of 65 miles and a top speed of 65 mph.⁵⁶ It is equipped with a brush DC motor (manufactured by Advanced DC Motors) and lead-acid batteries (manufactured by GNB). It does not have heating or air conditioning.⁵⁷ Currently, the convertible is not equipped with a top, but Renaissance is planning to design a top that can be retrofitted.⁵⁸

Renaissance plans to produce 500 "Signature Series" units and then start production of its base model. Production of up to 20 cars per day will begin in early 1995.⁵⁹ Renaissance has negotiated with automobile dealers in Florida, California, Nevada, and Arizona to offer the

⁵⁰ Ibid.

⁵¹ Noel Bureau, Deputy Director of Research and Scientific Affairs, PSA, quoted in *Ward's Auto World*, January 1995.

⁵² *Automotive Engineering*, January 1995.

⁵³ Ibid.

⁵⁴ Ibid.

⁵⁵ Ibid.

⁵⁶ Renaissance Cars product brochure.

⁵⁷ Ibid.

⁵⁸ Personal communication, Renaissance Cars, December 1994.

⁵⁹ Ibid.

Tropica for sale in their showrooms. Expansion to New York and Massachusetts may occur by the end of 1995.⁶⁰

Skoda. Skoda, a vehicle manufacturer based in the Czech Republic, has sold the U.S. distribution rights for its "Electra" EV models to Rama Wheel Corporation. Rama Wheel, a Canadian firm, plans to make the vehicle available in North America. The Electra EV, available in compact car and urban delivery van bodies, has a 23-horsepower (HP) DC motor and a 4-speed transmission. Now sold in Europe, the vehicle can reach a top speed of 50 mph and has a range of 50 miles per charge.⁶¹ The vehicle will be modified for the North American market to achieve a 75-mph top speed and a 60-mile range.⁶² The modified Electra will be sold for about \$25,000.⁶³ Skoda, 30 percent owned by Volkswagen, also plans to develop a purpose-built EV called the "Beta." The Beta will feature a welded-aluminum space frame with a composite body and will likely be fitted with Electrosources Horizon lead-acid batteries.⁶⁴ Rama Wheel Corporation will begin selling the Beta in 1995.

Solectria. Solectria, based in Arlington, Massachusetts, currently sells converted Geo Metros and Chevy S-10 pick-up trucks. In 1997, Solectria plans to produce a purpose-built EV, the "Sunrise." The four-seat coupe is expected to sell for less than \$20,000, provided that 20,000 or more initial orders are received.⁶⁵ The Sunrise is a lightweight, all-composite vehicle that will be powered by Solectria's 50-kW AC induction drive system. It also features an inductive charger developed by Hughes Power Control Systems.⁶⁶ The vehicle is expected to have a range of 120 miles on sealed lead-acid batteries and 200 miles on Ovonic nickel-metal-hydride batteries.⁶⁷

ZEV TECHNOLOGY CONSIDERATIONS FOR NEW YORK STATE

None of the large-volume OEMs interviewed for this report expressed support for the ZEV mandate. The large-volume OEMs are concentrating most of their current EV development

⁶⁰ Ibid.

⁶¹ *Electric Vehicle Progress*, May 15, 1994.

⁶² Ibid.

⁶³ Ibid.

⁶⁴ Ibid.

⁶⁵ Solectria press release, December 3, 1994.

⁶⁶ Ibid.

⁶⁷ Solectria vehicle specification sheet.

efforts on the California market. The major OEMs claim to have done very little work in evaluating EVs for use in the Northeast. The colder ambient temperature in New York State may significantly affect the range and performance of EVs during the wintertime, and could jeopardize the overall success of the ZEV mandate. This section discusses the general effects of cold temperatures on EV performance and summarizes some actual experience based on discussions with EV fleet operators.

Effects of Cold Temperatures on EV Performance

Although relatively little data are available on EV operation in cold climates, the major OEMs have identified several vehicle factors that may contribute to a decline in EV performance in cold weather:

- Higher aerodynamic drag due to greater air density;
- Increased rolling resistance from lower tire pressure and stiffening of the tire material;
- Increased use of auxiliary loads: electric heater, heater blower motor, windshield wipers, and headlights;
- Increased torque needed to travel through slush and snow; and
- Higher viscosity of lubricating oils and greases.

According to Ford Motor Company, the accumulation of these vehicle factors could reduce vehicle range over the FUDS by nearly 60 percent at 0°F compared to 70°F.⁶⁸ The Ford estimate assumes:

- A 6 kW electric heater is used 100 percent of the time;
- A constant 15 mph wind is blowing in one direction (the vehicle is assumed to travel a square route, thus encountering both a tailwind and headwind);
- There are 2 inches of slush on the ground; and

⁶⁸ Booz-Allen analysis of data presented by Ford Motor Company at a site visit in July 1994.

- The heater blower motor, windshield wipers, tail lights, and headlights are on continually.

Except for the electric heater, these factors also reduce the range of conventional internal combustion engine vehicles. However, because conventional vehicles typically have a longer range than EVs the effects are not as critical to the user. The individual and cumulative effects of each of the factors are summarized in Table 3-4.

Additionally, batteries lose capacity to store energy when they are very cold. According to Ford, nickel-cadmium and nickel-metal-hydride batteries both lose about 20 percent of their capacity, and lead-acid batteries lose nearly 60 percent, when operated at 0°F ambient temperature compared to their nominal capacity at 70°F. When the incremental battery effects are added to the vehicle effects under the same assumptions outlined previously, nickel-cadmium and nickel-metal-hydride EVs will achieve only 46 percent of their nominal range at 0°F compared to 70°F on the FUDS. For lead-acid batteries, the loss in range is even more pronounced—lead-acid-based EVs will have less than 25 percent of their range at 0°F compared to 70°F.

Note that all the 70°F range values cited by Ford are for vehicles tested in accordance with federal test procedures, which presume no auxiliary loads are used, the wind speed is zero, and the road is clean and dry. In reality, these are ideal conditions that would not reflect actual driving conditions on a 70°F day. Thus, a portion of the losses due to vehicle drag and wind speed is not directly attributable to cold-weather operation and could occur even on a 70°F day.

As shown in Figure 3-2, data provided by GM on its Impact appear to support Ford's claims. In fact, the data provided by GM indicates somewhat more severe performance penalties in cold weather than the data from Ford. The Impact is equipped with a high-efficiency air conditioner/heat pump and uses lead-acid batteries. The Impact data show an 82 percent reduction in range at 0°F compared to 70°F during 55-mph steady-state driving, using assumptions similar to those used by Ford, discussed previously. Note that the mechanical effects line shown in Figure 3-2 would apply to conventional as well as electric vehicles. The range loss with cold lead-acid batteries is quite substantial and dictates development of a battery warming strategy, such as heating devices that activate when the charger is plugged in.

Table 3-4. Weather-Related Effects that Reduce EV Range, 0°F Compared to 70°F

Source: Booz-Allen analysis of data presented by Ford Motor Company
at a site visit in July 1994

Range Reduction Effect 1	Effect on Range at 0°F ² Compared to 70°F	
	Range Reduction (%)	Remaining Range (%)
Cold weather drag	16	84
Auxiliary loads	4	80
Wind	1	79
Slush	5	72
Electric heater, 6kW	15	57

1 All of these effects (except for the electric heater) also apply to conventional vehicles. However, because conventional vehicles typically have a longer range than EVs the effects are not as critical to the user.

2 0°F cold soak with no thermal management.

Actual Fleet Experience

Booz-Allen interviewed EV fleet operators in New York State to assess actual fleet experience during the winter. Interviews conducted with the New York Power Authority, Consolidated Edison (Con Edison), and the Long Island Lighting Company (LILCO) suggest that EV range decreases in cold weather even when passenger compartment heaters are not used. It is important to note that the decreased range estimates are based on the impressions of the personnel interviewed and that none of the vehicles are equipped with battery thermal management systems.

The New York Power Authority estimates that the range of their TEVans (equipped with nickel-cadmium batteries) decrease approximately 30 percent when temperatures are at or below 15°F, even when the passenger compartment heater is not used.⁶⁹ Con Edison estimates that the range for its TEVans (equipped with either nickel-iron and nickel-cadmium batteries) decreases 10 to 20 percent. The range decrease for its G-Vans (equipped with lead-acid batteries) is approximately 20 to 25 percent.⁷⁰

⁶⁹ Personal communication with New York Power Authority EV fleet manager, July 1994.

⁷⁰ Personal communication with Con Edison EV fleet manager, July 1994.

Figure 3-3. Relative Effects of Ambient Temperatures on Range at 55-mph
Steady-State Driving

Source: General Motors data presented at a site visit in July 1994

These EV fleet operators do take special precautions with their EVs during the winter. For example, LILCO does not drive the EVs when the ambient temperature is below 30°F.⁷¹ The New York Power Authority does not drive its EVs when the temperature is below 0°F, and has instructed its drivers to minimize use of the heater.⁷² Similarly, Con Edison also instructs its drivers to minimize use of the heater during cold weather.⁷³

Some EV energy use data in cold and warm weather were collected by Detroit Edison Company from August 1986 to June 1989. During this time, Detroit Edison operated seven GM Griffon electric vans fitted with brush DC traction motors and tubular plate lead-acid batteries.

Figure 3-3 presents the average monthly energy use for the GM Griffon electric vans compared to the average monthly temperature in Detroit. As seen from the figure, average monthly energy consumption increased up to 60 percent during the winter compared to the summer. Prior to February 1988, four of the seven vans were equipped with a prototype battery heating system that used AC-powered resistance heating panels installed beneath the battery modules. After February 1988, only two vans had a battery heating system, which may account for the drop in peak energy consumption during the 1988-89 winter. According to Detroit Edison, while total energy consumption decreased, the penalty of having to deal with reduced battery capacity in cold weather more than offset any energy savings benefit from not using the thermal management system.⁷⁴ Additional details about the vehicle and test program can be found in "On-Road Test and Evaluation of the GM Griffon Electric Van."⁷⁵

Assessment of Cold Weather Issues

With the proper technology, it appears that EV range problems in cold weather could be solved. Cold temperatures are less of a concern when EVs are parked indoors or plugged into a wall outlet (on-grid). However, plugging into a power grid may not always be possible or practical for EV drivers. The amount of additional heat needed during travel depends greatly upon the trip type and driver comfort levels.

⁷¹ Personal communication with Long Island Lighting Company EV fleet manager, July 1994.

⁷² Personal communication with New York Power Authority EV fleet manager, July 1994.

⁷³ Personal communication with Con Edison EV fleet manager, July 1994.

⁷⁴ SAE paper, M. William Trip, Detroit Edison Company, date not available.

⁷⁵ Ibid.

Figure 3-3. Comparison of Average Monthly Energy Use and Average Monthly Temperatures in Detroit from August 1986 to June 1989

Source: Detroit Edison, "On-Road Test and Evaluation of the GM Griffon Electric Van"

The "Big Three" OEMs and some fleet operators have raised serious concerns about cold weather issues, and they have significant data on which to base their claims. However, independent hardware developers, such as Solectria, are more optimistic that cold weather issues can be resolved.

A recent report published by the Northeast Alternative Vehicle Consortium⁷⁶ described the differing views on cold weather issues as "a relatively polarized public debate." The report presents an extensive engineering analysis of cold weather and thermal management issues. It concludes that a properly designed EV will not encounter severe range reduction or passenger discomfort in the winter, even in severe cold (0°F). The report also notes that there are few days per year with temperatures below 25°F in large metropolitan areas in the Northeast. However, the report's analysis is based partially on using thermal management components, such as heat pumps and electrically heated windshields. Although these components are based on current technology, they have not been engineered, incorporated into vehicle designs, or deployed.

⁷⁶ "Electric Vehicle Thermal Management for Cold Weather Operation," prepared by Arthur D. Little for the Northeast Alternative Vehicle Consortium and Advanced Research Projects Agency, October 1994.

EVs that are used in the Northeast will probably require some sort of thermal management system for the battery, to minimize loss of battery capacity during cold weather conditions. Such a system would be needed for all of the near-term battery technologies: lead-acid, nickel-cadmium, and nickel-metal-hydride. Solectria has developed a thermal management system for use while the vehicle is connected to the charging station. Similar in principle to an electric blanket, this relatively simple system uses grid AC-powered resistive elements in insulation around the various battery locations on the vehicle. The battery generally stays warm after being disconnected from the grid, if the vehicle is not left idle and unplugged for long periods. Initial indications are favorable from the 20-car Boston Edison commuter demonstration during the winter of 1994-95 using the Solectria system, but no quantitative data are available.⁷⁷ Solectria also is investigating other means of mitigating the effects of winter weather, such as passenger compartment heating during grid charging, heated seats, and improved insulation.

Overall, there are very few data to establish the effectiveness of on-grid thermal management. Anecdotal evidence suggests that it works well for twice-daily commute trips, but there are few data on other types of trips. An extensive demonstration of EV thermal management was being conducted in Vermont during the winter of 1994-95 using Solectria vehicles. No data were available on this demonstration when this report was published.

The cost, complexity, and overall energy use of thermal management systems will increase for off-grid systems. To date, an off-grid thermal management system for the near-term battery technologies has not been developed. However, the benefits in increased range resulting from off-grid thermal management may outweigh the engineering and economic costs. EVs produced for California probably will not require thermal management systems.

EVs used in the Northeast also probably will require fuel-fired heaters (resistive heaters can be used in California vehicles). Use of fuel-fired heaters will require on-board storage of a small amount of liquid fuel. Under the current ZEV definition, no fuel evaporative emissions are allowed by the heater, and the heater cannot be operated at ambient temperatures above 40°F. Therefore, the fuel-fired heaters will likely burn diesel fuel, propane, or natural gas. Diesel fuel has a very low vapor pressure, has essentially no evaporative emissions in the winter, and is safe. The Ford Ecostar, some of which are equipped with diesel-fuel-fired heaters, has received ZEV certification from CARB.

⁷⁷ Personal communication with Solectria engineering staff, February, 1995.

Section 4

BATTERY/ENERGY STORAGE DEVICES REVIEW

How an electric vehicle stores energy is clearly the single most important aspect of its design. Each battery technology has its own strengths and weaknesses. No one single battery has all the desirable qualities for EV applications, and there is no clear choice of which battery is best, either now or for the future. To frame the discussion, this report uses three broad categories for battery technologies:

- Near-Term: battery technologies that are currently ready for use in electric vehicles (defined by Booz-Allen);
- Mid-Term: battery technologies that could double current EV range and could potentially be ready for EV use by 1999 (defined by the United States Advanced Battery Consortium [USABC]); and
- Long-Term: battery technologies that could quadruple current EV range and potentially could be ready for EV use in the next decade (defined by USABC).

Most existing EVs use near-term electrochemical batteries, such as lead-acid, nickel-cadmium, and nickel-iron cells, to store energy on board. Progress is being made on mid-term battery technologies, such as the nickel-metal-hydride battery. Limited vehicle demonstrations of mid-term batteries are under way. For long-term battery technologies, such as lithium-based batteries, research at the basic cell and module level is ongoing. Other energy storage/conversion devices have been proposed, such as fuel cells, ultracapacitors, and flywheels. However, these advanced technologies have been used in only a handful of vehicles and still require much research and development before they are viable.

This section summarizes the current state of battery technologies, and focuses on batteries currently ready for widespread vehicle use. The section also includes a discussion of more advanced, future technologies. Finally, battery industry development activities are discussed.

BATTERY TECHNOLOGY OVERVIEW

It is possible to rate the various battery technologies in terms of a few major performance characteristics. This allows easy comparison of the technologies, and gives an indication of how well each battery will perform in an EV application. The most commonly used characteristics are specific power, energy density, specific energy, cycle life, and cost. Each of these terms is defined as follows:

- "Specific power" measures how much power per unit weight a battery can deliver instantaneously. This is important for vehicle acceleration and regenerative current receptivity. Specific power is measured in watts per kilogram (W/kg).
- "Energy density" measures how much electrical energy per unit volume a battery can store. It is desirable to have energy density as high as possible so that space on board the vehicle will be conserved. Energy density is measured in watt-hours per liter (Wh/l).
- "Specific energy" measures how much electrical energy per unit weight a battery can store. Higher specific energy will allow either a lighter weight vehicle or a longer driving range. Specific energy is measured in watt-hours per kilogram (Wh/kg).
- "Cycle life" measures the durability of the battery, and is measured in number of cycles. It is commonly defined as the number of charge/discharge to 80 percent depth-of-discharge (D.O.D.) cycles a battery can withstand over its useful life without significant performance degradation.
- "Cost" measures the battery cost in terms of the energy storage capacity. Cost is measured in dollars per kilowatt-hour (\$/kWh).

The characteristics of major battery technologies are shown in Table 4-1. The values given represent the battery characteristics for a complete, vehicle-ready battery pack, based on current technology. These are manufacturers' claims, and not all are independently verified at this time.

Table 4-1. Characteristics of Current Battery Technologies

Source: USABC, battery developers' data, and Booz-Allen analysis

Current Battery Technologies	Specific Power (W/kg)	Energy Density (Wh/l)	Specific Energy (Wh/kg)	Cycle Life at 80% D.O.D.	Cost (\$/kWh)
Lead-acid ¹⁻⁵	35 ¹ to 300 ²	50 ³ to 90 ²	15 ¹ to 45 ²	300 ⁴ to 600 ²	70 ⁵ to 400 ²
Nickel-iron ⁶	70 to 130	60 to 100	35 to 60	400 to 1200	400 to 500
Nickel-cadmium ⁷	100 to 200	60 to 100	30 to 60	1,000 to 1,500	500
Nickel-metal-hydride ⁸⁻¹¹	140 ⁸ to 200 ⁹	100 ⁸ to 210 ⁹	55 ⁸ to 80 ⁹	1000 ⁹	150 ¹⁰ to 800 ¹¹
Sodium-sulfur ¹²	90 to 120	75 to 110	80 to 120	250 to 500	300
Sodium-nickel-chloride ¹³	150	160	100	500	>1,000
Lithium-polymer ¹⁴	100	100	150	300	>1,000

1. Trojan product data for the SLI lead-acid battery.
2. Based on Horizon product data.
3. Based on Johnson Controls product data for the flow through lead-acid battery.
4. Based on Optima product data for sealed lead-acid battery.
5. Based on Delco Remy product data for the sealed lead-acid battery.
6. Based on Eagle Picher product data.
7. Based on SAFT product data for the nickel-cadmium battery.
8. Based on SAFT product data for the nickel metal-hydride battery.
9. Based on Ovonic product data.
10. Ovonic projection for cost under full production.
11. Current Ovonic selling price to General Motors.
12. Based on ABB product data.
13. Based on AEG product data.
14. Based on product data and future projections by W.R. Grace and Johnson Controls.

In addition to the performance characteristics shown in Table 4-1, there are other important factors in assessing the status of battery technology. One criterion often used by industry analysts is the developmental stage of a battery technology. There are a number of stages that a technology must go through before there is high confidence that the technology is ready for mass production and widespread use. These development stages include the following:

1. Single cell demonstration;
2. Multiple cell demonstration;
3. Single module demonstration;
4. Multiple module demonstration;
5. Product configuration;
6. Vehicle integration;

7. Vehicle test and demonstration;
8. Pilot production; and
9. Mass production.

There is consensus among battery developers that this process takes at least 3 to 5 years, barring any unforeseen technical barriers. Even established technologies, such as lead-acid and nickel-cadmium, must go through at least part of this development process if changes are made in the basic cell design.

In general, lead-acid, nickel-cadmium, and nickel-iron batteries are furthest along in the development process. Nickel-metal-hydride and other mid-term technologies are between steps 3 and 6 of the process. Lithium-based, long-term batteries are at steps 1 to 2.

NEAR-TERM BATTERIES

Current state-of-the-art batteries include the following technologies:

- Lead-acid;
- Nickel-cadmium; and
- Nickel-iron.

Each of these technologies is in widespread use, has been service-proven, is in mass production, and has well-known performance characteristics. With the possible exception of the mid-term nickel-metal-hydride battery, it is likely these will be the only battery technologies ready for EV use in 1998 to meet the sales mandate.

Lead-Acid Batteries

Lead-acid batteries are attractive for several reasons, including low cost, abundant materials, years of development and manufacturing experience, a good safety record, a well-developed servicing and recycling infrastructure, and some potential for performance improvement.

However, there are many inherent shortcomings to this technology, including low specific energy and low cycle life. A few leading battery companies, such as Johnson Controls, Delco AC, and GNB have developed sealed, maintenance-free, "dry" lead-acid cells to address some of the problems. Other more exotic approaches to improving lead-acid performance have included forced circulation of the electrolyte and bi-polar electrodes. Bi-polar electrodes have both anode and cathode sites mounted on the same plate, which makes use of the cell material more efficient.

Electrosources, Inc. and its subsidiary, Horizon Battery Technologies, are developing an advanced lead-acid battery, and they have received funding from the Electric Power Research Institute (EPRI) for their program. Horizon claims that this battery could meet the USABC mid-term goals, and be capable of 50-percent recharging in 8 minutes and 99-percent recharging in 30 minutes.¹ They also claim the battery will have specific energy of 45 Wh/kg or greater, cycle life of 600 at 80% depth of discharge, and cost of \$150 to \$200/kWh. Horizon had announced plans to manufacture 20,000 of these batteries in 1994, although it did not meet that goal. It has built an 88,000-square-foot production facility capable of producing 5,000 kWh of batteries per month.

Horizon recently delivered approximately 400 battery modules to the Sacramento Municipal Utility District (SMUD), under a program funded by the Advanced Research Projects Agency. In preliminary tests by SMUD, the Horizon batteries have demonstrated improved performance over other lead acid batteries. However, SMUD would not as yet confirm the performance claims made by Horizon.²

Nickel-Cadmium Batteries

The leading manufacturer of nickel-cadmium batteries is Saft Nife, and their U.S. subsidiary, Saft America. Saft offers a full product line of nickel-cadmium batteries for heavy-duty applications, including traction applications such as mining vehicles and auxiliary traction power for trolley buses. Nickel-cadmium batteries are also in use in some Japanese and European EVs. Saft has several years of mass production experience with this technology.

Nickel-cadmium batteries offer much higher energy density and cycle life than lead-acid batteries. However, these batteries cost about five times more than lead-acid batteries, primarily due to the nickel content of the cells. Although nickel-cadmium batteries can be charged quickly, thermal management is a problem and recharging efficiency is poor at high temperatures. Cadmium is also very toxic, and this is a problem throughout the battery's life cycle, from manufacturing to in-vehicle use to recycling.

¹ Horizon product literature, November 1994.

² Sacramento Municipal Utility District, personal communication, February 1995.

Nickel-Iron Batteries

Nickel-iron batteries are also a mature technology, and have been manufactured for several decades. Manufacturers include Saft, Car-Go Battery Company, and Synergistic Batteries, Inc. The first commercially produced electric vehicles at the turn of the century used nickel-iron batteries. This battery is attractive due to high specific energy and cycle life. Like the nickel-cadmium battery, however, the cost of the nickel-iron battery is high due to the nickel content. Other drawbacks include the need for frequent watering, significant hydrogen production during use, and low recharging efficiency. Some research is currently under way to solve these problems. However, it is unlikely that nickel-iron batteries will meet the USABC mid-term goals.

MID-TERM ADVANCED BATTERIES

Mid-term advanced batteries include the following technologies:

- Nickel-metal-hydride;
- Sodium-nickel-chloride; and
- Sodium-sulfur.

While each of these batteries offers the potential for greatly improved performance compared to current technology, none currently meets all the USABC mid-term performance criteria. Furthermore, none is projected to meet the USABC cost criteria for mid-term batteries in the foreseeable future. It is not expected that any of these technologies, with the possible exception of nickel-metal-hydride, will be ready for EV use in 1998 to help meet the ZEV sales mandate.

USABC is pursuing an aggressive development plan for these mid-term technologies. Elements of the plan include the following:

- Continue materials and process research and development to achieve cost and performance criteria;
- Produce battery pack prototypes capable of achieving mid-term criteria; and
- Verify candidate technology at mid-term criteria via USABC test procedures (shelf life, cycle life, and battery performance).

USABC's primary concern is that it is uncertain when any of the candidate technologies will meet mid-term criteria. More significantly, it is not clear when USABC will be able to consolidate its research and development efforts on the most promising technology.

Nickel-Metal-Hydride Batteries

Ovonic has been making a number of claims regarding the nickel-metal-hydride battery. These include twice the specific energy and three times the energy density of lead-acid batteries. Ovonic also is claiming a very high cycle life, in the range of 2,000 to 3,000 cycles. The batteries are expected to have a high tolerance for overcharging and over-discharging, and will be maintenance-free. If these claims are true, the results would be quite beneficial for EV performance and general acceptance.

Ovonic's technical claims have not been clearly proven in a vehicle demonstration. An 18 kWh Ovonic battery pack was recently installed in a Solectria Force, and the preliminary results are good but not conclusive. Ovonic claims the range for this vehicle is 150 miles of city/highway driving, while independent CARB tests indicate 129 miles. Also, the cost of the nickel-metal-hydride battery remains high, though Ovonic claims the cost will be reduced substantially in mass production.

Sodium-Nickel-Chloride Batteries

The sodium-nickel-chloride battery is manufactured primarily by AEG Anglo Batteries. AEG Anglo claims the battery will meet all USABC mid-term performance goals, although the cost is a major problem. The battery is maintenance-free and can operate if an individual cell fails. The battery operates at a temperature of about 300°C (572°F), and cannot supply power below 270°C (518°F) without permanent damage to the battery. If the battery is allowed to cool down to ambient temperature, it can be re-heated, but only very slowly. Re-heating takes approximately 48 hours. While this presents a thermal management and vehicle integration problem, it also eliminates the problem of poor battery performance in cold weather; although nonbattery-related cold weather effects still will impact the vehicle.

Existing batteries have demonstrated cycle lives of up to 600, and AEG Anglo has set the goal of 1000 cycles by 1998. At this time, it appears the battery will still be under development in 1998, and not ready for production. Idaho National Engineering Laboratory is currently testing prototype battery cells for the USABC. BMW, Mercedes Benz, Volkswagen, and Opel are testing EVs powered by sodium-nickel-chloride batteries.

Sodium-Sulfur Batteries

Sodium-sulfur batteries show promise due to their high specific power and energy, low maintenance, low self-discharge, long shelf life, high recharging efficiency, and low materials costs. Developers involved with sodium-sulfur batteries include Asea Brown Boveri, RWE, Powerplex, Eagle Picher Industries, and Chloride Silent Power.

Sodium-sulfur batteries must be heated to between 300°C (572°F) and 350°C (662°F) to function properly and for their electrolytic reactions to be fully effective. While this presents a thermal management and vehicle integration problem, it also eliminates the problem of poor battery performance in cold weather, although non-battery cold weather effects still will exist in the vehicle. The batteries are housed in double-walled vacuum containers (Thermos-bottle type). If the electrodes solidify from lack of use, built-in heaters can re-melt the sodium and sulfur.

Other problems with sodium-sulfur batteries include premature cell failure, low cycle life, high manufacturing costs, and safety considerations. In addition, Ford Ecostar EVs equipped with sodium-sulfur batteries have suffered from fires. This clearly represents a setback for the technology, and probably eliminates any chance the technology will be ready in 1998. The cause of the fires is still under investigation, although some of the Ecostars were recently put back into service.

LONG-TERM ADVANCED BATTERIES AND OTHER ENERGY STORAGE DEVICES

Long-term advanced batteries and other advanced energy storage technologies include the following:

- Lithium-iron (or other metal)-sulfide batteries;
- Lithium-polymer batteries;
- Fuel cells;
- Flywheels;
- Ultracapacitors; and
- Super-conducting magnetic energy storage devices.

Each of these long-term advanced technologies is discussed in the following paragraphs.

Lithium-Iron (or Other Metal)-Sulfide Batteries

The lithium-iron (or other metal)-sulfide battery class includes a few variations on the basic chemistry, including the lithium-aluminum-iron-sulfide battery and the lithium-iron-mono-di-sulfide battery. These batteries are characterized by high operating temperatures (400°C to 450°C, 750°F to 850°F). The current density and charge acceptance are very high, but the life is poor. Also, complicated electrical arrangements are necessary for bypassing fully charged modules in a battery pack.

Lithium-Polymer Batteries

The lithium-polymer battery is under development by W.R. Grace, Valence Technology, 3M Corporation, and Quebec Hydro. The battery offers high specific energy and the potential for low manufacturing (materials) cost. However, there is a significant variance in the voltage level in relation to depth of discharge, and there are some safety problems with the battery.

Fuel Cells

Fuel cells convert the chemical energy stored in a fuel (hydrogen or a hydrocarbon from which hydrogen can be extracted) into electricity. A fuel cell's fundamental advantage over batteries is that it does not have to be recharged. It will continue to produce electricity as long as fuel is being supplied. Energy Partners, Inc. has built a passenger car using a proton exchange membrane (PEM) fuel cell. As part of a DOE program, Allison Turbines is developing a 10 kW PEM power module for use in passenger cars. Two 30-foot prototype transit buses have been built in North America using fuel cells and batteries for propulsion. The Ballard Power Systems bus uses PEM fuel cells, and the DOE-Georgetown bus uses a phosphoric acid fuel cell.

Flywheels

The most promising type of flywheel energy storage technology is that of American Flywheel Systems Inc. (AFS). AFS has combined all the recent improvements in technology to produce what it calls an "Electro-Mechanical Flywheel Battery" (EMFB). There are also commercially available electro magnetic flywheel storage units from Magnet-Motor GmbH in Germany. However, these are the low-storage-capacity type designed for public transport vehicles and are unsuitable for electric vehicle applications. Flywheels exhibit excellent specific power characteristics, but specific energy remain problematic. Safety issues related to mechanical containment of flywheels have not been fully resolved.

Ultracapacitors

The ultracapacitor is capable of storing and discharging electrical energy very quickly. It shows promise for EV applications as a load leveling-device in conjunction with other battery technologies. The ultracapacitor has been under development for approximately five years at Idaho National Engineering Laboratories. An ultracapacitor with sufficient size and energy density for a practical EV demonstration has not yet been developed.

Super-Conducting Magnetic Energy Storage Devices

Super-conducting magnetic energy storage devices are based on the storage of an electrical current in a coil of superconducting wire. This current will continue indefinitely, effectively making the superconducting coil a permanent magnet. A practical superconductor that can operate at liquid-nitrogen temperatures has not yet been developed.

BATTERY INDUSTRY DEVELOPMENT ACTIVITIES

Most of the activities in the EV industry are centered around the USABC, formed by Ford, General Motors, and Chrysler in January 1991. Later that year, EPRI joined, and the DOE signed a cooperative funding agreement with USABC. DOE agreed to match industry funding on a 50-percent cost-share basis. Total USABC program expenditures are now approximately \$262 million, half government funding and half battery developers' funding.

The purpose of USABC is to "develop for commercialization advanced battery systems that will accelerate the market potential of EVs by improving EV range and performance." USABC has established two battery categories based on the probable timing of each technology's development: mid-term and long-term. The earliest possible date that a mid-term battery could be in pilot production is 1999, according to USABC. No reliable production timing estimate has been made for long-term batteries.

Ultimately, for EVs to be successful, batteries must achieve certain performance and cost goals. USABC has quantified several battery goals for both mid-term and long-term technologies. The major USABC goals are summarized in Table 4-2.

Table 4-2. Major USABC Goals

Source: DOE Office of Transportation Technologies, September 1994

	Mid-Term Batteries	Long-Term Batteries
Specific Power (W/kg)	150	400
Energy Density (Wh/l)	135	300
Specific Energy (Wh/kg)	80	200
Shelf Life (years)	5	10
Cycle Life at 80% D.O.D. (cycles)	600	1,000
Ultimate Cost (\$/kWh)	<150	<100

USABC has been awarding a number of cost-share contracts to battery developers. These contracts are summarized in Table 4-3. In addition to funding shown in Table 4-3, USABC funding also has gone to several DOE national laboratories, including the National Renewable Energy Laboratory (NREL), Lawrence Berkeley Laboratory (LBL), Sandia National Laboratory (SNL), Argonne National Laboratory (ANL), and the Idaho National Engineering Laboratory (INEL).

Table 4-3. USABC Battery Developer Contracts

Source: DOE Office of Transportation Technologies, September 1994

Developer	Technology	Time Frame	Start Date	Funding ¹
Ovonic	Nickel-metal-hydride	Mid-Term	5/92	\$19.9M
Saft America	Nickel-metal-hydride	Mid-Term	12/92	\$20.7M
Chloride Silent Power	Sodium-sulfur	Mid-Term	8/93	\$12.1M
Saft America	Lithium-iron-disulfide	Long-Term	12/92	\$17.3M
W.R. Grace, Johnson Controls	Lithium-polymer	Long-Term	1/93	\$27.4M
3M, Hydro Quebec, Argonne National Lab	Lithium-polymer	Long-Term	12/93	\$32.9M
Yardney	Nickel-based	Mid-Term	1/94	\$2.5M
			TOTAL	\$132.8M

1 The total cost of each program is approximately double the amount shown, due to the 50/50 cost share provision in each contract.

There are some significant activities outside of USABC as well. A number of independent battery developers are pursuing advanced lead-acid battery designs, in hopes of achieving greater performance at a low cost. This group is led by Horizon Battery Technologies and the Advanced Lead-Acid Battery Consortium (ALABC). Long-term battery technologies are being developed under the Hybrid-Electric Vehicle Program sponsored by DOE, NREL, Ford, and General Motors. Many foreign developers are also active, particularly in Europe and Japan, such as Hoppecke (Germany), VARTA (Germany), Silent Power GmbH (UK and Germany), and Japan Storage Battery (Japan). Some non-USABC developers have significantly different research approaches than the USABC. The most significant difference of opinion is whether or not lead-acid technology can be improved substantially. However, nearly all battery developers worldwide use the USABC performance goals as a benchmark.

Section 5

ZEV INFRASTRUCTURE

An adequate infrastructure to support ZEVs will be critical to the success of New York State's ZEV mandate. There are a number of infrastructure issues that must be addressed:

- Battery charger development and availability;
- Charging station locations;
- Codes and standards implementation (building and electrical codes and vehicle/grid interface);
- Battery disposal and recycling;
- EV insurance requirements;
- Health, safety and emergency response; and
- Public awareness.

Some of these issues can be resolved relatively easily, without new technology developments or significant expenditures. One of the major forums where infrastructure issues are being dealt with is the National Electric Vehicle Infrastructure Working Council.¹ This section discusses some of the more urgent infrastructure issues—ones that could present major obstacles in implementing the ZEV mandate.

BATTERY CHARGER DEVELOPMENT AND AVAILABILITY

One of the most important factors related to infrastructure is minimizing battery recharge time. This factor is affected by both battery technology and the charging system used. Current charger development efforts are focused on reducing charge time.

Charging equipment for EVs can be located on or off the vehicle. On-board chargers allow a vehicle to be recharged almost anywhere there is a compatible electrical outlet. However, off-board chargers reduce vehicle weight, and can allow for greater power and quicker charging times. Some advanced EVs use special techniques to integrate the charging function within the drive system components to minimize the need for additional equipment.

¹ Led by the Electric Power Research Institute, the Infrastructure Working Council meets quarterly to discuss infrastructure issues. Some meetings are open to any attendees and summary minutes are published quarterly.

EV battery chargers generally accommodate 110- or 220-volt household electrical current. The higher voltage chargers require some special installation, but cut down on charging time by approximately a factor of two. State-of-the-art recharging times range from 2 to 10 hours for a full-capacity charge. For example, GM Impacts used in the PrEView Program use the Delco "Magne-Charge" 220-volt, 30-amp inductive system for at-station charging (at a fixed location, probably at home). A portable charger, rated at 110 volts and 12 amps, will also be supplied for "opportunity" charging wherever there is 110-volt, 15-amp electrical service. At 220 volts, the nominal charge time is 2 to 3 hours; at 110-volts it is 8 to 10 hours.²

State-of-the-art chargers typically have microprocessors that monitor voltages of individual battery modules to ensure proper charging, and some provide on-grid thermal management. Improper charging of battery packs can cause excessive gassing, shorten battery life, and waste energy. The types of chargers currently in use are generally those supplied with the vehicle by its manufacturer.

Several companies are working on fast charge systems that will provide a full recharge in less than one hour. Chrysler and Norvik Technologies have developed a "Smart Charging System" that can automatically determine the battery type and charge it without overcharging. The Smart Charging System currently provides a full charge in about 25 minutes, but that time is expected to be reduced to 10 minutes in the future.

Nissan also is developing a fast-charging system that was unveiled on its FEV electric concept car. The fast chargers require a large electrical power supply of 400 volts and 140 amps. The system can recharge nickel-cadmium batteries to 40 percent capacity in six minutes, and sealed lead acid batteries to 40 percent in 12 minutes.

Delco Electronics is marketing the "Magne-Charge" inductive charging modules developed by Hughes Power Control Systems—both Delco and Hughes are subsidiaries of General Motors. Unlike conventional conductive chargers, inductive charging systems transfer power without direct contact. The Magne-Charge inductive coupler resembles a small plastic paddle that is inserted into a vehicle charge port, and the on-board battery pack computer controls the charging process.

² "GM's PrEView Impact Electric Vehicle," *Automotive Engineering*, February 1995, pp. 85-89.

Inductively coupled chargers are preferred by some over conductive systems due to their perceived greater safety, especially in adverse weather conditions, because vehicle users are not required to handle high voltage connections.

EV CHARGING STATION LOCATIONS IN NEW YORK STATE

The EV charging station infrastructure in New York State is in an embryonic state. Several electric utility companies and cities within the State have been demonstrating fleets of EVs and have built charging stations to accommodate them. For example, Con Edison has four charging stations in Manhattan and four on Long Island.³ Other electric utility companies across the State have constructed a few charging stations in conjunction with EV demonstration programs.

Telephone interviews with three major New York State electric utility companies indicate they do not have plans for widespread construction of charging stations, although all three are participating in EV demonstration programs.⁴ The utilities anticipate that the majority of charging would be carried out at the home of the EV owner or in centralized locations for fleet operations. The electric utility companies also would like to see EV chargers co-located with gasoline service stations in the near-term. The electric utility companies indicated they are waiting for the Society of Automotive Engineers (SAE) to issue charging station standards before they invest in development of charging technology.

To facilitate the introduction of ZEVs in 1998, more charging stations are needed, and the issue of who will pay for them must be resolved. At-home EV charging stations are relatively simple to install, and electrical outlets are widely available, although the outlets may have to be upgraded to accommodate higher voltages and currents. A bigger issue arises with determining who should pay for the charging stations. An overnight charging station can be installed in a homeowner's garage or at a fleet site for less than \$750.⁵ However, fast-charge stations may cost at least an order of magnitude more.⁶

³ Personal communication, Con Edison, August 1994.

⁴ Personal communications, Niagara Mohawk, Long Island Lighting Company, and Con Edison, November 1994 to February 1995.

⁵ Personal communication, Detroit Edison, 1994.

⁶ Personal communications, Electric Transportation Coalition staff, January 1995.

Winter weather conditions also pose special problems related to charging station location. Charging time increases in cold temperatures and snow buildup could interfere with outdoor charging stations. Niagara Mohawk has investigated the use of indoor charging stations, where temperatures could be controlled. However, indoor charging presents other problems, such as fire and explosion hazards. During battery charging of some battery types, hydrogen gas is released into the air; therefore an adequate ventilation system is required to prevent buildup of this explosive gas. Niagara Mohawk has halted construction of indoor charging facilities until this issue can be addressed.⁷

CODES AND STANDARDS IMPLEMENTATION

Several industry working groups have been formed to develop standards for on-board and off-board vehicle chargers. Standards will ensure the compatibility of EVs with various chargers and should help reduce costs. Due to their lower cost, conductive chargers will likely become the industry standard as opposed to inductive chargers, at least in the near-term. However, General Motors, Hughes Power Control Systems, Boston Edison, and others are strongly advocating the use of inductive charging. The SAE is planning to issue standards in the near future. At the time this report was published, the SAE standards had not been released.⁸ There may be delays in issuing the standards due to the rapid pace of technological development for charging systems.

Operators of mixed-model EV fleets already are experiencing problems caused by a lack of standardization in other EV components. Requirements for different power supplies for different chargers is both an inconvenience and an expense to EV fleet operators like Detroit Edison. For example, the Chrysler TEVan that Detroit Edison operates uses a charger that requires 208-volt, 3-phase power, compared to standard 110-volt and 220-volt chargers used in other EVs.

At this time, there are no building standards in place in the State of New York for EV charging stations. This issue should be resolved before the 1998 ZEV sales mandate takes effect.

BATTERY DISPOSAL AND RECYCLING

Battery disposal and recycling should not pose serious problems. Lead-acid and nickel-metal-hydride batteries are the most likely battery choices for EVs in the near-term. Lead-acid batteries from gasoline-powered vehicles are routinely recycled. The lead and sulfuric acids inside the

⁷ Personal communication, Niagara Mohawk, January 1995.

⁸ Personal communication, EPRI, February 1995.

batteries are encased in heavy-duty plastic. During the recycling process, the acids are neutralized, the metal is smelted back into reusable lead, and the plastic casing is cleaned and melted. The lead and the plastic are then used to make new batteries.

Nickel-metal-hydride batteries contain no toxic components and disposal should not cause serious environmental problems. Currently, an infrastructure for recycling nickel-metal-hydride batteries does not exist. However, in view of the relatively high cost of nickel, recycling centers for nickel-metal-hydride-batteries are expected to open as these batteries gain wider use.⁹

Other types of batteries may pose disposal problems. For example, the cadmium used in nickel-cadmium batteries and the bromine used in zinc-bromine batteries are toxic and must be disposed of carefully or recycled.

INSURANCE REQUIREMENTS FOR EVS

Private passenger automobile insurance costs are influenced by three main factors: driver history; the vehicle model; and vehicle location and use. Insurance rates for vehicle models are based on historical data such as the frequency of accidents, severity of injuries, cost to repair, frequency of theft, and presence of air bags.

Initially, EVs will not have significant history on which to base insurance rates. Each insurance company probably will use its own discretion to set rates. However, some companies may be unfamiliar with EVs and public awareness programs may be needed. If it can be shown that EVs pose no greater risk than other automobiles currently on the road, insurance rates should be comparable to conventional vehicles.

At least one insurance company operating in New York State is taking a proactive role with EVs. The Government Employees Insurance Company (Geico) is offering a 75 percent discount on basic insurance rates to EV owners.¹⁰ Geico is interested in the public relations benefit from this policy and also believes EVs are a good risk because they will likely be driven less than their gasoline-powered counterparts.

⁹ Personal communication, Ovonic Battery Company, November 1994.

¹⁰ Personal communication, Geico New York, September 1994

Booz-Allen also interviewed the other top insurance companies in New York State: Allstate¹¹ and State Farm.¹² Neither company has a clearly defined EV policy. However, Allstate has made tentative plans to sponsor EVs for use at the 1996 Olympic Games in Atlanta, and has set up temporary displays of electric vehicles in its Virginia headquarters.¹³

HEALTH, SAFETY, AND EMERGENCY RESPONSE

A key area requiring preparation by government agencies is the response to emergencies involving EVs, particularly auto accidents. Based on product liability case law, it is the responsibility of the EV manufacturers to address hardware issues such as battery quick-disconnect, safety labeling, and battery electrolyte containment. To address special emergency procedures, fire department and other emergency response personnel must be trained. The New York City Fire Department is the only major fire department in New York State that has already given special training to some personnel. Some New York City firefighters have been trained in emergency egress and other safety issues from alternative fuel vehicles, including electric vehicles.¹⁴

PUBLIC AWARENESS PROGRAMS

Some New York State electric utilities have programs to increase the public's awareness of EV capabilities. Niagara Mohawk has bought US Electric Car EVs for use by their employees and will install charging stations at homes and at work. Long Island Lighting Company is working on a project to produce an EV station car for use by transit commuters, similar to the pilot project being run by Boston Edison. The station car would be picked up by the commuter at a subway station, driven home, and returned in the morning on the way back to work. The charging facilities for the vehicles would be located at the subway station.

11 Personal communication, Allstate New York, August 1994 and February 1995.

12 Personal communication, State Farm New York, September 1994.

13 Personal communication, Allstate Virginia, March 1995.

14 Personal communication, Brooklyn New York Fire Department division staff, November 1994.

FUTURE TECHNOLOGY STATUS AND BARRIERS

INTRODUCTION

Much progress has been made with ZEV technology in recent years. The ZEV sales mandates of California, New York, and other states have focused research and development efforts on improving the technology as much as possible. However, several technological and other barriers still exist that could impede the success of ZEVs.

This section identifies and assesses the likelihood of overcoming the major barriers. Barriers are classified into battery, vehicle, infrastructure, and marketing/public acceptance categories.

Figure 6-1 presents the Booz-Allen methodology followed in this study.

Figure 6-1. ZEV Barriers Analysis Methodology

The assessment of state-of-the-art and emerging technology was included in previous sections of this report. The subsequent steps in the analysis are discussed in detail in the following sections.

IDENTIFICATION OF BARRIERS

While conducting the ZEV Technology Assessment, the Booz-Allen study team identified a number of barriers to the ultimate success of electric vehicles. The barriers were identified through personal interviews, review of ZEV literature, site visits at ZEV and component development facilities, and other data collection efforts. Table 6-1 lists the barriers identified. Table 6-1(a) lists battery/energy storage barriers, and Table 6-1(b) lists other (non-battery) barriers.

Table 6-1(a). ZEV Battery/Energy Storage Barriers

Source: Booz-Allen analysis

BATTERY/ENERGY STORAGE TYPE	MAJOR BARRIERS
Lead-Acid	<ul style="list-style-type: none"> • Weight/specific energy • Cycle life • Current density
Nickel Cadmium	<ul style="list-style-type: none"> • Energy density • Cost/nickel content • Toxicity
Nickel Metal Hydride	<ul style="list-style-type: none"> • Cost
Sodium Sulfur	<ul style="list-style-type: none"> • Charge/discharge efficiency • Thermal management • Cycle life • Safety • Mechanical failures due to cell fragility
Sodium Nickel Chloride	<ul style="list-style-type: none"> • Cost • Thermal Management • Voltage variance over discharge cycle
Lithium-based Batteries	<ul style="list-style-type: none"> • Scale of cell and battery pack • Rechargeability • Materials development • Manufacturability
Other Long-Term Batteries	<ul style="list-style-type: none"> • Scale of cell and battery pack • Compatibility with infrastructure • Rechargeability
Fuel Cells	<ul style="list-style-type: none"> • Hydrogen Storage • Cost • System management and complexity
Flywheels	<ul style="list-style-type: none"> • Outer-edge speed • Control electronics • Size • Safety/physical containment
Ultracapacitors	<ul style="list-style-type: none"> • Charge density • Cost
Superconducting Magnetic Energy Storage Devices	<ul style="list-style-type: none"> • Temperature of superconductivity • Manufacturability of superconducting materials

Table 6-1(b). Other ZEV (Non-Battery/Energy Storage) Barriers

Source: Booz-Allen analysis

BARRIER CATEGORY	MAJOR BARRIERS
Vehicle	<ul style="list-style-type: none"> • Range • Air conditioning/heater/passenger comfort • Cold weather performance • Safety
Infrastructure	<ul style="list-style-type: none"> • Charging time • Charging station implementation/cost • Sales, parts, and service • Codes and standards • Safety/emergency services • Battery supply and recycling • Legal environment (e.g. insurance, registration)
Marketing/Public Acceptance	<ul style="list-style-type: none"> • Purchase price • Market size • Choice of models/body styles • Product lead time • User incentives (e.g. tax, preferred lanes/parking, other subsidies) • User education • Manufacturers' economies of scale

LIKELIHOOD OF OVERCOMING BARRIERS

For each of the barriers identified, the threshold level of progress needed to “overcome” the barrier, the amount of development needed to make a significant improvement in ZEV viability, can be defined. Threshold levels can be quantified in some cases. For example, a threshold level of progress for a battery technology can be defined as the specific energy (in Wh/kg) needed to make a significant improvement in vehicle driving range. Threshold levels of progress needed to overcome each identified barrier are defined in this section.

To estimate the likelihood of overcoming each barrier within a certain time frame and the potential benefits of doing so, two methods were used in the study:

- Survey of ZEV experts and industry participants; and
- Engineering and scientific analyses.

The results of each of these methods were then combined by the study team into a qualitative estimation for each barrier, expressed as a “low”, “medium”, or “high” probability of overcoming the barrier.

Survey of ZEV Experts and Industry Participants

An informal focus group of 30 ZEV experts and industry participants was formed, and each participant was interviewed. The group was chosen by Booz-Allen to represent as broad a cross-section of viewpoints and areas of expertise as possible, and to accumulate a high level of collective knowledge and experience. Representatives were chosen from the private, public, and academic sectors. Table 6-2 shows the number of participants in each industry sector and their expertise category.

Table 6-2. Categorization of Survey Participants

		DISCIPLINE			TOTAL
		Technical/ Research	Marketing/ Managerial	Policy/ Regulatory	
INDUSTRY SECTOR	Automotive Industry	7	3	0	10
	Private EV Interest	8	2	0	10
	Academic or Government	5	0	5	10
	TOTAL	20	5	5	30

Interviews were conducted concerning the future of ZEV technology and the participant's estimation of the time frame in which certain barriers could be overcome.¹ A method similar to the Delphi technique² was used in the interview process, although most of the interviews were conducted individually by phone. Each interview began with a general discussion of ZEV issues and an exchange of information. Participants then were asked to give their own estimation of the likelihood that certain barriers could be overcome, and when. They were asked to quantify their estimations, in terms of the probability of overcoming the barrier, for each study year (1998, 2000, 2002, and 2004) for each major barrier category.

A key factor in conducting this survey was the definition of "overcoming" the barriers in each major category. The following definitions of overcoming barriers were used in the survey:

¹ Interviews were conducted from October 1994 to January 1995.

² The Delphi technique is a decision making tool used in the fields of market research and operations research. It typically involves assembling several experts in a field, and using their subjective and personal knowledge to assess the probabilities associated with one-time future events. The Delphi technique is based on Bayesian probability and decision theory for one-time (as opposed to recurring) events. See Marketing Research Methodological Foundations, Fifth edition, p. 98 et seq, by Gilbert A. Churchill, Jr., The Dryden Press, Chicago, 1991.

- **Battery/Energy Storage Barriers.** Overcoming the barriers for each battery/energy storage type is defined as meeting all the USABC mid-term goals, or a majority of the USABC long-term goals, in at least a pre-production configuration of the battery/energy storage device.
- **Vehicle Barriers.** Overcoming the vehicle barriers is defined as achieving performance and vehicle features for electric vehicles that are competitive with conventional gasoline vehicles, on the basis of usefulness to the user.
- **Infrastructure Barriers.** Overcoming the infrastructure barriers is defined as achieving charging time and charging convenience equivalent to refueling conventional gasoline vehicles. In addition, other elements of the ZEV infrastructure will be in place such that there are no major inconveniences for ZEV users (when compared to conventional vehicles) and there are no major safety problems with ZEVs.
- **Marketing/Public Acceptance Barriers.** Overcoming the marketing/public acceptance barriers is defined as achieving ZEV market situation (including purchase price, features, and market incentives) that will create a natural demand for ZEVs equal to or greater than the regulated market.

To create as much consistency as possible among the participants, it was assumed that the current schedule for the ZEV mandates in each state will remain unchanged through the year 2004. The ZEV market size is assumed to be as stated in Section 7 of this report.

Table 6-3 gives aggregated data on the survey participants' opinions and estimations concerning the future of ZEV technology. The averages (x_{mean}) of the percent probabilities given by participants for each barrier category and year are shown, along with the sample standard deviation (s_{n-1}), the minimum response given (x_{min}), and the maximum response given (x_{max}).

Table 6-3. Summary of ZEV Survey Results—Probabilities of Overcoming Barriers

BARRIER CATEGORY	SURVEY STATISTICS	STUDY YEAR			
		1998	2000	2002	2004
Batteries	<u>x_{mean}</u>	<u>21%</u>	<u>27%</u>	<u>41%</u>	<u>56%</u>
	s _{n-1}	16.63%	21.63%	31.78%	35.65%
	x _{min}	0%	0%	0%	10%
	x _{max}	50%	70%	90%	100%
Vehicles	<u>x_{mean}</u>	<u>17%</u>	<u>22%</u>	<u>36%</u>	<u>49%</u>
	s _{n-1}	13.37%	15.49%	26.75%	35.42%
	x _{min}	0%	0%	0%	0%
	x _{max}	40%	40%	70%	100%
Infra- structure	<u>x_{mean}</u>	<u>32%</u>	<u>36%</u>	<u>47%</u>	<u>60%</u>
	s _{n-1}	28.21%	28.75%	31.64%	32.66%
	x _{min}	0%	0%	10%	10%
	x _{max}	80%	80%	100%	100%
Marketing	<u>x_{mean}</u>	<u>22%</u>	<u>28%</u>	<u>38%</u>	<u>52%</u>
	s _{n-1}	16.19%	21.50%	31.90%	36.76%
	x _{min}	0%	0%	0%	10%
	x _{max}	40%	60%	80%	100%

Engineering and Scientific Analyses

Engineering and scientific analyses were performed on selected battery and energy storage technologies, as well as other ZEV barriers. The engineering and scientific analyses consist of the following elements:

- Review of existing technical papers, articles, and periodicals focused on the technology;
- Interviews with selected technology specialists, component suppliers, and manufacturers; and
- Feasibility assessment based on Booz-Allen expertise in vehicle engineering.

Information obtained in the ZEV database development, the ZEV expert survey, and other elements of the technology evaluation described in this report also were used in these engineering and scientific analyses.

The primary goal of these analyses is to determine the nature of the claims being made about the selected technologies, and whether or not they are:

- based largely on existing factual evidence; and/or
- probable or possible based on extrapolation of technology trends or logical arguments rooted in a fundamental understanding of engineering principles.

While each identified barrier was analyzed at some level, it was beyond the scope of the study to develop a detailed discussion of each barrier analysis. The authors of this report have chosen three key energy storage technologies to discuss in detail here:

- Lead-acid battery;
- Nickel-metal hydride battery; and
- Flywheels.

These detailed discussions are presented in the following subsections.

Lead-Acid Battery. Lead-acid batteries are attractive for several reasons, including low cost, abundant materials, years of development and manufacturing experience, a good safety record, a well-developed servicing and recycling infrastructure, and some potential for performance improvement. However, there are many inherent shortcomings to this technology, including low specific energy and low cycle life. A few leading battery companies, such as Johnson Controls, Delco AC, and GNB have developed sealed, maintenance-free, "dry" lead-acid cells to address some of the problems. Other more exotic approaches to improving lead-acid performance have included forced circulation of the electrolyte and bi-polar electrodes. Bi-polar electrodes have both anode and cathode sites mounted on the same plate, which makes for more efficient use of the cell material.

Lead-acid batteries are based on half-cell reactions involving lead, lead oxide, sulfuric acid, lead sulfate, and water. In the reactions during discharge, lead is dissolved, lead sulfate (PbSO_4) is formed at each electrode, and the concentration of the electrolyte (sulfuric acid) is reduced. During charging, the process is reversed, and hydrogen and oxygen are produced. At close to 100 percent state of charge, the hydrogen and oxygen will be in gaseous form. In a conventional flooded lead-acid battery, this gas will be vented into the atmosphere, necessitating the occasional watering of the battery. In sealed/maintenance free lead-acid batteries, this gas is recombined in the battery, thus eliminating the need for watering.

There are four distinct types of lead-acid battery plate constructions:

- Flat plate;
- Tubular plate;
- Bipolar; and
- Spiral wound.

Each of these battery types can have either "flooded" electrolyte or gel electrolyte. There are also three types of battery cases: vented, sealed, and valve-regulated.

One of the largest problems with the lead-acid battery is its weight. Approximately 65 percent of the battery weight is in lead or lead-based parts. Approaches to reducing the weight (i.e. increasing the specific energy) center around increasing the effective surface area and current density of the lead in the battery. This is the objective of the Horizon spiral wound design. Another approach to improving the lead-acid battery is to place the anode and cathode as close together as possible, thereby reducing internal resistance and increasing current density. The bipolar configuration achieves this by impregnating both anode and cathode material on the same substrate. Both the spiral wound and bipolar configurations promote a more uniform concentration of the electrolyte during discharging, which increases battery efficiency.

A "theoretical limit" to the specific energy that lead-acid technology can achieve is sometimes discussed in relation to battery development. However, there is no consensus on what this limit is. Due to of the battery chemistry, lead is dissolved in the electrolyte during discharge. Therefore, enough lead must be available on the electrode surface to both conduct electrical current and dissolve during the discharge cycle. This is the primary physical constraint preventing further reductions in the amount of lead used in the battery.

The performance of lead-acid batteries during both charging and discharging is significantly affected by temperature. The available battery capacity and the charge acceptance rate (expressed in amperes) decrease at low temperatures. At high temperatures, the capacity increases, but the charge acceptance decreases above a certain threshold level. Ideally, all cells within a battery pack should be kept at the same temperature, within the range of 60°F to 100°F. In electric vehicles, this may be difficult to achieve without a thermal management system.

Nickel-Metal-Hydride Battery. The nickel-metal hydride battery uses a nickel-based cathode, similar to those used in nickel-iron and nickel-cadmium batteries. The anode is a metal-hydride and the electrolyte is a potassium alkaline solution, with some lithium added. To fabricate the battery, the cathode is built from a perforated nickel plated stainless steel or pure nickel strip. The anode is prepared by depositing metal hydride powder on a nickel screen that is sintered in a furnace at about 900°C for about five minutes. The cathode and anode are wound up together with a separator into a "jelly roll" configuration. This jelly roll is inserted into a metal can that acts as a negative terminal. Then the electrolyte is added and a cover is welded onto the can. On the cover is a positive terminal, which is welded to the cathode, and a vent cap. The designers can modify the battery shape to be suitable for a vehicle application. The Ovonic battery prototype is prismatic in shape.

The advantages of the nickel-metal-hydride battery are summarized as follows:

- High specific energy; approximately twice that of lead-acid batteries, and significantly more than nickel-cadmium batteries;
- Good specific power;
- Good performance in low ambient temperatures;
- No maintenance required; and
- Ruggedness with respect to charging, and able to handle rapid charging.

The disadvantages of the nickel-metal-hydride battery are summarized as follows:

- Cost of the materials is a problem—some rare metals are used in the battery;
- Sensitivity to overheating, that may necessitate some type of active cooling system, along with a pressure relief valve; and
- Some toxic substances within the battery.³

The largest barrier to the success of the nickel-metal-hydride battery appears to be its cost. Both the nickel and the metal alloy used for the anode are particularly expensive materials, in the range of \$50 to \$65 per pound. Ovonic has stated that the cost of the battery can be reduced to \$150/kWh, from the current cost of about \$800/kWh. The authors estimate this to be the approximate cost of the materials in the battery, not including any labor or capital cost to fabricate the battery. Therefore, Ovonic cannot achieve its cost goal of \$150/kWh based solely on mass production economies of scale and progress on the production learning curve. Some significant savings also must come from a reduction in the use of expensive materials in the battery, while still maintaining performance. Some of the Ovonic literature has hinted that this problem is being addressed. However, no breakthroughs in the area of materials cost reduction have been announced.

Flywheels. Flywheel systems have been used in many energy storage applications for hundreds of years. A flywheel stores energy as kinetic energy due to its rotational motion. Spinning a flywheel faster increases the amount of energy it stores. The stored energy then can be recovered through mechanical means, such as a clutch, or electrical means by turning a generator. Flywheels have been used for mechanical engine starter systems, speed-regulation of machines, gyroscopes, and power sources for toy vehicles.

Flywheel energy storage systems have been tested with some success on city buses in Munich, Germany, and an electric trolley in Basel, Switzerland. These flywheel systems are relatively heavy, operate at low speed (12,000 rpm maximum), and store very little energy. They are used to absorb the braking energy of the vehicle through an electro mechanical coupling, store it for a very short time and return it to the drivetrain of the vehicle during acceleration. This type of flywheel can not store much energy and spins down quickly. It is effective on a bus in city traffic

³ The most toxic substance in the battery, the nickel itself, will probably also be the most diligently recycled, due to its high value.

due to the frequent stops, when it can reduce the acceleration power demands on the vehicle's engine or electric motor; however, it is unsuitable for electric vehicle applications because it stores very little energy and is only able to store that energy for short periods due to frictional effects.

Recent developments in flywheel technology include the development of suitable magnetic bearing systems, composite high-speed flywheel materials, light weight vacuum containers, and electro mechanical flywheel storage systems. Small magnetic bearing systems allow bearings for a flywheel storage system to be virtually free of mechanical friction because there is no physical contact between the flywheel and its supporting structure. New composite materials such as Kevlar™ and improved fiberglasses allow the construction of flywheels that are much stronger and can tolerate the high rotational speeds (up to 200,000 rpm) necessary for high energy storage. These new materials also allow the construction of high strength, lightweight vacuum vessels that also act as shielding to contain the high speed debris of a flywheel structural failure. Improvements in AC motor and controller technology has increased the efficiency of flywheel energy storage by allowing a spinning flywheel to act as both a motor and a generator for energy storage and release. These improvements in technology allow flywheel energy storage systems to be considered as possible future alternatives to conventional chemical battery technology.

The potential advantages offered by flywheel storage systems include the following:

- **High energy and power densities.** The storage capacity of this system is limited only by the construction materials' ability to tolerate higher rotational speeds.
- **Short recharge times.** It should be possible to charge up the flywheel system rapidly as there are few limitations to its charge rate compared to chemical batteries.
- **High ratio of power delivered to storage capacity.** The rate at which the stored energy is released is not limited by chemical properties as it is in chemical batteries.
- **Reduced temperature sensitivity.** A flywheel system's capacity and performance are not affected significantly by temperature extremes.

- **High number of recharge cycles.** With no wear on parts and no chemical decomposition or contamination problems, a flywheel system should not be affected by the number of recharge cycles.
- **Non-toxic materials.** A flywheel system does not contain toxic materials.
- **Non-corrosive materials.** A flywheel system does not contain corrosive materials.
- **Low heat operation.** A flywheel system does not create heat as a function of charge or discharge rate.

The potential disadvantages offered by flywheel storage systems include:

- **Special mountings to prevent vibrations.** Magnetic bearing systems are very sensitive to shock and vibration, and an automotive application can be an extremely hostile vibration environment.
- **Vacuum-sealed container.** Vacuum integrity of the flywheel housing is an absolute requirement for such systems to perform at their best.
- **Gyroscopic forces.** To prevent extreme vehicle handling and/or structural problems, the rotational speeds of counter-rotating flywheels must be controlled carefully to cancel each others' gyroscopic effects, or the flywheels must be mounted on gimbals.
- **Mechanical and electronic complexity.** The electronics and mechanics of flywheel systems are very complex and precise, therefore equipment cost may be high.
- **High-cost construction materials.** The high-strength, lightweight materials required to build the flywheels and containment vessels, such as carbon fiber composites, are currently very expensive.
- **Safety.** Containment of the flywheel in the event of a collision or bearing failure has not been addressed fully.

The relatively low-speed flywheel systems that are commercially available today are only suitable for large public transit vehicles (and possibly applications in hybrid electric vehicles). There are currently no flywheel storage systems suitable for electric vehicle use. American Flywheel Systems projects their EMFB to reach 20.4 Wh/kg by 1998 and 27.3 Wh/kg by 2000. To reach these goals, several significant technological breakthroughs will be required.

From a materials standpoint, the high strength composite fibers necessary for the construction of the flywheel and vessels for vacuum and failure containment exist. However, conventional (non magnetic) bearing materials need much more development to be suitable for such high rpm application.

From an electronics standpoint, magnetic bearings exist, but problems with shock and vibration sensitivity in an automotive application will have to be solved. The AC motor controller and permanent magnet AC motor technology required to control a flywheel storage system have been demonstrated.

From a cost standpoint, the materials and electronic components required to make a flywheel storage system practical are more expensive than conventional chemical batteries. Unless a breakthrough in materials, production, and electronic control costs is made, it will likely remain a relatively expensive storage system.

AFS projects the life cycle costs of advanced EMFB's in the future as follows:

- Fiberglass Flywheel: 2 cents/kWh-recharge cycle
(\$2,000 for a 21.8 kWh flywheel, rated at 4000 cycles lifetime); and
- Kevlar™ Flywheel: 3 cents/kWh-recharge cycle
(\$6,000 for a 43.6 kWh flywheel, rated at 4000 cycles lifetime).

If the energy storage capacity and reliability goals can be met, the increased expense of a flywheel storage system may become acceptable due to its increased service life.

Consolidated Assessment of Barriers

Based on the Booz-Allen analysis methods, a consolidated assessment of the barriers has been developed. Qualitative ratings for each barrier in each study year are given. The qualitative probability ratings are "low", "medium", and "high", defined as follows:

- **Low Probability.** The Booz-Allen analysis projects a less-than-25-percent chance of the barrier being overcome.
- **Medium Probability.** The Booz-Allen analysis projects a 25-to-75-percent chance of the barrier being overcome.
- **High Probability.** The Booz-Allen analysis projects a greater-than-75-percent chance of the barrier being overcome.

Table 6-4 presents the consolidated estimation of the probabilities of overcoming barriers and the potential benefits of doing so.

Table 6-4. Consolidated Probabilities of Overcoming Barriers

Source: Booz-Allen analysis

BARRIER	YEAR				
	1996	1998	2000	2002	2004
<u>Battery/Energy Storage</u>					
Lead-Acid	Low	Low	Low	Medium	Medium
Nickel Cadmium	Low	Low	Low	Low	Medium
Nickel Metal Hydride	Low	Medium	Medium	Medium	High
Sodium Sulfur	Low	Low	Low	Medium	Medium
Sodium Nickel Chloride	Low	Low	Low	Low	Medium
Lithium-based Batteries	Low	Low	Low	Low	Medium
Other Long-Term Batteries	Low	Low	Low	Low	Medium
Fuel Cells	Low	Low	Medium	Medium	Medium
Flywheels	Low	Low	Medium	Medium	Medium
Ultracapacitors	Low	Low	Low	Medium	Medium
Super-conducting Magnetic Energy Storage Devices	Low	Low	Low	Low	Medium
<u>Vehicle</u>					
Range	Low	Low	Low	Medium	Medium
Air Conditioning/Passenger Comfort	Low	Low	Medium	Medium	High
Cold Weather Performance	Medium	Medium	High	High	High
Safety	Medium	High	High	High	High

Table 6-4 (continued). Consolidated Probabilities of Overcoming Barriers

Source: Booz-Allen analysis

BARRIER	YEAR				
	1996	1998	2000	2002	2004
Infrastructure					
Charging Time	Low	Low	Low	Medium	Medium
Charging Station Implementation/Cost	Low	Low	Medium	Medium	Medium
Sales, Parts, and Service	Low	Medium	Medium	High	High
Codes and Standards	Medium	High	High	High	High
Safety/Emergency Services	Medium	High	High	High	High
Battery Supply and Recycling	Low	Medium	Medium	High	High
Legal Environment	Medium	High	High	High	High
Marketing/Public Acceptance					
Purchase Price	Low	Low	Low	Low	Medium
Market Size ¹	Low	Low	Low	Low	Low
Choice of Models/Body Styles ²	NA	NA	NA	NA	NA
Product Lead Time	Low	Medium	Medium	Medium	High
User Incentives ²	NA	NA	NA	NA	NA
User Education ²	NA	NA	NA	NA	NA
Consumer Acceptance ²	NA	NA	NA	NA	NA
Manufacturers' Economies of Scale	Low	Low	Medium	Medium	High

1. It is assumed that market size through 2004 will be only the "regulated" market in states that have already enacted the California LEV/ZEV regulations. For the purposes of this study, it is assumed that no additional states will enact the regulations. The probability assessment of the "market size" barrier refers to the likelihood that demand will meet or exceed the regulated market.
2. In this context, the assessment of certain marketing/public acceptance barriers is beyond the scope of the study.

FUTURE ZEV SCENARIOS

Based on the assessment of ZEV technology barriers, it is possible to construct plausible scenarios for future years. The scenarios contained in this section focus on the vehicle capabilities. Due to the uncertainty involved, three alternative scenarios have been constructed for each study year:

- **ZEV High Certainty Scenario.** The high certainty scenario is based on technological achievements that have already been made or are nearly certain to occur in the future.
- **ZEV Probable Scenario.** The probable scenario is based on technological achievements that have not yet been made, but almost certainly will be achieved in time for the study year in question.
- **ZEV Optimistic Scenario.** The optimistic scenario is based on technological achievements that have not yet been made, but have a possibility of occurring. These technological achievements would be expected if certain favorable events come to pass, or anticipated breakthroughs occur.

The projected characteristics of the state-of-the-art ZEV in each of the scenarios are shown in Table 6-5.

Note that only the compact, two-door body style is considered in this analysis. It is further recognized that for any particular vehicle, there will be design trade-offs between certain parameters. For example, additional driving range can be achieved if substandard levels of passenger comfort are provided. The scenarios described assume a compromise level, or "middle-of-the-road," design philosophy concerning such trade-offs.

Table 6-5. ZEV Technology Scenarios

Source: Booz-Allen analysis

SCENARIO	Nominal Range ¹ (miles)	Initial Vehicle Cost	Life-Cycle Cost (\$/mile)	Charge Time (100% using 220 VAC)	Cold Weather Performance ²
High Certainty					
1998	60	\$38,500	\$0.58	4 hours	Fair
2000	60	\$37,000	\$0.56	4 hours	Fair
2002	80	\$27,000	\$0.43	3 hours	Fair
2004	80	\$26,600	\$0.41	3 hours	Fair
Probable					
1998	90	\$23,875	\$0.36	3 hours	Fair
2000	100	\$21,700	\$0.33	2 hours	Fair
2002	110	\$17,000	\$0.27	2 hours	Good
2004	120	\$15,500	\$0.24	2 hours	Good
Optimistic					
1998	120	\$15,750	\$0.24	90 minutes	Good
2000	150	\$14,700	\$0.22	60 minutes	Good
2002	180	\$12,550	\$0.20	60 minutes	Good
2004	200	\$11,900	\$0.18	30 minutes	Good

1. On the FUDS driving cycle.

2. For this analysis, cold weather performance is defined as follows. "Poor" performance means that the vehicle is unusable on average 10 or more days per year in New York City, "Fair" is four to nine days per year, and "Good" is three or less.

Section 7

ZEV COSTS

This section presents an analysis of ZEV costs compared to gasoline-powered vehicles. The analysis is focused on estimating the costs of owning and operating ZEVs in the 1998 to 2004 time frame. The key factors in determining ZEV costs are initial vehicle price (including vehicle equipment, development and labor costs), battery replacement cost, maintenance cost, and fuel cost.

First, we discuss projected ZEV sales volume, because this information provides the context for understanding the level of investment required to produce a ZEV. This discussion includes an analysis of projected sales for the three states that have formally adopted a ZEV sales requirement (California, Massachusetts, and New York) and estimates sales volume if all 12 Northeast states that comprise the Ozone Transport Commission implement a ZEV mandate.

After sales volume projections have been established, we present a detailed discussion of initial vehicle costs and the most likely approaches that OEMs will take to meet the ZEV sales mandate. As part of this analysis, projected initial vehicle costs for 1998, 2000, 2002, and 2004 are summarized. Finally, we discuss the other key factors (battery replacement cost, maintenance cost, and fuel cost) and perform a sensitivity analysis to test different assumptions.

PROJECTED SALES OF ZEVS

To estimate the cost of owning and operating ZEVs, it is necessary first to project the volume and types of ZEVs that will be produced and sold. New York State, California, and Massachusetts have adopted a formal ZEV sales mandate; together these three states account for approximately 20 percent of new car sales in the U.S., as shown in Table 7-1.

Table 7-1. New Passenger Car Registrations for New York, California and Massachusetts

Source: American Automobile Manufacturers Association, *Motor Vehicle Facts & Figures*, 1991 - 1994 editions

	1993	1992	1991	1990	1989	5-Yr Avg.	Percent of Total U.S.
Total U.S.	8,406,237	8,056,777	8,234,017	9,159,629	9,852,617	8,741,855	
California	880,172	879,731	1,005,904	1,059,926	1,136,430	992,433	11.35%
Massachusetts	210,437	200,921	194,630	233,941	282,233	224,432	2.57%
New York	489,030	486,033	496,029	584,112	647,582	540,557	6.18%
						Total 3-State	20.10%

From 1998 to 2002, seven OEMs are required to meet the ZEV sales mandate: General Motors, Ford, Chrysler, Toyota, Honda, Nissan, and Mazda. Although market share varies from year to year for individual manufacturers, these OEMs consistently sell approximately 90 percent of all automobiles in the Northeast and California, as shown in Table 7-2.

Table 7-2. Passenger Car Market Share by OEM

Source: Booz-Allen analysis based on registration and sales data, *Ward's Automotive Yearbook*, 1994

OEM	New York	California	Massachusetts	Wt. Avg
GM	31.1%	24.7%	28.5%	27.2%
Ford	18.4%	21.1%	21.8%	20.4%
Chrysler	10.9%	5.8%	9.6%	7.9%
Toyota	9.5%	14.1%	11.3%	12.3%
Honda	10.2%	14.1%	5.6%	11.8%
Nissan	7.4%	6.9%	9.1%	7.4%
Mazda	2.5%	3.2%	3.4%	3.0%
Total	90.0%	89.9%	89.4%	89.8%

Beginning in 2003, the ZEV sales requirement extends to all OEMs that sell more than 3,000 light- and medium-duty vehicles in California. This encompasses almost 100 percent of light-duty sales. This also applies to New York State and Massachusetts as their ZEV requirements are based on this California sales definition. The intermediate-volume manufacturers that are subject to ZEV requirements in 2003 include BMW, Hyundai, Isuzu, Mercedes Benz, Mitsubishi, Volkswagen, and Volvo.

By applying ZEV percentage requirements to projected sales of new cars and light-duty trucks (under 3,750 GVWR), the total estimated ZEV sales volume for each state can be calculated. Table 7-3 summarizes the results. It is important to note in this table that annual sales estimates are based on 1993 new-registration rates of passenger cars and light-duty trucks, and average annual growth rates of 1.3 percent and 3.4 percent, respectively, were assumed.¹ Although Table 7-1 shows generally declining new vehicle registrations, this trend is not expected to continue.

¹ These annual growth rates were derived from the 1993 New York State Energy Plan projections for total vehicle registrations in New York State, and the same growth rates were assumed for California and Massachusetts.

Table 7-3. Estimated Annual ZEV Sales for New York State, California, and Massachusetts

Source: Booz-Allen analysis

MY ¹	% Reqt.	NY	Calif	Mass	Total
1998	2%	11,861	22,973	5,152	39,986
1999	2%	12,069	23,402	5,243	40,714
2000	2%	12,281	23,841	5,336	41,458
2001	5%	31,245	60,726	13,577	105,548
2002	5%	31,799	61,876	13,820	107,495
2003	10%	64,731	126,105	28,136	218,972
2004	10%	72,002	139,826	31,283	243,112

1. Model Year.

It is important to note that actual ZEV sales could exceed the mandated requirements shown in Table 7-3, especially prior to 1998. Companies such as U.S. Electricar, Solectria, Renaissance Cars, and others will likely continue to produce and sell EVs. However, any ZEVs sold by these companies will earn credits that will probably be sold to the Big Seven OEMs to reduce their required ZEV units. Moreover, some other OEMs such as Peugeot, Volkswagen, and Hyundai are considering selling ZEVs before their required 2003 introduction date. Again, any ZEVs sold by these companies would earn credits that can be sold or banked internally to offset the company's future requirement. Due to this credit feature, the values shown in Table 7-3 should provide a fairly good estimate of the total number of ZEVs that will be produced and sold, although exact sales may vary from year to year.

Table 7-4 presents an estimate of the number of ZEVs that each OEM is responsible for producing and delivering for sale in New York State, California, and Massachusetts. These results were calculated using OEM market share distributions for 1993 (from Table 7-2) and should be considered rough approximations since market share can vary from year to year by as much as 5 percent per OEM. In terms of number of units required, General Motors must produce the most ZEVs, followed in order by Ford, Toyota, Honda, Chrysler, Nissan, and Mazda. Beginning in 2003, intermediate volume manufacturers must begin selling ZEVs.

Table 7-4. Required ZEV Sales by OEM for New York State, California, and Massachusetts
(Source: Booz-Allen analysis)

MY	GM	Ford	Chrysler	Toyota	Honda	Nissan	Mazda	Other
1998	10,831	8,153	3,120	4,948	4,737	2,932	1,207	0
1999	11,028	8,301	3,176	5,039	4,824	2,985	1,229	0
2000	11,229	8,453	3,234	5,131	4,913	3,039	1,251	0
2001	28,586	21,522	8,231	13,065	12,510	7,738	3,186	0
2002	29,112	21,920	8,382	13,307	12,742	7,880	3,245	0
2003	59,298	44,652	17,071	27,110	25,959	16,052	6,610	22,220
2004	65,846	49,572	18,961	30,091	28,812	17,823	7,338	24,670

Expansion of the ZEV program to other states could result in an increase in the sales levels shown in Table 7-4. In December 1994, the U.S. Environmental Protection Agency (EPA) approved a low-emission vehicle program petition submitted by the Ozone Transport Commission (OTC). The OTC is comprised of environmental commissioners from 12 Northeast states and the District of Columbia. OTC member states include Maine, New Hampshire, Vermont, Rhode Island, Connecticut, Pennsylvania, New Jersey, Delaware, Maryland, and (northern) Virginia, as well as New York and Massachusetts. Although the petition allows each state the option to implement ZEVs, it is unclear at this time which, if any, of these states will adopt a ZEV sales requirement.

If a ZEV sales requirement is adopted throughout the OTC region, ZEV sales volumes could double compared to the New York State, California, and Massachusetts levels. However, significant opposition to the mandates has been voiced in some OTC member states. Adoption of a ZEV sales requirement throughout the OTC region is not likely to occur within the time frame of this analysis (1998 to 2004); therefore, sales volume estimates for New York State, Massachusetts, and California were used for the cost analysis. Figure 7-1 shows the estimated annual sales of ZEVs if a ZEV sales requirement is implemented in all of the OTC states and California.

Figure 7-1. Estimated Annual ZEV Sales That Could Result from Implementation of a ZEV Mandate in the OTC Region

Source: Booz-Allen analysis based on vehicle registration data contained in the *New York State Energy Plan, 1994* and the American Automobile Manufacturers Association, *Motor Vehicle Facts & Figures, 1993*

INITIAL VEHICLE COSTS

Due to the nascent nature of the industry, the future cost of a ZEV cannot be predicted with any great certainty. Nonetheless, one approach to estimating the future cost is to segregate its individual cost components. The cost to produce an EV will be the sum of the following main cost components:

- Vehicle equipment cost, including vehicle chassis and powertrain;
- Battery cost;
- Development cost, including research, design and engineering, testing, and facility and tooling; and
- Labor cost.

Retail prices of today's gasoline-powered cars range from \$8,000 for a no-frills subcompact to more than \$100,000 for a luxury sedan or high-performance sports car. Similarly, the cost of an EV can vary greatly depending on its performance, engineering, styling, and nameplate. In general, the greater the acceleration, power, range, and efficiency, the higher the cost of the EV. These parameters will be affected by the type of equipment (e.g., motor and battery pack) the manufacturer installs.

At present, EVs are mostly hand-built in very small quantities; the highest-selling EVs are produced in hundreds of units per year, compared to hundreds of thousands of units for the most popular gasoline-powered models. As EV volumes increase beyond the hand-built stage into mass production, costs should decline substantially as economies of scale result in more efficient and cost-effective manufacturing and assembly.

Furthermore, some of the technologies being considered for EVs are still in the development phase or in the early stages of commercialization. Efficient manufacturing techniques are still being researched and production facilities being designed. As manufacturers become more familiar with producing vehicles and vehicle components on a mass production basis, product reliability and durability should improve.

In addition to the cost of production, the cost of marketing and selling should be factored in. These costs would include advertising, promotions, and dealer preparation and training. Additionally, a fair rate of return on investment should be allocated to the manufacturer and the dealer. The profit margin fluctuates depending on the state of the economy and the demand for a particular model, but is typically about five percent.² Selling costs and profit are added to the ultimate retail price of the vehicle but are not considered part of the cost of producing the vehicle.

Vehicle Equipment Cost (Excluding Battery)

Excluding the battery pack, the vehicle chassis and powertrain are the main subsystems on an EV. Chassis and powertrain costs can be estimated reasonably and are discussed in detail.

Chassis Cost. Chassis options vary from gliders to purpose-built bodies which maximize the use of lightweight materials and energy-efficient features. A glider is a conventional vehicle body in which the gasoline engine, fuel tank, and emission control system have not been installed.

² Booz-Allen analysis.

Currently, EV converters purchase complete vehicles (sometimes at discounted fleet prices) and remove the engine and other unnecessary components before installing an electric powertrain. However, OEMs are now considering making gliders available to smaller EV converters in exchange for ZEV credits.³

Gliders will probably be widely used prior to 1998 by smaller, nontraditional OEMs that are not subject to the mandate. Renaissance Tropica model and Solectria Sunrise are notable exceptions. A glider will cost an EV converter from about \$3,000 to \$4,000 less than a complete vehicle due to the savings from the engine, emission controls, and fuel system.⁴ Additional savings will result from eliminating the labor needed to remove gasoline-related components. The vehicle assembly labor savings have been estimated at 60 percent.⁵

In 1998, large OEMs must begin ZEV production in order to satisfy regulatory requirements, and the electric vehicle market will expand to approximately 40,000 units per year. To sustain such a market, EVs must move beyond fleets and into the general public. To maximize performance and therefore appeal to the general public, the OEMs likely will develop chassis which, if not purpose-built for EVs, will be designed specifically to accommodate EVs. Chrysler, for example, has announced it is working on a new minivan chassis that will be used for both electric and gasoline powertrains.

If carbon-composite body panels and aluminum chassis are used for EVs, the price of a chassis may increase by several hundred dollars compared to a steel body. Carbon-fiber materials cost about \$20 per pound, compared to \$0.38 per pound for steel.⁶ However, part of the increased materials cost can be offset by taking advantage of the moldability of carbon composites to reduce the number of parts and to simplify assembly steps. Amerigon estimates that the cost of materials and labor associated with composite body panels and aluminum frames is about \$500 more than for a conventionally built steel vehicle, at a volume of about 10,000 units per year.⁷

³ "Ford/Electracar Venture," *Wall Street Journal*, November 16, 1994; *Investors Business Daily*, December 8, 1994.

⁴ Booz-Allen estimate.

⁵ "Near-Term Electric Vehicle Costs", prepared for the Northeast Alternative Vehicle Consortium, October 1994.

⁶ *Ward's Auto World*, July 1994.

⁷ Personal communication, Kevin Gunning, Amerigon, October 1994.

Powertrain Cost. Powertrain options for EVs include brush DC motors , permanent-magnet DC motors, and AC induction motors, along with the associated electronics. Nearly all the major OEMs and many smaller EV manufacturers, such as U.S. Electricar and Solectria, are planning to use AC powertrains for their 1998 model year offerings. AC powertrains are favored for their improved performance and efficiency compared to conventional DC systems. Permanent-magnet DC motors also are being considered by OEMs such as BMW. Brush DC motors may continue to be installed in some converted EVs due to their low price; however, they are expected initially to find only limited application in OEM-built vehicles. However, research and development is underway that will result in improved efficiency and performance.

Pro EV is the North American distributor of General Electric's brush DC systems. Pro EV currently offers a 27-HP, DC shunt motor and controller with regenerative braking for a list price of \$4,600.⁸ A 21-HP, DC series motor and controller system sells for \$4,200.⁹ Each of these systems contains a motor, controller, dash display, and accelerator box. An on-board battery charger will add another \$750.¹⁰ Discounts are available for multiple orders.¹¹

The price of brush DC motors should decrease with volume production. Advanced DC Motors projects that in volumes of 1,000 or more units, its 85-HP(maximum) series wound motor system would sell for \$1,000 each.¹² A controller and other powertrain electronics can be purchased separately for \$700;¹³ a complete system would thus cost about \$1,700. For 20,000 or more units, motor prices could fall to \$400 to \$600, and total system prices to less than \$1,000.¹⁴

AC powertrains, such as those used in the Solectria Force and the U.S. Electricar Sedan, currently cost about \$15,000 to \$25,000 in small production quantities.¹⁵ These units are mainly hand-built, and there is substantial room for cost improvements. In quantities of about 1,000 units, prices should drop to \$8,000 to \$10,000.¹⁶ Westinghouse has begun a study sponsored by the

⁸ Manufacturer price list, not dated.

⁹ Ibid.

¹⁰ Ibid.

¹¹ Personal communication, Don Rodes, Pro EV, December 1994.

¹² Personal communication, Advanced DC Motors, December 1994.

¹³ Ibid.

¹⁴ Ibid.

¹⁵ Personal communication, equipment manufacturers, July to December 1994.

¹⁶ Booz-Allen estimate based on discussions with equipment manufacturers.

U.S. Department of Defense to manufacture a 100-HP, AC powertrain for \$2,500.¹⁷ Westinghouse believes that it will be able to achieve this goal in about 5 years.¹⁸

Brushless permanent-magnet DC motors may offer an option to AC induction powertrains. Performance and costs are very similar to AC systems. Unique Mobility currently sells its permanent-magnet system at approximately \$24,000 on an individual basis.¹⁹ However, in production quantities of more than 30,000 units per year, the system is projected to sell for less than \$2,000.²⁰

Initial Battery Cost

Unless a major technological breakthrough occurs, lead-acid or nickel-cadmium appear to be the choice for EV batteries before the year 2000. These battery technologies are relatively mature, and plans have been developed for volume production. The status of battery technologies was previously reviewed in Section 4; key points will be summarized here to estimate costs.

A conventional lead-acid battery currently costs between \$70 and \$100 per kWh and has a life of 2 to 3 years. A 17-kWh sealed battery pack, such as the one used in the GM Impact, would cost \$1,500 to \$2,000 and should last 25,000 to 30,000 miles before needing replacement. Advanced lead-acid batteries are now under development that would improve the energy density, although at higher cost. The ALABC has targeted a cost goal of \$150 per kWh for an advanced lead-acid battery with 50-Wh/kg specific energy (500 cycles over the simplified FUDS by 1997).²¹

At present, nickel-cadmium batteries have substantially higher costs than conventional lead-acid batteries with prototype units costing up to \$1,000 per kWh. In full production quantities of 50,000 to 100,000 units per year, the NiCd Electric Vehicle Information Center projects that nickel-cadmium batteries will cost \$200 per kWh.²² Saft has installed a pilot production line in Europe capable of making 5,000 electric vehicle packs per year, with further expansion anticipated.²³

¹⁷ Personal communication, Westinghouse, December 1994.

¹⁸ Ibid.

¹⁹ Personal communication, Kevin Barnes, Unique Mobility, February 1995.

²⁰ Ibid.

²¹ Personal communication, ALABC, April 1995.

²² Hugh Morrow, NiCd Electric Vehicle Information Center, February 1994.

²³ SAFT product literature.

However, due to the present lack of a recycling infrastructure for cadmium in the United States, nickel-cadmium probably will not be widely used for 1998 model ZEVs.

Nickel-metal-hydride appears to be a very promising technology for batteries in the mid-term. These batteries are only available today in prototype packs. Ovonic Battery Company has publicly stated that its nickel-metal-hydride batteries will be available in 1998 at \$150 per kWh.²⁴ The USABC has established a different timeline; it has stated that an operational pilot plant for nickel-metal-hydride can be on-line by mid-1999 and a higher volume production plant by mid-2001.²⁵ Panasonic and Saft also are working on developing nickel-metal-hydride batteries, with production planned to begin later this decade.

Development Cost

For new gasoline models, the major OEMs are accustomed to spending more than \$1 billion for design, engineering, testing, and tooling. Chrysler, for example, allotted \$1.3 billion to its Dodge/Plymouth Neon project, a relatively small sum by industry standards.²⁶ The development cost for the Neon included tooling for two new satellite stamping plants, a plastic fascia plant, and development of a new engine and 5-speed manual transmission.²⁷

For its new Mystique/Contour line, Ford spent \$6 billion in development costs, a high sum by industry standards.²⁸ To justify this level of investment, Ford says it needs to sell 75,000 Mystiques and 250,000 Contours. Assuming sales remain constant for 4 years, the \$6-billion development cost would amortize to an average of \$5,200 per vehicle over the first 4 model-years (assuming 5 percent cost of capital).

Development costs can be lowered considerably, however, with efficient engineering and by minimizing investment in new capital equipment and facilities. The Dodge Viper, for example,

²⁴ Mike Fetchenko, Vice President of Ovonic Battery Company; testimony at California Air Resources Board Public Meeting to Consider a Status Report on the Implementation of the Low-Emission Vehicle Regulations, May 12, 1994.

²⁵ John Williams, Chairman of USABC, testimony at California Air Resources Board Public Meeting to Consider a Status Report on the Implementation of the Low-Emission Vehicle Regulations, May 12, 1994.

²⁶ *Automotive Engineering*, October 1994.

²⁷ *Ward's Auto World*, December 1994.

²⁸ *Ward's Automotive Yearbook* 1994.

was developed for a reported \$50 million.²⁹ The development process for the Viper was extremely streamlined, going from concept car to production vehicle in less than 3 years. Suppliers were brought into the development process early to share some initial engineering and design costs; composite body panels were used to reduce tooling costs.³⁰ Chrysler sells approximately 1,000 units of the Viper per year at a cost of \$60,000 each.

Press reports suggest that as of early 1994, General Motors had spent \$300 million and Ford \$150 million on their EV development efforts.³¹ The amount spent by other OEMs is not known. The needed development cost for a ZEV model is speculative since there are no previous EV-specific mass production data. OEMs have considerably less experience in designing and manufacturing EVs than gasoline vehicles, which may lead to some initial inefficiencies in the development process.

Industry analysts have proffered estimates of about \$100 million to more than \$1 billion investment needed to develop an EV. Amerigon, for example, estimates that an automaker using its running chassis would need to spend about \$110 million, compared to more than \$260 million if the automaker were to develop an EV independently.³² To develop the Solectria Flash (a proposed new production EV), Boston Edison (Solectria's partner in the venture) estimates that gearing up for production of 20,000 cars per year would require funding of about \$300 to \$500 million.³³ Ford has suggested that its up-front costs would range from \$800 million to \$1.8 billion to produce 40,000 electric vehicles (roughly the first four years of the mandate).³⁴

Based on their previous history with gasoline models, it seems plausible that a large OEM, such as GM or Ford, could spend between \$500 million and \$1 billion to develop and produce a purpose-built ZEV. Assuming a four-year product cycle and five percent real cost of capital, this investment would require amortization of \$141 to \$282 million per year. For GM and Ford, amortized development costs would add from \$9,000 to \$12,000 (assuming \$500 million initial

²⁹ *Manufacturing Engineering*, April 1992.

³⁰ *Ibid.*

³¹ *Ward Automotive Yearbook*, 1994.

³² Personal communication, Kevin Gunning, Amerigon, October 1994.

³³ *Boston Globe*, December 2, 1994.

³⁴ Presentation by Bob Kiessel, Ford Motor Company, at the California Air Resources Board workshop on Zero-Emission Vehicles, March 24, 1994.

investment; double those values for \$1 billion initial investment) to the average price of a ZEV over the first four years of the mandate.

Four years is the typical amortization period used by OEMs to recoup investment costs. Models typically turn over (i.e., are redesigned) every four years, and OEMs try to recoup costs as quickly as possible. However, in the case of ZEVs, a longer outlook may be more appropriate. Much of the experience gained in developing the first ZEV model can be applied beyond the first four years; using flexible manufacturing techniques, production processes can also be extended beyond the first model run. If development costs are amortized over seven years (rather than four years), a \$500 million initial investment would add about \$2,800 and \$3,700 to the unit price of a car for GM and Ford, respectively. These values would be doubled for a \$1-billion initial investment.

Labor Costs

According to the U.S. Department of Labor, Bureau of Labor Statistics, the average automotive production employee earned \$15.46 per hour in 1992; benefits added another \$9.66 for a total labor cost of \$25.12 per hour.³⁵ In 1992, Business Week reported that the total cost of labor per car averaged \$1,872 for Chrysler, \$2,358 for GM and \$1,563 for Ford.³⁶

Electric vehicles have fewer parts and ultimately should be simpler to assemble than gasoline-powered vehicles. This is especially true for purpose-built vehicles with composite bodies. In the initial years of the mandate, however, labor costs for EVs are likely to remain near the average costs for gasoline vehicles. Amerigon, for example, estimates labor costs at \$2,000 per car for purpose-built EVs using its running chassis.³⁷ However, as assembly steps are streamlined, Booz-Allen believes that labor cost savings of more than 50 percent are possible for EVs compared to conventional vehicles.

Longer-Term Vehicle Cost

Once electric vehicles reach production volumes similar to current conventional gasoline vehicles, most industry experts agree that an EV, excluding the battery pack, can be priced about the same or even slightly lower than a conventional gasoline vehicle. Recent quotes from two domestic OEMs confirm this expectation:

³⁵ AAMA, *Motor Vehicle Facts & Figures*, 1994.

³⁶ Business Week, November 9, 1992.

³⁷ Personal communication, Kevin Gunning, Amerigon, October 1994.

"Electric vehicles actually can be produced for less than conventional vehicles, but as they say in the ads, 'batteries not included.' "

Bob Lutz, President of Chrysler Corporation³⁸

"It's not hard to see that we can build an electric vehicle that's as cheap, or maybe even slightly cheaper, than our current internal combustion engine vehicle. But it's very hard to see how I'm going to take a battery and have it compete in cost with a \$50 fuel tank. The bottom line on the cost is in the battery."

John Wallace, Director , Electric Vehicle Development Programs, Ford Motor Company³⁹

Likely OEM Approaches Toward the ZEV Mandate

Booz-Allen believes that in the initial years of the mandate, OEMs will not devote the resources needed to produce an in-house EV if amortizing the development cost requires raising per vehicle prices by more than \$10,000 to \$15,000 compared to a similar gasoline model. Other options are available from 1998 to 2000—the two percent years—to avoid having to make such a large and probably unrecoverable investment.

Some OEMs will purchase ZEV credits, or acquire complete vehicles for repackaging and marketing under their own nameplates, from nontraditional OEMs in order to satisfy their ZEV requirements. Mazda, with its under-1,500-units-per-year requirement, will almost certainly take this route. U.S. Electricar, Renaissance Cars, Solectria, and other non-traditional OEMs are all earning ZEV credits for EVs they sell. Since these companies are not subject to the ZEV mandate, they have no internal use for ZEV credits and should be willing to trade/sell the credits to other OEMs.

The ZEV credit guidelines grant more credits to ZEVs that are sold in early years. For example, a 1995 model-year ZEV will earn 1.5 times the credit of a 1998 model-year ZEV. The ratio decreases to 1.4 and 1.3 for 1996 and 1997 model-year ZEV sales, respectively.⁴⁰ Given this credit "discounting" in favor of early ZEVs, it appears likely that enough credits will be available to offset the first one or two years of the mandate for OEMs that pursue this approach. By acquiring

³⁸ Investors Business Daily, December 10, 1994.

³⁹ Quoted in California Environmental Protection Agency, California Air Resources Board, Staff Report, 1994 Low-Emission Vehicle and Zero-Emission Vehicle Program Review, April 1994.

⁴⁰ Refer to 6NYCRR Part 218, Subpart 4 Zero Emission Vehicle Sales Mandate.

ZEV credits, a major OEM can delay its own production start date until it can meet the mandated percentages more economically.

OEMs also can enter into joint ventures with each other to share development costs. The three domestic OEMs already have begun to do this through the USABC, Partnership for a New Generation of Vehicles (PNGV) and other consortiums, some of which are funded partially by the federal government. It is also not uncommon for the OEMs to share vehicle designs and production facilities. For example, Mazda helped design the Ford Escort; the Honda Passport is a repackaged Isuzu; Toyota and GM each own 50 percent of an assembly plant in Northern California that produces Geo Prizms/Toyota Corollas.

Some OEMs likely will produce their own ZEVs, but use design features for gasoline vehicles to minimize development costs. By designing a chassis that will be used by both gasoline and electric powertrains, Chrysler, for example, is able to spread a portion of its development costs over a much wider sales base (Chrysler sells nearly 500,000 gasoline-powered minivans per year). The result may be a less than absolutely optimal electric vehicle, but is justifiable in view of the savings in cost. Other OEMs, particularly Honda or Nissan, will likely pursue the same strategy. Additionally, OEMs may seek to increase their sales base by marketing electric vehicles in Japan, Europe, and other parts of the world where there is growing interest in ZEVs.

The bottom line is that sufficient options are available to the OEMs that will enable them to avoid making very large investments in ZEVs in the initial years of the mandate. By delaying large scale investment until ZEV volumes increase, development costs can be recouped more quickly. A possible drawback of this approach, however, is that these ZEVs may not meet the performance or quality expectations of consumers. This trade-off must be considered carefully by the OEMs.

Projected Initial Vehicle Cost

Booz-Allen's assessment of costs for ZEVs for the 1998, 2000, 2002, and 2004 model-years is summarized in Tables 7-5 through 7-8. These costs reflect Booz-Allen's estimate of the most probable technology/cost options for ZEVs; plausible ranges around that estimate also are indicated in the tables. The focus of the assessment is on ZEVs that will be produced to meet the sales mandate (i.e., vehicles produced by an OEM or ZEVs manufactured by a nontraditional OEM and whose credits are transferred or sold). A four-passenger commuter car similar in size to a conventional gasoline subcompact is assumed as the base vehicle body. Other assumptions used in deriving the costs are described following the tables. All costs shown in this section are in 1994 constant dollars, unless otherwise specified.

Projected 1998 ZEV Costs. Table 7-5 summarizes the cost projections for ZEVs in 1998.

Table 7-5. Projected Technology and Cost for ZEVs in 1998

(Total ZEV Market Size: 40,000 units)

Source: Booz-Allen analysis

	Probable	Plausible Range
Vehicle chassis (redesigned base gasoline chassis)	\$5,000	\$3,500 to \$8,000
AC induction/DC permanent-magnet powertrain	\$3,500	\$2,500 to \$5,000
Advanced lead acid battery pack (25 kWh @ \$175/kWh)	\$4,375	\$3,750 to \$5,000
Labor	\$2,000	\$1,500 to \$2,500
Amortized development (R&D, tooling, etc.)	\$9,000	\$4,500 to \$18,000
Total Production Cost	\$23,875	\$15,750 to \$38,500

The technology assumptions listed in Table 7-5 represent a compromise between two initially conflicting objectives: minimize cost and maximize performance. Actual costs can be higher or lower depending on performance needs. For example, if an OEM chose to build EVs equipped with series DC powertrains, component costs could be as much as \$2,000 lower in 1998.

Similarly, use of gliders will reduce component as well as development costs. In order to meet the mandated percentages, however, Booz-Allen believes that a minimum level of performance and quality will be required for 1998 models:

- EVs should nominally achieve a 100-mile range in city driving under favorable ambient conditions;
- EVs should be able to accelerate about as quickly as today's subcompact cars (0 to 60 mph in roughly 15 seconds); and
- EVs should be engineered to similar levels of comfort and safety as small conventional gasoline vehicles.

Booz-Allen believes that 1998 model-year ZEVs should be equipped with the most advanced technology reasonably available. Thus, the total production cost shown in Tables 7-5 through 7-8 does not represent the minimum possible cost but rather the most reasonable based on this perception of technological needs.

According to Electrosources, an advanced lead-acid battery will have a specific energy of about 50 Wh/kg. A 25-kWh battery pack therefore would weigh 500 kg (1100 pounds). The GM Impact,

equipped with 1100 pounds of batteries and an AC induction drivetrain (characteristics similar to the assumptions listed for the ZEV in Table 7-5) is able to achieve energy use of 0.19 kWh/mile over the Federal Urban Driving Schedule (see Table 3-3). The Impact, however, is equipped with an advanced lightweight vehicle chassis rather than a redesigned gasoline vehicle chassis as assumed in this scenario. Therefore, an energy use rate of 0.20 kWh/mile is probably an appropriate assumption for the projected 1998 ZEV. At 0.20 kWh/mile, the projected 1998 ZEV should be able to travel 100 miles at an 80 percent battery depth of discharge.

As seen from Table 7-5, amortized development cost represents the single largest cost component. The \$9,000 cost shown in the table assumes a total initial investment of \$300 million. This level of investment would be needed to design and engineer a well-performing electric vehicle and to construct production facilities. Approximately \$50 million of this sum was assumed to be amortized over the first three model years (1998 through 2000, the two percent years) to account for model-specific development costs, while the remaining \$250 million was amortized over seven model years. Amortization over seven years assumes that some equipment and design features can be used for subsequent models. A hypothetical manufacturer producing 6,000 ZEVs per year (roughly equivalent to one-seventh of the total ZEV market) from 1998 through 2000 was used as the basis for calculating the amortized levels. The range of plausible costs in the table assume amortization of \$150 million and \$600 million in investment costs for the low and high ranges, respectively.

Projected 2000 ZEV Costs. Table 7-6 summarizes the cost projections for ZEVs in 2000.

Table 7-6. Projected Technology and Cost for ZEVs in 2000

(Total ZEV Market Size: 41,000 units)

Source: Booz-Allen analysis

	Probable	Plausible Range
Vehicle chassis (redesigned base gasoline chassis)	\$5,000	\$3,500 to \$8,000
AC induction/DC permanent magnet powertrain	\$2,500	\$2,500 to \$4,000
Nickel-metal-hydride battery pack (20 kWh @ \$175/kWh)	\$3,500	\$3,000 to \$4,500
Labor	\$1,700	\$1,200 to \$2,500
Amortized development (R&D, tooling, etc.)	\$9,000	\$4,500 to \$18,000
Total Production Cost	\$21,700	\$14,700 to \$37,000

For the 2000 model year, the total ZEV market size remains nearly the same as in 1998.

Component costs are expected to decline with greater experience in manufacturing and more confidence in the growth of the market. The most significant technological change from 1998

may be the availability of an advanced mid-term battery such as nickel-metal-hydride. Nickel-metal-hydride batteries have a higher specific energy than advanced lead-acid, thereby requiring lower on-board storage weight to achieve equivalent range. This weight savings will translate into better overall energy efficiency for the vehicle.

A nickel-metal-hydride battery produced in 2000 should have a specific energy of 80 Wh/kg (see Section 4). A 20-kWh pack therefore would weigh about 550 pounds. At 550 pounds, an energy use rate of 0.18 kWh/mile should be possible. A 100-mile range can be achieved when using 90 percent of the battery storage capacity.

Projected 2002 ZEV Costs. Table 7-7 summarizes the cost projections for ZEVs in 2002.

Table 7-7. Projected Technology and Cost for ZEVs in 2002

(Total ZEV Market Size: 107,000 units)

Source: Booz-Allen analysis

	Probable	Plausible Range
Vehicle chassis (purpose-built chassis)	\$4,500	\$3,500 to \$6,000
AC induction/DC permanent-magnet powertrain	\$2,000	\$1,500 to \$2,500
Nickel-metal-hydride battery pack (20 kWh @ \$150/kWh)	\$3,000	\$2,800 to \$3,500
Labor	\$1,000	\$1,000 to \$2,000
Amortized development (R&D, tooling, etc.)	\$6,500	\$3,750 to \$13,000
Total Production Cost	\$17,000	\$12,550 to \$27,000

In 2002, the ZEV market grows to five percent of new vehicle sales, or about 107,000 total units for New York State, California and Massachusetts. The expansion of the market in 2002 will likely lead to a redesign of previous EV models to attract more customers. Use of EV-optimized, composite chassis will help reduce vehicle weight and improve aerodynamics, thus increasing vehicle efficiency and range. Assuming an energy use rate of 0.15 kWh/mile, urban driving range should improve to 120 miles at 90 percent battery discharge.

To pay for the vehicle redesign, a new development expenditure of \$50 million was assumed to occur in 2001. Amortized over four years at an average of 23,000 ZEVs per year (roughly one-seventh of the total market from 2001 to 2004), the per vehicle costs come to just over \$600 per year. However, continued amortization of the \$250 million expended in 1998 increases total development costs to \$6,500 per vehicle.

Projected 2004 ZEV Costs. Table 7-8 summarizes the cost projections for ZEVs in 2004.

Table 7-8. Projected Technology and Cost for ZEVs in 2004

(Total ZEV Market Size: 243,000 units)

Source: Booz-Allen analysis

	Probable	Plausible Range
Vehicle chassis (purpose-built chassis)	\$3,000	\$2,800 to \$6,000
AC induction/DC permanent-magnet powertrain	\$2,000	\$1,800 to \$2,500
Nickel-metal-hydride battery pack (20 kWh @ \$150/kWh)	\$3,000	\$2,800 to \$3,500
Labor	\$1,000	\$800 to \$1,600
Amortized development (R&D, tooling, etc.)	\$6,500	\$3,750 to \$13,000
Total Production Cost	\$15,500	\$11,950 to \$26,600

In 2003, the ZEV market further expands to 10 percent of new vehicle sales, and intermediate-volume manufacturers begin to sell ZEVs. In 2004, costs are projected to be very similar to those shown previously for 2002. While component costs continue to decline slightly with increased volume and experience, development costs remain constant to amortize investments made in previous years.

Summary of Cost Projections. Booz-Allen's cost estimates are graphically depicted in Figure 7-2.

Figure 7-2. Summary of ZEV Cost Projections

Source: Booz-Allen analysis

LIFE-CYCLE COSTS

The cost to own and operate a ZEV consists of the following factors:

- Initial vehicle price;
- Battery replacement cost;
- Maintenance cost; and
- Fuel cost.

Other ownership and operating costs include insurance and license, financing, parking and storage fees, car washes, road tolls, etc. These costs, however, are presumed to be the same for ZEVs and conventional gasoline vehicles and therefore are not included in this analysis.

At present, ZEV buyers can receive a federal income tax deduction. Some states have adopted or are considering adopting financial incentives to reduce the initial cost of ZEVs. The presence or absence of monetary subsidies and tax exemptions can affect life cycle costs; however, such incentives likely will be removed once ZEVs become more widespread in the transportation market. In the analysis presented in this section, life-cycle costs are calculated without explicitly considering subsidies or exemptions. The effect of financial incentives can be seen in the sensitivity analyses presented at the end of Section 7.

Initial Vehicle Price

Initial vehicle prices paid by consumers will depend on the manufacturer's production and selling costs, plus profit. The projected cost to produce a ZEV was previously described. Selling costs include advertising, promotions, and shipping vehicles to dealer showrooms. Selling costs are estimated at 10 percent, and profit margins for the OEM and the dealer total eight percent.⁴¹ These costs (18 percent) are added to the projected probable OEM costs to obtain projected retail prices (Table 7-9).

For comparison, a subcompact gasoline vehicle is included in Table 7-9. The Ford Escort was selected as a suitable gasoline baseline, although other subcompacts have similar cost and performance characteristics. The 1995 Ford Escort is equipped with an 88-horsepower, 1.9-liter, 4-cylinder engine and has a manufacturer's suggested retail price of \$9,560.⁴² The Escort is presently certified to California Transitional Low-Emission Vehicle (TLEV) standards; by 2002, in

⁴¹ Booz-Allen estimate.

⁴² *Ward's Auto World*, October 1994.

order to meet Ultra-Low-Emission Vehicle (ULEV) standards, the Escort is projected to require an additional \$300 worth of hardware adjustments.⁴³

Table 7-9. Projected Retail Price of ZEVs and Conventional Vehicles

(All prices in constant 1994\$)

Source: Booz-Allen analysis

MY	ZEV	Escort
1998	\$28,173	\$9,560
2000	\$25,606	\$9,560
2002	\$20,060	\$9,860
2004	\$18,290	\$9,860

In order to calculate costs on a per mile basis, assumptions must be made concerning vehicle life and annual miles traveled. Electric vehicles are believed to have longer lives than gasoline vehicles since electric motors are less susceptible to deterioration than gasoline engines. Electric vehicle batteries, however, must be replaced at regular intervals and can constitute a significant expense. Amortization of electric vehicle batteries is discussed separately.

The average car in the United States today is about eight years old and travels 12,500 miles per year.⁴⁴ Newer cars tend to travel more miles than older cars. Table 7-10 shows average miles traveled based on vehicle age group.

Table 7-10. Average Annual Miles Traveled per Vehicle

Based on Vehicle Age Group, 1990

Source: AAMA, *Facts & Figures*, 1994; based on U.S. Department of Transportation

Vehicle Age	Annual Miles
0 to 2 years	16,811
3 to 5 years	13,706
6 to 9 years	12,554
10 or more years	9,176
Average	12,458

⁴³ Based on recent Honda announcement that the ULEV standards are achievable with \$200 to \$300 in new emissions hardware, as demonstrated by the Honda Prelude; see, for example, *Business Week*, January 23, 1995.

⁴⁴ AAMA, *Motor Vehicle Facts & Figures*, 1994.

For simplicity, the life-cycle cost analysis will assume that ZEVs travel the national average of 12,500 miles per year. (Average-miles-traveled data for vehicles registered only in New York State are not available.) The ZEVs projected to be produced from 1998 to 2004 should be able to achieve this annual mileage, although a significant number of them may be used in niche applications that require less mileage. Assuming ZEVs are driven six days a week, 12,500 miles per year translates into 40 miles per day; this is well within the assumed urban range of 100 and 120 miles for 1998/2000 and 2002/2004 ZEVs, respectively. As a sensitivity check, ZEV initial cost also is calculated for 10,000 miles of annual travel (equivalent to 32 miles per day, six days per week). Table 7-11 summarizes the equivalent per mile costs of purchasing a ZEV (less battery costs) assuming an EV life of 12 years (same as gasoline vehicles).

Table 7-11. ZEV Initial Costs on a Per Mile Basis Not Including Battery Costs

Source: Booz-Allen analysis

MY	ZEV		Escort 12,500 mi/yr
	10,000 mi/yr	12,500 mi/yr	
1998	\$0.28	\$0.23	\$0.09
2000	\$0.26	\$0.21	\$0.09
2002	\$0.20	\$0.16	\$0.09
2004	\$0.18	\$0.15	\$0.09

Note: 1994 constant dollars, $i=6\%$, 12-year vehicle life.

Lifetime Battery Cost

The ALABC has set a battery life goal of over 500 cycles with less than 20 percent capacity loss, equivalent to about 3 to 4 calendar years. The USABC has set a mid-term goal of 600 cycles or about 5 years for mid-term batteries. Nickel-metal-hydrate batteries are expected to meet this goal by 2000. By 2004, nickel-metal-hydrate batteries may be able to achieve a seven-year life.⁴⁵

At 12,500 miles per year, the per mile battery replacement cost, in constant 1994 dollars, is summarized in Table 7-12.

⁴⁵ Booz-Allen assessment based on statements made by Ovonic Battery Company and the USABC.

Table 7-12. Per Mile Battery Replacement Cost

(in 1994 constant dollars)

Source: Booz-Allen analysis

MY	Technology	Life (yr)	Cost/Mile
1998	Lead-Acid	4	\$0.08
2000	NiMH	5	\$0.07
2002	NiMH	5	\$0.06
2004	NiMH	7	\$0.04

Note: $i=6\%$, 12,500 miles per year traveled

Vehicle Maintenance and Tire Cost

According to the American Automobile Association (AAA), maintenance costs for 1994 model year Ford Escorts averages \$0.023 per mile.⁴⁶ Throughout their life, gasoline vehicles require regular oil and filter changes and tune-ups, as well as occasional replacement of wearable parts such as spark plugs, constant velocity boots, mufflers, starter batteries, etc. AAA also estimates tire replacement costs at \$0.07 per mile for 1994 model year Escorts.⁴⁷ At \$0.07 per mile, a set of four tires lasting 50,000 miles would cost \$350.

Maintenance information for electric vehicles is limited primarily to older technology vehicles with simple DC series motors and lead-acid batteries that require watering. Data for current technology vehicles with sophisticated controller/inverters and sealed batteries are not available. From an engineering perspective, the cost of maintaining electric vehicles should be lower than for gasoline vehicles since EVs do not require oil changes or extensive tune-ups and have fewer moving parts. Electric motors are generally more reliable and long-lived than combustion engines. Electronic components have proven to be durable in stationary applications, but it is unclear how they will be affected by the temperature extremes, vibration, and dirt experienced by on-road vehicles.

Due to the need to maximize efficiency, electric vehicles likely will use low-rolling resistance tires. The Michelin "Coefficient" tires used on the GM Impact have an inflation pressure of 50 psi and a unique tread design to maintain the rigidity needed for good traction and long tread wear. The "Coefficient" tires will cost more than conventional tires, although the exact price has not

⁴⁶ "Your Driving Costs," American Automobile Association, 1994 edition.

⁴⁷ Ibid.

been set.⁴⁸ Additionally, the greater weight of EVs may lead to faster tread wear, although they may spend less time at high speeds compared to conventional vehicles. Tire costs will therefore be slightly higher for EVs.

For this analysis, ZEV maintenance and tire replacement costs are assumed to be equivalent to the same costs for gasoline vehicles, \$0.03 per mile. The lower maintenance cost for ZEVs is assumed therefore to be offset by higher tire costs. As more advanced technology ZEVs enter the population, better data will become available to allow a more complete analysis of maintenance and tire replacement costs. As will be shown later, maintenance and tire costs are actually only a very small portion of total life-cycle costs.

Fuel Cost

Unleaded regular gasoline currently retails for about \$1.20 per gallon in the Northeast.⁴⁹ Since the 1995 Ford Escort is rated between 25 and 30 mpg in city driving,⁵⁰ fuel cost equals \$0.044 per mile for the Escort ($\$1.20 \div 27.5$ mpg). The DOE projects that motor gasoline prices will increase about 1.2 percent per year net of inflation.⁵¹

Electricity prices in the Northeast averaged \$0.084 per kWh in 1993.⁵² ZEVs in 1998 were projected previously to have an energy efficiency of 0.20 kWh/mi. This use rate refers to energy delivered from the battery pack and does not account for inefficiencies in the recharging process. Current battery charging/discharging systems have efficiencies of about 80 percent. An 80 percent efficiency in 1998 is assumed for this analysis. It is further assumed that there will be incremental efficiency improvements in future years. For ZEVs, then, total energy use rates are assumed at 0.25 kWh/mile in 1998, 0.22 kWh/mile in 2000 and 0.19 kWh/mile in 2002 and 2004. The DOE projects that end-use electricity prices in the transportation sector will increase about 0.3 percent per year net of inflation.⁵³

⁴⁸ Personal communication, Michelin, December 1994.

⁴⁹ *National Petroleum News*, December 1994.

⁵⁰ *Ward's Auto World*, October 1994.

⁵¹ Department of Energy, Energy Information Administration, 1995 Annual Energy Outlook, January 1995.

⁵² Public Utilities Fortnightly, October 1, 1994.

⁵³ Department of Energy, Energy Information Administration, 1995 Annual Energy Outlook, January 1995.

Projected 1998 through 2003 gasoline and electricity prices (adjusted for 1994 constant dollars) and equivalent per mile costs are summarized in Table 7-13. Electricity is currently not subject to excise taxes for motor fuels. Exemption from fuel taxes provides an incentive for electricity use in the transportation sector, which is consistent with current government policies. However, this situation will likely change once the loss in tax revenues becomes significant with increased EV penetration. For this analysis, no electricity taxes are assumed. For the EV penetration scenarios considered in this analysis, loss of tax revenue likely will not trigger the imposition of fuel taxes on electricity.

Table 7-13. Fuel Price Projections

(in 1994 constant dollars)

Source: Booz-Allen analysis

MY	Electricity		Gasoline	
	per kwh	per Mile	per gallon	per Mile
1998	\$0.085	\$0.021	\$1.34	\$0.049
2000	\$0.086	\$0.019	\$1.37	\$0.050
2002	\$0.086	\$0.016	\$1.41	\$0.051
2004	\$0.087	\$0.016	\$1.44	\$0.052

Total Life-Cycle Cost

Total life-cycle cost is calculated by summing together all of the individual cost components:

- Vehicle initial capital cost (without battery);
- Lifetime battery cost;
- Maintenance and tire cost; and
- Fuel cost.

Salvage costs are assumed to be zero for both the ZEV and conventional gasoline vehicle cases.

The assumptions used to derive the life-cycle costs were discussed previously in this section.

Table 7-14 shows the results of the analysis.

Table 7-14. Life-Cycle Cost Comparison

(\$ per Mile)

Source: Booz-Allen analysis

MY	ZEV	Escort
1998	\$0.36	\$0.17
2000	\$0.33	\$0.17
2002	\$0.27	\$0.18
2004	\$0.24	\$0.18

It can be seen from Figure 7-3 that ZEVs are expected to be more expensive to own and operate than gasoline vehicles in the years of the mandate. The primary reason for the increased life-cycle cost of ZEVs is the higher initial vehicle costs; Figure 7-3 shows the distribution of the different life-cycle cost components from ZEVs compared to the 1998 Escort.

Figure 7-3. Life-Cycle Cost Component Distribution (\$ per Mile)

Source: Booz-Allen analysis

Sensitivity Analysis

The life-cycle cost analysis presented relies on Booz-Allen's best estimate of operating and capital costs for ZEVs compared to a conventional gasoline vehicle, namely a Ford Escort. It is very useful also to examine how different cost assumptions may affect overall life-cycle costs. In this section, sensitivity analyses are performed to test different assumptions for vehicle initial cost, battery replacement cost, maintenance and tire cost, and fuel cost.

Capital cost is the single largest contributor to life-cycle costs for ZEVs. Initial vehicle purchase cost and battery purchase and replacement cost constitute a significant expense for ZEVs, driving up total life-cycle costs. To better understand how much reduction in capital cost is needed to bring the ZEV life-cycle cost to parity with small conventional gasoline vehicle cost, the sensitivity of capital cost is plotted in Figure 7-4. In Figure 7-4, tire and maintenance cost is held constant at \$0.03 per mile and electricity at \$0.021 per mile. Battery cost is allowed to vary from \$0.10 per mile to \$0.02 per mile. A \$0.10 per mile battery cost is equivalent to replacing a \$3,750 battery pack every 3 years, while a \$0.02 per mile cost is equivalent to replacing a \$1,500 battery pack every 6 years. Advanced lead-acid batteries are projected to cost \$0.08 per mile in 1998 while nickel-metal-hydride may range from \$0.04 to \$0.07 per mile during time frame from 2000 to 2004 (see Table 7-12). Conventional lead-acid batteries today cost about \$0.04 per mile.

Figure 7-4. Sensitivity of Capital Cost

Source: Booz-Allen analysis

Figure 7-4 reveals that in order to match the life-cycle cost of a gasoline Escort at \$0.17 per mile, the initial vehicle cost (not including battery) must be reduced to about \$10,000 when the battery cost is \$0.02 per mile, or about \$4,000 when the battery cost is \$0.08 per mile. This means that an advanced lead-acid battery-equipped vehicle in 1998 would need to have a total initial cost of about \$8,400 (vehicle and battery) with a battery replacement interval of about four years in order to compete on a life-cycle cost basis with the Escort. This assessment assumes 12,500 average annual miles traveled.

At \$0.04 per mile battery cost, the cost of today's conventional lead-acid or a projected future mid-term battery such as nickel-metal-hydride, initial vehicle cost (less battery) would need to be reduced to \$8,000 to achieve a \$0.17-per-mile life-cycle cost. As discussed previously, many OEMs project that once EVs reach sales volumes similar to gasoline models, an EV (less battery) could cost slightly less than a comparable gasoline vehicle. Thus, in the long-term, an EV life-cycle cost could reach parity with and even be somewhat lower than the current life-cycle cost for gasoline subcompacts.

Incremental variations in operating cost should have a similar effect on life-cycle costs. For example, in Figure 7-4, a \$0.02-per-mile change in operating cost would have the exact same slope as the lines shown in the figure for battery costs. The main difference between operating cost and capital cost, however, is that operating cost can be projected with greater certainty.

In this analysis, maintenance and tire costs were projected to total to \$0.03 per mile for ZEVs, the same costs used for conventional gasoline. Of that cost, \$0.023 was attributed to maintenance and repair and \$0.07 to tire replacement. More optimistic projections indicate that ZEVs may experience a 50 percent decrease in maintenance costs. Assuming no increase in tire replacement costs, a more optimistic projection of maintenance and tire costs would therefore be \$0.0185 per mile. In contrast, a more pessimistic projection may have ZEVs at the same maintenance cost and a 50 percent higher tire cost compared to a gasoline vehicle, for a total of \$0.0335 per mile. The difference in maintenance and tire cost projections between the optimistic and pessimistic case is thus \$0.015 per mile.

Electricity cost is subject to greater variability; however, this variability is mitigated on a per mile basis. The average cost of electricity in the Northeast is \$0.084 per kWh; however, individual utilities can assess much higher rates. Long Island Lighting Company (LILCO) has one of the highest electric rate schedules in the Northeast. On average, LILCO received \$0.01451 per kWh of electricity sold in 1993.⁵⁴ For an EV with an energy use rate of 0.20 kWh/mile, this translates into \$0.029 per mile, about \$0.02 less than gasoline on an mileage-equivalent basis. Peak residential electric rates for LILCO may be significantly higher than the \$0.01451 average. In contrast, New York State Electricity & Gas Corporation received an average of \$0.0768 per kWh.⁵⁵ This electric rate would result in a \$0.015-per-mile cost for a 0.20 kWh/mile EV. The range of plausible fuel costs for EVs therefore may span about \$0.02 per mile.

⁵⁴ Public Utilities Fortnightly, October 1, 1994.

⁵⁵ *Ibid.*

The general sensitivity of life-cycle costs to each cost component is summarized below:

- Vehicle initial cost—high (depends on vehicle life and annual miles traveled);
- Battery replacement cost – high (depends on battery life and annual miles traveled);
- Fuel cost—low; and
- Maintenance cost—very low.

This sensitivity analysis does not explicitly address ZEV purchase and use incentives. At present, EV buyers can receive a federal tax deduction from their income taxes. Some states have adopted or are considering adopting financial incentives to reduce the initial cost of ZEVs. The presence or absence of monetary subsidies and tax exemptions can affect life-cycle costs; however, such incentives will likely be removed once ZEVs become more widespread in the transportation market. In the analyses presented in this section, life-cycle costs are calculated without explicitly considering such subsidies or exemptions. To the extent that such incentives can be quantified in monetary terms for the consumer, the sensitivity analyses presented in this section can be used to project their effects.

Section 8

EMISSIONS IMPACT OF IMPLEMENTING ZEVS IN NEW YORK STATE

This section presents a preliminary estimate of the emissions impact of implementing ZEVs in New York State. Although ZEVs produce no direct exhaust or evaporative emissions, there will be an increase in emissions from power plants that produce electricity. Aggregate power plant emission factors¹ developed for New York State were used to calculate the emissions attributable to ZEVs, compared to the emissions from the internal combustion vehicles they would replace.

First, the estimated sales volumes of ZEVs presented in Section 7 are used to calculate electricity consumption of ZEVs. Then we present an overview of power plant emissions in New York State. In the final part of this section, we present a comparison of EV and conventional vehicle emissions.

ELECTRICITY CONSUMPTION BY ZEVS

Using the estimated sales volumes of ZEVs presented in Section 7, the population of ZEVs in New York State is projected to increase slowly, from approximately 12,000 in 1998 to 236,000 in 2004, as shown in Figure 8-1.

The total electricity consumption of the ZEV population in New York State was calculated using the following assumptions:

- Approximately 80 percent of ZEVs are passenger cars and 20 percent are small light-duty trucks (less than 3,750 pounds loaded vehicle weight);
- Passenger-car ZEVs use 0.25 kWh/mile in 1998 (including charging efficiency). Their energy needs decrease to 0.22 kWh/mile in 2000, and to 0.19 kWh/mile in 2002 and 2004;
- Small light-duty truck ZEVs use 0.30 kWh/mile through 2001. In 2002, their energy needs decrease to 0.25 kWh/mile; and
- Both passenger-car and small light-duty truck ZEVs travel 12,500 miles per year.

¹ 1993 New York State Energy Plan.

Figure 8-1. Estimated ZEV Population in New York State-1998 to 2004

Source: Booz-Allen analysis

The 80 and 20 percent share for passenger cars and small light-duty trucks is based on an analysis of registration data and reflects current distribution of cars and light trucks in the total vehicle population. Energy use rates for passenger car ZEVs were previously presented in Section 7 and are based on the capabilities of advanced EVs expected to be produced to satisfy the mandate.

To develop the assumed energy use rates for light-duty truck ZEVs, Booz-Allen considered the capabilities of current electric trucks and estimated the improvements that could occur with use of advanced technologies. Among the vehicles available, the Ford Ecostar and Chrysler TEVan best represent the range of electric trucks that could be produced by OEMs to meet the mandate. The Ecostar has an energy use rate of about 0.30 kWh/mile. Further efficiency improvements in the Ecostar to 0.25 kWh/mile may be possible by 1998.² The TEVan has been measured at 0.48 kWh/mile under normal driving conditions, but its efficiency is expected to improve to about 0.38 kWh/mile with the use of a more advanced technology.³ At a gross vehicle weight rating (GVWR) of 4,000 pounds, the Ecostar is closer to a light-duty truck than the TEVan (6,000 pounds GVWR). Therefore, Booz-Allen estimates that total wall-socket-to-vehicle electricity use for light-duty trucks may be approximately 0.30 kWh/mile for the 1998 through 2000 model years, improving to 0.25 kWh/mile in 2002 and 2004.

² Presentation by Bob Kiessel, Ford Motor Company, at the California Air Resources Board Workshop on Zero-Emission Vehicles, March 24, 1994.

³ Chrysler representative quoted in Light-Duty Vehicle Fuel Cycle Emissions Analysis, prepared by Energy International, Inc. for the Gas Research Institute, April 1994.

Based on these assumptions, the total estimated annual energy consumption by ZEVs is calculated as shown in Table 8-1.

Table 8-1. Annual Energy Consumption by ZEVs

Source: Booz-Allen analysis

Year	Number of Vehicles	Weighted Energy Use (kWh/mi)	Annual Mileage	Energy Consumption (mWh/yr)
1998	11,861	0.26	12,500	38,548
1999	23,930	0.26	12,500	77,773
2000	36,211	0.24	12,500	106,822
2001	67,456	0.24	12,500	198,995
2002	99,255	0.20	12,500	250,619
2003	163,626	0.20	12,500	413,156
2004	235,628	0.20	12,500	594,961

Due to losses in the transmission and distribution process, the actual increase in electrical energy output by utilities will be about eight percent higher than the vehicle consumption values shown in Table 8-1. The total electrical generation increase due to ZEVs, compared to total electrical demand in New York State, is shown in Table 8-2.

Table 8-2. Annual Electrical Generation Requirement Due to ZEVs

Source: *New York State Energy Plan 1994, Volume III-Supply Assessments 1994, p. 8, Table 9*

Year	ZEV Energy Use (gWh)	Total NY Energy Use (gWh)	ZEVs as % of Total NY
1998	42	151,813	0.03%
1999	84	153,390	0.05%
2000	115	155,261	0.07%
2001	215	157,449	0.14%
2002	271	159,504	0.17%
2003	446	161,657	0.28%
2004	643	163,916	0.39%

As seen from Table 8-2, the total annual electricity demand for ZEVs is only a very small portion of the total electricity demand in the State through year 2004, less than one-half percent.

However, ZEVs are likely to be concentrated initially in metropolitan areas where the recharging infrastructure will be established first. About 47 percent of the population of New York State resides in the eight-county area that makes up the State's primary metropolitan statistical area. The majority of residents in this area are customers of Con Edison and Long Island Lighting Company (LILCO). Total summer and winter generating capacities for these two utilities are shown in Table 8-3.

Table 8-3. Summer and Winter Generating Capacity of Con Edison and LILCO
(Source: U.S. Department of Energy, Energy Information Administration, *Inventory of Power Plants in the United States-1993, December 1994*)

	Summer Capacity (Mw)	Winter Capacity (Mw)
ConEdison	7,385	7,998
LILCO	4,063	4,442
Total	11,448	12,440

A preliminary assessment of ZEV impact on local capacities can be performed by making some rough assumptions of ZEV population and recharging schedules within the Con Edison/LILCO service territory. Assuming that 50 percent of ZEVs are recharged in the Con Edison/LILCO service territory, a total of 321 gigawatt-hours(gWh) /year of electricity would be consumed by ZEVs in the year 2004. If all these ZEVs are recharged 5 days a week during the same 6-hour period per day, then a total generating capability of 411 megawatts would be needed just to recharge these ZEVs, which represents 3.5 percent of the total summertime generating capability. This constitutes a significant load but should be manageable by 2004.

This very preliminary assessment suggests that increased electrical consumption due to ZEVs is unlikely to force the acquisition of additional generation capacity for the State, at least prior to 2004. This is particularly true if most recharging is performed during off-peak hours when there is excess generating capacity. However, this issue should be further investigated by New York State policy makers.

Another issue that needs to be investigated is whether local grids will be able to handle multiple fast-charge customers. If electrical requirements exceed the capacity of local grids during peak hours, then other sources of electrical generation may be needed. Natural gas-burning

generators, fuel cells, or large batteries that store electricity during periods of excess capacity are all potential off-grid sources of power for charging EVs.

POWER PLANT EMISSIONS

New York State's electric generation plants use a diverse set of fuels, with no one fuel comprising more than 25 percent of the total energy pool. Figure 8-2 shows the primary energy consumption shares for New York State electric utilities for years 1992, 2000 and 2012. In 1992, coal accounted for the largest share at 22 percent, followed by natural gas at 21 percent. By the year 2000, it is projected that natural gas will supply nearly 30 percent of the primary energy, while consumption of coal will decline to 18 percent. The natural gas share is projected to grow even larger by 2012.

Figure 8-2. Primary Energy Consumption by Electric Utilities in New York State

Source: *New York State Energy Plan*, Volume II: Issue Reports, 1994

Each type of power plant has different associated emission rates. Coal, natural gas and oil-burning plants all emit measurable amounts of five pollutants:

- Sulfur dioxide (SO₂);
- Nitrogen oxides (NO_x);
- Carbon dioxide (CO₂);
- Particulate matter (PM); and
- Volatile organic compounds (VOCs).

With the exception of CO₂, all these compounds are regulated air pollutants. CO₂ is not regulated strictly from either stationary or mobile sources, but is considered a greenhouse gas.

Nuclear and hydroelectric plants do not emit measurable quantities of these pollutants. They are considered to be zero-emission power sources.

Emission rates in tons per gigawatt-hour (gwh) output for 1992 electric-generation plants located in New York State are summarized in Table 8-4.

Table 8-4. Average Emission Rates for 1992 in New York State Utility Plants, by Fuel Type

Source: *New York State Energy Plan*, Volume III Supply Assessments 1994

Fuel	Tons/gWh				
	SO ₂	NOx	CO ₂	PM	VOC
Residual Oil	4.959	1.97	857	0.20	0.025
Distillate Oil	2.462	3.69	1,246	0.30	0.246
Natural Gas	0.003	1.35	653	0.03	0.007
Coal	10.295	3.32	1,118	0.20	0.015
Average (fossil only)	4.677	2.15	851	0.13	0.015
Average (all units)	2.781	1.28	506	0.08	0.009

Fossil fuel plants also release emissions of carbon monoxide (CO), a regulated air pollutant. However, the CO emission factors for power plants have not been developed. CO is harmful to human health mainly in urban areas, where high ambient levels can concentrate, and is not generally of concern in more rural areas, where most power plants are located. Moreover, power plants contribute relatively little CO compared to combustion-engine automobiles.

It should also be noted that PM emissions from power plants are somewhat less a concern than PM from vehicular sources. In comparison to other pollutants, PM remains relatively localized around the emission source. Because power plants tend to be located in more rural areas, it is thought that the human exposure to a given amount of PM emissions will be less when coming from a power plant than when coming from a vehicle.

Because of their large contribution compared to other sources, NOx and SO₂ are the emissions of most concern from electric generating plants. The 1990 Federal Clean Air Act Amendments established new emission requirements for electric utilities located in nonattainment areas. In these areas, existing generating facilities are required to install reasonably available control technology (RACT) to reduce air emissions. New sources must obtain offsets for any emissions they produce. These standards will be phased in from 1995 to 2000 and will mainly affect NOx.

Emissions of SO₂ are controlled by Title IV of the Clean Air Act. Title IV requires that in 2000, SO₂ emissions from New York State utilities be reduced by 33 percent from 1990 baseline levels.

Large generation plants must comply in 1995, with smaller plants to follow by 2000. A nationwide cap will be imposed, and averaging and credits trading will be allowed. Assuming full implementation of RACT and Title IV provisions, emission rates for New York State fossil fuel plants in 1998 are shown in Table 8-5.

Table 8-5. Average Emission Rates for 1998 New York State Utility Plants, by Fuel Type
Source: Booz-Allen analysis based on personal communication with the New York State Energy Office, 1994

Fuel	Tons/gWh				
	SO ₂	NO _x	CO ₂	PM	VOC
Residual Oil	3.471	1.26	857	0.20	0.025
Distillate Oil	1.723	3.25	1,246	0.30	0.246
Natural Gas	0.002	1.12	653	0.03	0.007
Coal	7.207	2.25	1,118	0.20	0.015

In 2003, NO_x emission rates will decrease with implementation of another 65 percent reduction agreed to by all of the OTC states. A NO_x emissions cap will be implemented on all power plants in the Northeast states. Implementation of this new measure should lower average NO_x emission rates to 0.15 lbs/mmBTU for New York State utilities, or about 0.75 tons/gwh.⁴

By multiplying expected emission rates by the percentage of each primary fuel expected to be consumed by utility plants, average emission rates for New York State power plants are calculated for each year from 1998 to 2004, as shown in Table 8-6. Data on the percentage consumption of each primary fuel were based on Reference Case H,⁵ which assumes 7,000 megawatts of new capacity will be needed by 2012, with the first unit installed in 1999. Reference Case H also contains fairly conservative projections about the extent to which demand side management (DSM) programs will be implemented.

In view of the very small electricity demand, it is appropriate to use average emission rates to calculate the emission impact due to ZEVs. If and when ZEVs have penetrated the transportation sector in sufficient quantities to force the addition of more capacity, then marginal emission rates should be used. (The State of New York is planning on adding more capacity in the 2000 time frame to satisfy its overall demand from industrial and residential customers.⁶) Because new power plants generally will be cleaner than average existing ones, use of marginal emission rates

⁴ Personal communication, Karl Michaels, New York State Energy Office, October 1994.

⁵ 1993 New York State Energy Plan.

⁶ Ibid.

may result in somewhat lower overall emissions. However, average rates should be a good approximation of utility emissions prior to 2004. Utility emissions in tons per year attributed to the additional electrical demand from ZEVs are summarized in Table 8-7.

Table 8-6. Average New York State Power Plant Emissions (tons/gwh)

Source: Booz-Allen analysis based on information provided by the New York State Energy Office, 1994

Year	% Fossil Fuel	Tons/gWh				
		SO ₂	NOx	CO ₂	PM	VOC
1998	58	1.65	0.90	490	0.066	0.010
1999	61	1.82	0.96	521	0.073	0.011
2000	59	1.67	0.91	497	0.069	0.011
2001	61	1.76	0.95	519	0.073	0.011
2002	59	1.68	0.91	499	0.070	0.011
2003	62	1.77	0.75	521	0.074	0.011
2004	60	1.71	0.75	505	0.071	0.011

Table 8-7. Utility Emissions Due to Electricity Demand by ZEVs (tons/year)

Source: Booz-Allen analysis

Year	Tons/gWh				
	SO ₂	NOx	CO ₂	PM	VOC
1998	69	38	20,418	3	0.43
1999	153	80	43,771	6	0.92
2000	192	105	57,310	8	1.24
2001	379	203	111,607	16	2.40
2002	456	246	135,117	19	2.91
2003	791	335	232,459	33	5.01
2004	1,102	482	324,461	46	7.05

It should be noted that nationwide SO₂ emission levels are capped under Title IV of the Clean Air Act. Therefore, increases in SO₂ emission levels as a result of ZEVs must be offset by emission decreases somewhere else. If all these offsets occur within New York State, implementation of ZEVs will have no overall impact on SO₂ emission levels within the State.

Dividing the values in Table 8-7 by the population of ZEVs and assuming ZEVs travel 12,500 miles per year, resulting ZEV emissions in grams per mile are obtained (Table 8-8).

Table 8-8. Equivalent Gram-Per-Mile Emission Rates Per ZEV
Source: Booz-Allen analysis

Year	Tons/gWh				
	SO ₂	NO _x	CO ₂	PM	VOC
1998	0.42	0.23	125	0.017	0.003
1999	0.46	0.24	133	0.018	0.003
2000	0.38	0.21	115	0.016	0.002
2001	0.41	0.22	120	0.017	0.003
2002	0.33	0.18	99	0.014	0.002
2003	0.35	0.15	103	0.015	0.002
2004	0.34	0.15	100	0.014	0.002

COMPARISON OF EV AND CONVENTIONAL VEHICLE EMISSIONS

Light-duty gasoline vehicles are regulated for direct emissions of the following pollutants:

- Evaporative VOCs;
- Exhaust VOCs;
- Exhaust CO; and
- Exhaust NO_x.

Direct vehicle emissions of CO₂ and SO₂ emissions during the refining and distribution process are not regulated at present. (CO₂ is regulated indirectly through the establishment of fuel economy standards.) Particulate matter emissions are regulated for diesel vehicles but not for gasoline.

There are no widely accepted, definitive studies quantifying the total life cycle emissions of gasoline vehicles. An analysis recently performed for the Gas Research Institute suggests the following life cycle emissions breakdown for a federal Tier 1 vehicle certified on reformulated gasoline (see Table 8-9). Direct vehicle emissions for this study were based on the simplified assumption that a 50,000 mile certification standard represents the average exhaust emissions of a vehicle over its lifetime.

CARB has also performed a simplified life-cycle analysis for Ultra-Low-Emission Vehicles (ULEVs) operating in Los Angeles and for average 1993 California in-use vehicles. These results are summarized in Table 8-10.

Table 8-9. Reformulated Gasoline Life-Cycle Emissions for a Tier 1 Vehicle (g/mile)
**Source: Energy International, Inc., *Light Duty Vehicle Full Fuel Cycle Emission Analysis*,
 prepared for the Gas Research Institute, April 1994**

	SO ₂	NO _x	CO ₂ ^a	PM	VOC	CO
Oil & Gas Production-Combustion	0.009	0.086	NA	0.005	0.007	NA
Oil & Gas Production-Fugitive	0.001	0.002	NA	0.000	0.127	NA
Petroleum Refining-Combustion	0.007	0.041	NA	0.004	0.001	NA
Petroleum Refining-Fugitive	0.027	0.008	NA	0.002	0.027	NA
Petroleum Marketing	0.000	0.089	NA	0.002	0.087	NA
MTBE Fuel Cycle	0.000	0.013	NA	0.000	0.003	NA
Total Fuel Cycle Emissions	0.044	0.239	93.8	0.013	0.252	93.8
Direct Vehicle Emissions (Tier 1)	0	0.4	370.3	0	0.444	370.3
Total Life-Cycle Emissions	0.044	0.639	464.2	0.013	0.696	464.2

a Disaggregated CO₂ data for each category are not available.

**Table 8-10. Estimated Life-Cycle Emissions for ULEVs and
 1993 California Fleet Average Cars (g/mile)**

Source: California Air Resources Board, Draft Technical Support Document for the Low-Emission Vehicle and Zero-Emission Vehicle Workshop, March 25, 1994

	SO _x	NO _x	PM	VOC
ULEVs	0.006	0.30	0.01	0.18
1993 CA In-use Car	0.05	1.2	0.01	1.5

In presenting its analysis, CARB acknowledged that the estimates may be understated since they do not consider "off-cycle" emissions that occur during hard accelerations, high speeds and other driving conditions not represented by current test cycles. Inclusion of off-cycle emissions could increase total direct vehicular emissions.

By comparing the ZEV emission rates previously calculated in Table 8-8 with those shown in Tables 8-9 and 8-10 for gasoline vehicles, some conclusions about the emission benefits of ZEVs may be drawn:

- ZEVs may have substantial VOC and CO emission reduction benefits compared to gasoline-powered cars, and moderate NO_x emission reduction benefits;

- ZEVs may increase particulate matter emissions. A more in-depth analysis is needed to evaluate the overall impact of the increase (life cycle analyses were not performed to sufficient precision);
- ZEVs potentially can cause substantial increases in emissions of SO₂. As mentioned previously, total allowable SO₂ emissions are capped by the Clean Air Act. If emission offsets for SO₂ occur within New York State, there will be no overall increase in SO₂ emission inventories due to ZEVs; and
- Power plants are usually located in rural areas away from large population centers.⁷ Increased emissions by power plants in rural areas may have a lesser overall impact on the health of residents compared to emissions from automobiles concentrated in urban areas.

Table 8-11 quantifies the differences in emissions between ZEVs and various types of gasoline vehicles. In reviewing these numbers, the assumptions and limitations of this analysis and the life-cycle analyses performed for gasoline vehicles and ZEVs should be kept in mind.

Table 8-11. Comparison of ZEV and Gasoline Vehicle Emission Rates (g/mile)

Source: Booz-Allen analysis

	SO _x	NO _x	CO ₂	PM	VOC
1993 California In-Use Car	0.05	1.2	—	0.01	1.5
Federal Tier 1 Vehicle	0.044	0.639	464.2	0.013	0.696
ULEV	0.006	0.3	—	0.01	0.18
1998 ZEV	0.42	0.23	125	0.017	0.003
% of 1993 CA In-Use Car Emissions	841%	19%	—	169%	0.17%
% of Federal Tier I Emissions	955%	36%	27%	130%	0.38%
% of ULEV Emissions	7007%	77%	—	169%	1.46%
2004 ZEV	0.34	0.15	99.92	0.014	0.002
% of 1993 CA In-Use Car Emissions	678%	12%	—	141%	0.14%
% of Federal Tier I Emissions	771%	23%	22%	109%	0.31%
% of ULEV Emissions	5654%	49%	—	141%	1.21%

⁷ LILCO and Con Edison have a significant number of power plants in urban and nonattainment areas.

Section 9

FINDINGS AND CONCLUSIONS

This section summarizes our findings and conclusions based on the previous sections of the report.

THE ZEV MANDATE IN CALIFORNIA AND THE NORTHEAST HAS SPURRED MUCH RESEARCH AND DEVELOPMENT ON EVS AND EV COMPONENTS AND HAS INSPIRED MANY ENTREPRENEURS TO ENTER THE EV MARKET

Since the initial adoption of the ZEV mandate in 1990, work has intensified on readying EVs for commercial production. The "Big Three" OEMs have very active EV development programs, both on an individual basis and as part of industry consortia such as the U.S. Advanced Battery Consortium. Although their plans are more closely guarded, the major Japanese OEMs also have formed battery research consortia and are developing pre-production prototypes. Nonetheless, the major vehicle manufacturers oppose the ZEV mandate, citing the uncertainty of customer demand for EVs.

A number of other, generally smaller companies, though, are eager to capitalize on the perceived market for EVs. These companies are involved in all aspects of EVs, from selling complete vehicles to manufacturing drivetrain components and researching battery technologies. As a result of the combined efforts of the vehicle OEMs and other EV-associated companies, EV technology has improved markedly in the past five years. Motors, controllers, and climate control systems are lighter in weight and higher in efficiency. Vehicles have better performance and are designed to provide the same ease of operation and comfort as conventional cars. Substantial effort also has been devoted to improving battery technology, although batteries remain the EV's Achilles heel.

IT IS LIKELY THAT A NUMBER OF BARRIERS TO ZEV SUCCESS WILL CONTINUE TO EXIST THROUGH THE YEAR 2004

A consolidated estimate of the likelihood of overcoming ZEV barriers from 1996 to 2004 was conducted as part of this study. While there is a medium to high likelihood that vehicle and infrastructure barriers can be overcome by the year 2004, it is likely that battery barriers will persist. The pessimistic estimate of vehicle range and cost in 2004 is 100 miles and \$0.41/mile, respectively. The optimistic estimate is 220 miles and \$0.18/mile.

IT IS LIKELY THAT RANGE WILL CONTINUE TO BE THE KEY PERFORMANCE LIMITATION OF EVS

State-of-the-art EVs can match the acceleration, handling, and overall driveability of conventional gasoline cars. Range is the major limiting factor. EVs today have a range of about 50 to 80 miles in city driving, and about 20 miles more under highway conditions, using lead-acid batteries. Proven and affordable quick-charge technology to mitigate the range limitation does not exist currently.

LEAD-ACID, NICKEL-CADMIUM, AND NICKEL-IRON BATTERIES ARE CURRENTLY THE ONLY EV BATTERIES AVAILABLE ON A COMMERCIAL BASIS

Sealed, maintenance-free battery packs are now available for use in EVs. Lead-acid batteries are characterized by high specific power, enabling rapid acceleration, and relatively low cost. However, lead-acid batteries suffer from poor specific energy, thus limiting range, and require replacement every 20,000 to 30,000 miles. With additional research and development over the next several years, incremental improvements in lead-acid batteries can be expected.

Nickel-cadmium batteries offer better energy density, power density, and cycle life than lead-acid, but at about five times the cost. Cadmium is also a toxic compound, causing concerns about battery recycling. Nickel-iron batteries have similar performance characteristics as nickel-cadmium, but also require periodic maintenance. Due primarily to high cost, neither of these nickel-based batteries are likely candidates for future EV applications.

NICKEL-METAL-HYDRIDE BATTERIES OFFER THE BEST POTENTIAL FOR IMPROVING VEHICLE RANGE AND PERFORMANCE IN THE MID-TERM

Of the medium-term batteries being researched by the USABC and other organizations, nickel-metal-hydride batteries show the most promise for early commercial viability. Prototype batteries have demonstrated about twice the specific energy of current lead acid batteries and slightly better specific power. Cycle life has not yet been proven, but battery developers project that the nickel-metal-hydride batteries can be designed to last 100,000 miles of vehicle driving. The greatest remaining unresolved issue is cost.

The domestic OEMs appear to be cautiously optimistic about the ability of nickel-metal-hydride batteries to provide the type of performance needed to satisfy EV customers. There is, however, a major disagreement between the OEMs and the battery developers, primarily Ovonic Battery Company, about when nickel-metal-hydride batteries may become commercially viable for use in EVs.

Other batteries being discussed as mid-term candidates are sodium-nickel-chloride and sodium-sulfur. Both of these batteries must be maintained at high temperatures in order to function properly. Of the two battery types, sodium-nickel-chloride appears to be more practical for mid-term EV use due to its lower cost and longer projected life. Sodium-nickel-chloride batteries have a slightly higher projected specific energy compared to nickel-metal-hydride, but have lower specific power and higher cost.

OTHER BATTERIES AND ENERGY STORAGE DEVICES OFFER THE POTENTIAL FOR EVEN GREATER RANGE AND PERFORMANCE, BUT WILL NOT BE COMMERCIALY AVAILABLE UNTIL THE NEXT DECADE

Lithium-based batteries may provide EVs with range and acceleration similar to gasoline vehicles in the long term. Research on these battery types is currently at the cell level, and additional effort is required to develop and optimize full battery packs suitable for vehicular use. Other long-term technologies include fuel cells and flywheel systems. Although these technologies show a lot of promise, cost and reliability issues are far from being resolved.

THE PERFORMANCE OF EVS IN COLD WEATHER IS A CRITICAL ISSUE THAT MUST BE MONITORED, BUT VEHICLE THERMAL MANAGEMENT SYSTEMS NOW BEING DEVELOPED SHOULD ALLEVIATE THE PROBLEM

In cold weather, all vehicles suffer from range degradation caused by higher aerodynamic drag, increased rolling resistance, thickening of oils and greases, and increased use of auxiliary loads. This condition is exacerbated in EVs due to their limited range compared to conventional internal combustion vehicles. EVs must also contend with decreased battery capacity in cold weather. Of the near and mid-term battery candidates, lead-acid batteries appear to experience the largest capacity loss, with a 20 to 50 percent decrease in range during wintertime conditions. Nickel-metal-hydride batteries appear to lose about 15 percent range at 0°F. Batteries that operate at high temperatures, such as sodium-sulfur or sodium-nickel-chloride, may not experience any noticeable capacity loss. Cold weather effects can likely be minimized with proper EV design and

thermal management systems. However, this will require that EVs operated in New York be different from those used in California.

THE COSTS OF EVS ARE LIKELY TO BE HIGHER THAN FOR COMPARABLE GASOLINE MODELS THROUGH THE YEAR 2004

EV costs will depend upon production volume and the quality and type of components used. Purpose-built EVs sold in 1998 will undoubtedly cost more than their gasoline peers. The cost analysis performed in this study indicates that ZEV costs will continue to be 25 percent or more higher than their gasoline counterparts through 2004. The higher vehicle purchase price and the cost of battery replacements for ZEVs are likely to be of much greater significance than savings in their reduced energy and maintenance cost.

THERE WILL BE AN EMISSIONS BENEFIT FOR ZEV USE IN NEW YORK, BUT THERE MAY BE SOME OFFSETTING SIDE EFFECTS DUE TO POWER PLANT EMISSIONS

ZEVs may have substantial VOC and CO emission reduction benefits over gasoline-powered cars, and moderate NOx emission reduction benefits. ZEVs may increase particulate matter emissions. A more in-depth analysis is needed to evaluate the overall impact of the increase (life cycle analyses were not performed to sufficient precision). ZEVs can potentially cause substantial increases in emissions of SO₂. Total allowable SO₂ emissions from power plants are capped by the Clean Air Act. If emission offsets for SO₂ occur within New York State, there will be no overall increase in SO₂ emission inventories due to ZEVs. It should also be noted that some power plants are located in rural areas away from large population centers. Increased emissions by power plants in rural areas may have a lesser overall impact on the health of residents compared to emissions from automobiles concentrated in urban areas.

THE INFRASTRUCTURE FOR EVS IN NEW YORK STATE DOES NOT YET EXIST

A few isolated charging stations currently exist in New York State. Many more will be needed for the ZEV sales mandate to be successful. A comprehensive statewide plan for building such stations will be needed. Other issues to be resolved include utility power quality, standards for plugs and cords, public education, battery recycling, safety training, vehicle registration, and insurance coverage. Proper planning and funding is required, but none of these infrastructure issues is insurmountable.