Staff Report

1998 ZERO-EMISSION VEHICLE BIENNIAL PROGRAM REVIEW

July 6, 1998

California Environmental Protection Agency
Air Resources Board

EXECUTIVE SUMMARY

This report provides a comprehensive review of the Air Resources Board's (ARB or Board) zero-emission vehicle (ZEV) program. This report and the Board hearing in July 1998 serve as the biennial review to update the Board on the progress made towards meeting the requirements of ARB's ZEV program. Within the report, ARB staff outlines the progress made by auto manufacturers, ARB and other government agencies and private industry groups toward commercialization of ZEVs. The report focuses primarily on progress made after the modifications that were made in March of 1996 which included Memoranda of Agreement between ARB and the seven largest auto manufacturers.

The ZEV program was approved by ARB in September 1990 as part of the Low-Emission Vehicle regulations. These regulations required the seven largest auto manufacturers to produce ZEVs beginning with model year 1998. Specifically, in model years 1998 through 2000, two percent of the seven largest auto manufacturers' new vehicle fleet were required to be ZEVs and this percentage was to increase to five percent in model years 2001 and 2002 and ten percent in model years 2003 and beyond. The ten percent requirement in model years 2003 and beyond applied to the intermediate volume auto manufacturers as well.

In March 1996, ARB modified the Low-Emission Vehicle regulations. The requirement for ten percent ZEVs in model years 2003 and beyond was maintained. However, in place of the requirement for ZEVs in model years 1998 through 2002, ARB entered into Memoranda of Agreement (MOAs) with the seven largest auto manufacturers affected by the regulations. These MOAs included commitments from the auto manufacturers to:

- offset the emission benefits lost due to the elimination of the ZEV requirements in model years 1998 to 2002 through a national low-emission vehicle program or other program that would provide equivalent air quality benefits;
- continue investment in ZEV and battery research and development and place specified numbers of advanced battery-powered ZEVs in marketplace demonstration programs (up to 3,750 vehicles total);
- participate in a market-based ZEV launch by offering ZEVs to consumers in accordance with market demand; and
- provide annual and biennial reporting requirements.

The auto manufacturers are making progress towards meeting their MOA commitments. To offset the emission benefits lost due to the elimination of the ZEV requirement in model years 1998 through 2002, all seven of the auto manufacturers opted-in to the National Low-Emission Vehicle program beginning in 2001, three years earlier than could be required under federal law.

The auto manufacturers' commitment to continue ZEV research and development and to participate in a market-based launch is going according to schedule. There are a variety of vehicles available now and we expect even greater variety as well as wider availability over the next few years. Cost of zero-emission vehicles is a primary concern, as expected in the introductory years of the program. Additionally, infrastructure and range are also concerns. However, in general, those that have leased ZEVs have been very pleased with the performance and quality of the vehicles.

The performance and quality of today's ZEVs is directly related to the progress made in battery technology. The placement of advanced battery-powered electric vehicles (EVs) has provided an unprecedented amount of technical information regarding battery performance and reliability. ARB staff has evaluated information from four of the most promising advanced battery technologies, nickel-metal-hydride (NiMH), sodium-nickel-chloride (NaNiCl), lithium-ion (Li-Ion) and lithium polymer (Li-Poly). Of the four technologies evaluated, NiMH and NaNiCl could be available in production quantities (>10,000/year) by 2003. Li-Ion could be near to achieving production quantities by 2003 if development hurdles are resolved soon. The decision about whether or not to go into full production of Li-Poly batteries will likely be made by 2003.

ARB staff compared our estimates of life cycle, specific energy (an energy per unit weight measurement related directly to range), specific power (which relates to hill-climbing and acceleration capability) and cost with the United States Advanced Battery Consortium (USABC) goals for these characteristics. USABC has identified mid-term, commercialization and long-term goals for advanced batteries. The table below illustrates the comparison between USABC's goals and ARB's estimates of performance characteristics for the four most promising advanced battery technologies.

Performance Characteristics for Advanced Batteries

	Life Cycle (cycles)	Specific Energy (W-hr/kg)	Specific Power (W/kg)	Cost ($/kWhr)
USABC Goals				
Mid-term	600	80	15	< 150
Commercialization	1,000	150	300	< 150
Long-term	1,000	200	400	< 100
ARB Estimates for 2003				
NiMH	1,000	90	300	250
NaNiCl	1,000	100	200	250
Li-Ion	1,000[a]	120	300	300
Li-Poly	1,000	150	315	< 250

[a] Calendar life may be an issue.

Because the only technology currently capable of meeting the ZEV requirements is the battery powered electric vehicle, progress toward the 2003 requirement of ten percent ZEVs starts with battery technology. Significant work is being done to increase the range (specific energy) and reduce the cost while maintaining or improving performance capabilities. It will be vital to achieve lower cost if ZEVs are to proliferate in the marketplace. ARB will continue to monitor the progress made toward cost reduction during our biennial reviews. ARB staff believes that the MOAs are instrumental in ensuring that technology continues to advance. As these technologies are learned-out and production volumes increase, cost is expected to be reduced.

General Motors was the first auto manufacturer to introduce an EV for public lease. In December 1996, General Motors began offering the EV1 for lease in the South Coast, San Diego and Arizona. General Motors has since increased the market area of the EV1 to include Sacramento and the Bay Area. In addition to the EV1, General Motors began leasing the S-10 to fleet operators in 1997. Currently, both the EV1 and S-10 use lead-acid batteries. Lead-acid batteries are not considered advanced batteries as defined in the MOAs and, therefore, neither of these vehicles meet the definition of an advanced battery-powered ZEV. However, these vehicles do meet the requirement in the MOAs to provide ZEVs according to market demand and they indicate the commitment by General Motors to begin preparing the marketplace for a full scale launch of ZEVs by 2003. Further, to meet the requirement in the MOAs for advanced battery-powered ZEVs, General Motors has indicated an intent to lease both the EV1 and the S-10 with nickel-metal-hydride batteries in late 1998.

Honda introduced the EV PLUS for lease in May 1997 and has the distinction of being the first manufacturer to offer EVs using advanced batteries (NiMH) to the general public. Because the Honda EV PLUS uses advanced batteries, it meets the MOA requirement to place advanced battery-powered ZEVs in the marketplace.

Toyota began offering EVs to fleet operators late in 1997. Toyota's RAV4 uses NiMH batteries. The RAV4 also meets the requirement in the MOAs to place advanced battery-powered ZEVs in the marketplace. Thus far, Toyota has received requests for RAV4s exceeding the requirements of the MOA. Toyota is planning to make the RAV4 available to the public within two years.

Chrysler began offering the Electric Powered Interurban Commute (EPIC) minivan to some fleet operators in 1997. The EPIC uses advanced lead-acid batteries, therefore, this vehicle meets the MOA requirement to place advanced battery-powered ZEVs in the marketplace for model year 1998.

Ford introduced EVs as 1998 model year vehicles. Ford's Ranger EV pickup truck is available for sale or lease to fleet operators throughout California and the rest of the country. The use of lead-acid batteries in the Ranger means it does not meet the MOA requirement for placing advanced battery-powered ZEVs. However, by offering Rangers, Ford will meet the MOA requirement to offer ZEVs in accordance with market demand. Ford has committed to offering an advanced battery-powered Ranger in late 1998.

Nissan will introduce ZEVs as 1998 model year vehicles. Nissan is the first auto manufacturer to offer a Li-Ion battery-powered EV, the Altra. Lithium-ion batteries have greater specific energy than NiMH batteries and are in an earlier stage of development than NiMH batteries. Therefore, it make take more time for Li-Ion battery-powered vehicles to penetrate the market to the extent that NiMH battery-powered vehicles have done. To meet Nissan's MOA commitment to place advanced battery-powered ZEVs, a limited number of Altra EVs will be leased to fleet operators during 1998.

All of the auto manufacturers remained non-specific regarding their plans for the 2003 requirement for ten percent ZEVs. Most auto manufacturers believe that more than one vehicle platform will be necessary to meet the ZEV requirement. Some of the auto manufacturers are currently developing new platforms to address the 2003 ZEV requirement. However, there has been reluctance by some to commit to further vehicle platform design development until more advanced battery technologies become widely available. It is necessary for all auto manufacturers to recognize the importance of indicating preparation and product plans for the ten percent requirement in 2003 in their annual and biennial reports. ARB staff will continue to follow manufacturer progress toward the 2003 requirement to ensure that product plans are in place in a timely manner.

In addition to auto manufacturer commitments in the MOAs, ARB is expected to fulfill a list of obligations. Under the terms of the MOAs, ARB committed to:

- facilitate the purchase of ZEVs in state fleets;
- work with other state agencies, local governments and private industry to address various infrastructure issues;
- continue to work with emergency response officials to create a comprehensive emergency response training program; and
- support reasonable incentive programs.

ARB, CEC and other state agencies and public industry groups have made progress towards all the MOA commitments. First, Master Service Agreements have been executed with General Motors and Honda and are being developed with Ford and Toyota. These agreements will greatly simplify the lease processes for all state agencies, California universities and local governments. ARB staff is currently working with senior managers at state agencies to encourage leasing of ZEVs by the agencies. Second, there are currently well over 500 EV recharging stations throughout California and ARB continues to work with other state agencies, local governments and private industry to address infrastructure issues as they arise. Third, to date, at least 25 trainers have registered to teach emergency response personnel about EVs and the differences in response procedures for incidents involving EVs. Over 200 students have taken the class. Finally, there are a number of incentives available with buy-down incentives of up to $5,000 per vehicle and home recharging incentives to assist with the cost associated with the installation of a home recharger. ARB continues to work with state and local government, auto manufacturers and other stakeholders to determine the most effective ways to support the introduction of ZEVs into the marketplace.

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1.0 BACKGROUND

California suffers from some of the worst air pollution problems in the nation. Mobile sources account for well over half of the ozone-forming emissions in California and passenger cars and light-duty trucks are responsible for a significant portion of the mobile sources. For these reasons, ARB has been the leader in the development of programs designed to significantly reduce emissions from mobile sources. Our efforts are paying off. Air quality in California has improved dramatically over the past 25 years, in significant part due to state and federal initiatives to control pollution from motor vehicles.

In November 1994, ARB adopted a comprehensive set of amendments to the California State Implementation Plan for Ozone (SIP) that demonstrate early and continuing progress toward attainment of the ozone standard as required by the 1990 Federal Clean Air Act amendments. The SIP includes new measures focused on light-duty vehicles, such as vehicle scrappage and implementation of advanced technologies, as well as measures targeting heavy-duty vehicles and off-road equipment. Even with these new measures, however, the SIP includes a shortfall that will require ARB to obtain additional emission reductions from as yet unspecified measures.

The Low-Emission Vehicle (LEV) regulations were adopted by ARB in 1990 and are a cornerstone of the SIP. These regulations establish increasingly stringent emission standards for four new classes of vehicles, transitional low-emission vehicles, low-emission vehicles, ultra-low-emission vehicles and zero-emission vehicles (ZEVs). The LEV regulations also establish a fleet average emission rate for non-methane organic gas that must be met by each auto manufacturer. The fleet average emission rate became effective with model year 1994 and decreases each year through 2003. Auto manufacturers may produce any mix of low- and zero-emission vehicles as long as the annual fleet average emission rate is met. The only caveat is that the seven largest auto manufacturers were required to produce ZEVs in quantities equal to two percent of the new vehicle fleet in model year 1998, increasing to five percent in model years 2001 and 2002 and increasing to ten percent in model year 2003. In model year 2003, the intermediate auto manufacturers would also be required to meet the ten percent ZEV requirement.

At the time the LEV regulations were adopted, low- and zero-emission vehicle technology was in the very early stages of development. The Board believed it would be necessary to follow the status of both technologies, in particular, the status of ZEV technology and readiness of the consumer market for ZEVs. Thus, the Board directed staff to provide an update on the LEV and ZEV programs on a biennial basis. This third biennial report serves as an update to the Board on the status of ZEV technology and readiness of the consumer market for ZEVs.

The only technology currently capable of meeting the ZEV requirements is the battery-powered electric vehicle (EV). Because of concerns regarding the status of battery technology, in August 1995, ARB provided funding to establish a Battery Technology Advisory Panel. The purpose of the independent panel, which was comprised of individuals with extensive experience in science and battery technology development, was to evaluate the readiness of battery technology for the 1998 implementation of the ZEV program. The panel concluded that, as a result of the ZEV program, there have been a number of technological advances, including the rapid acceleration of developments in ZEV technology, both in electric and fuel cell applications. However, the panel determined that advanced batteries would not be available in production quantities until the beginning of the next century.

Although the developments in battery technology have been yielding further improvements, ARB believes that an early introduction of ZEVs that cannot perform to consumer expectation would harm the ZEV program as a whole. ARB maintains that advanced-battery powered ZEVs are necessary to provide the performance and durability that most consumers expect from vehicles, thereby ensuring the successful introduction of ZEVs into the marketplace. Therefore, in March 1996, the Board modified the ZEV requirement to encourage a more market-based approach to the early years of ZEV introduction while maintaining the ten percent requirement for ZEVs in 2003 and beyond.

To ensure that our air quality goals are met and that progress toward the commercialization of ZEVs continues, the seven largest auto manufacturers entered into Memoranda of Agreement (MOAs) with ARB. The MOAs commit the auto manufacturers to production of ZEVs in quantities consistent with public demand, public demonstration programs and continuing research efforts into advanced-battery powered electric vehicles. The MOAs also commit the ARB to continue working with other state and local government agencies and private industries to facilitate the purchase of ZEVs in government fleets, provide the necessary infrastructure for ZEVs and support reasonable incentives. This report provides an update of the progress made by the seven largest auto manufacturers, ARB, and other state and local agencies towards meeting the goals of the MOAs.

1.1 Why the ZEV Program is Important to ARB

The ZEV program, as modified in March 1996, will provide direct exhaust, fuel evaporative and fuel marketing emission reductions of 14 tons per day of oxides of nitrogen (NOx) and non-methane organic gas (NMOG) in the South Coast Air Basin in 2010. These reductions are substantial when considered within the context of all the SIP measures needed to approach attainment in California's most severe air quality regions. In fact, the ZEV program provides California with its greatest hope of long-term substantial emission reductions from the light-duty vehicle fleet by providing an opportunity for extremely clean vehicles to compete in the marketplace.

The long-term benefits of ZEVs are exemplified by the fact that, despite stringent standards for vehicle emissions and fuels, population growth and the trend in our state towards increasing yearly travel per vehicle have made it difficult to reduce fleetwide emissions. These trends not only affect the number of miles driven per year, they also affect the efficiency of travel. With more people driving more miles, traffic slowdowns and stop-and-go traffic patterns increase. As mentioned above, at this time, the most promising near-term technology capable of meeting the ZEV standards is the EV. EVs provide a solution to the problems of our growing population and vehicle mileage as well as problems associated with the aging of conventional gasoline-powered vehicles.

Even when we include power plant emissions associated with the use of EVs (as shown in Table 1) EVs are over ten times cleaner than even the cleanest emitting vehicle required by ARB. There are no idling emissions when EVs are stopped in traffic. Unlike a conventional gasoline-powered vehicle, an EV does not have an emission control system that can deteriorate over time. Thus, even as they age, there is no increase in emissions from EVs. Further, EVs eliminate increases in emissions associated with tampering and mal-maintenance. Finally, an EV does not require smog checks and will never become a gross emitter. These benefits are essential to the long-term achievement of California's air quality goals.

Although EVs provide greater air quality benefits than any other technology available today, there are emissions associated with EVs resulting from power plants generating electricity. Because California utilizes a relatively clean mix of power generation, these emissions are extremely small. A comparison of the power plant emissions associated with an EV to the emissions from a gasoline-powered ultra-low-emission vehicle (ULEV), the lowest-emitting vehicle required by ARB, and the emissions from an average conventionally-fueled 1996 model year vehicle is shown in Table 1.

Table 1
Emissions of Ozone Precursors in the South Coast Air Basin
(pounds over ten year life)

Vehicle	NOx	NMOG
EV/Power plant emissions	4	<1
Gasoline ULEV[a]	79	35
Gasoline Average 1996 vehicle[a]	150	120

[a] These numbers include exhaust, evaporative, running loss and marketing emissions.

1.2 The Memoranda of Agreement

In 1996, all seven major auto manufacturers affected by the original requirement for ZEVs in 1998 and the Executive Officer of the Air Resources Board signed the MOAs. The MOAs are intended to ensure the successful introduction of ZEVs into the marketplace. They include binding commitments from each of the seven auto manufactures as well as from ARB.

The MOAs include four major provisions that pertain to auto manufacturers:

- offset emission benefits lost due to the elimination of the ZEVs requirements in 1998 through 2002 through a national low-emission vehicle program or another program that would provide equivalent air quality benefits;
- continue investment in ZEV and battery research and development and place specified numbers of advanced battery-powered ZEVs in marketplace demonstration programs (up to 3,750 vehicles total);
- participate in a market-based ZEV launch by offering ZEVs to consumers in accordance with market demand; and
- annual and biennial reporting requirements.

First, the MOAs formalize the auto manufacturers' commitments to introduce low-emission vehicles nationwide in 2001, three years earlier than could be required under federal law.

Manufacturers are required to produce and deliver for sale a combination of vehicles that complies with a nationwide annual fleet average NMOG rate, which would be equal to 0.075 grams per mile (g/mi) NMOG for passenger cars and light-duty trucks up to 3,750 pounds and 0.1 g/mi NMOG for light-duty trucks 3,751-5,750 pounds. Manufacturers would also be required to install on-board diagnostic systems on all NLEVs to be consistent with California regulations on all NLEVs. The emission reductions from the NLEV program due to the normal migration of out-of-state vehicles into California will offset the emission reductions associated with the ZEV program in the years 1998 through 2002 thereby maintaining the integrity of our SIP.

Second, the MOAs formalize the manufacturers' commitment to continued ZEV research and development through participation in a Technology Development Partnership. Under the partnership, auto manufacturers will each produce their pro rata share of 3,750 advanced battery vehicles between 1998 and 2000 and place them in demonstration programs designed to validate the new technology. The ZEVs produced under the partnership would be placed in California by means of either selling, leasing or otherwise transferring the vehicles to consumers who will use them on a frequent, regular basis and provide feedback to the manufacturers. Each manufacturer's share of the total ZEVs to be placed in demonstration programs is presented in Table 2.

Table 2
Auto Manufacturer MOA Advanced Battery Demonstration Commitments

Calendar Year	Number of Vehicles (Based on Average Market Share)							**Total by Year**
	Chrysler	Ford	General Motors	Honda	Mazda	Nissan	Toyota	
1998	51	181	182	101	28	70	135	748
1999	103	363	365	202	55	141	271	1,500
2000	103	363	366	203	55	141	271	1,502
Total								**3,750**

To receive MOA ZEV credit towards the commitments enumerated in Table 2, a ZEV must use advanced batteries. For the purposes of the MOAs, "advanced battery" means a battery with a specific energy of at least 40 watt-hours per kilogram (W-hr/kg) for the 1998 calendar year and at least 50 W-hr/kg for 1999 and subsequent calendar years. Specific energy is the amount of energy per unit of weight and is related directly to range capability. The amount of credit given in the MOA for an advanced battery-powered ZEV is based on the specific energy of the batteries. Manufacturers may reduce the total number of ZEVs required (as indicated in Table 2) if the batteries used in the vehicles have a specific energy over 50 W-hr/kg. Table 3 indicates the number of credits that would be granted for a ZEV using advanced batteries.

Table 3 MOA ZEV Credits Allowed for an Advanced Battery-Powered ZEV	
Specific Energy	**Number of ZEV credits allowed**
40 W-hr/kg (1998 only) 50 W-hr/kg (1999 and 2000)	One
60 W-hr/kg	Two
90 W-hr/kg	Three

The advanced battery-powered vehicles that are being produced today have specific energy ratings of between 55 and 85 W-hr/kg depending on the battery technology used and the vehicle weight. It is expected that near-term advanced battery-powered EVs will fall within this range for specific energy as well. Linear interpolation between the number of ZEV credits is allowed for ZEVs with specific energy over 50 W-hr/kg. Therefore, ZEVs placed as part of the Technology Development Partnership are expected to generate 1.5 to 2.5 MOA ZEV credits per vehicle. The resulting total number of ZEVs expected to be placed during the MOA period is approximately 2,000.

In addition to placement of advanced battery-powered ZEVs, the MOAs require auto manufacturers to offer ZEVs for sale according to their estimate of market readiness. The purpose of this element of the MOA is to demonstrate that the manufacturer is committed to developing the market for ZEVs during the 1998 through 2002 time frame. Market development entails more than just offering ZEVs to consumers. It also includes providing the necessary infrastructure to support ZEVs and maintaining excellent customer service. The early purchasers of ZEVs will largely influence the public perception of ZEVs and the widespread acceptance of ZEVs in the marketplace. Although we do not expect ZEVs to infiltrate the market in large quantities in the introductory years, it is important that the ZEVs being leased or purchased during these years meet or exceed customer expectations. The long-term success of the ZEV program depends largely on the initial reaction to ZEVs and is essential to our air quality goals in California.

Finally, the MOAs require manufacturers to file an annual report within 90 days after the close of each calendar year and a biennial report in November of each year preceding the scheduled biennial ARB reviews. The annual reports must provide information regarding ZEVs placed in California and the United States during the previous calendar year. The annual report must also contain information regarding the purchase of advanced battery prototypes prior to 1998 and the placement of ZEVs under the Technology Development Partnership. The biennial report, required in November 1997 and every other year until 2003, must specify manufacturer ZEV product plans for each model year through 2003. Each manufacturer will provide the ARB with a report detailing annual capacity to produce ZEVs as well as product plans for model years through 2004. The purpose of the biennial report is to show how the manufacturer intends to ramp up to the 2003 requirement of ten percent ZEVs.

In addition to the auto manufacturer obligations in the MOAs, ARB committed to working with state and local governments and others to help ensure the development of ZEV infrastructure and the removal of barriers to ZEV introduction. Specifically, ARB is committed to:

- Facilitate the purchase of ZEVs in state fleets;
- Address insurance and financing issues;
- Ensure the availability of battery recycling by working with various state agencies;
- Work with local governments, as needed, on planning and permitting charging stations;
- Ensure adequate training for installation and maintenance of EV charging systems by working with utilities and electrical contractor trade groups;
- Continue to support the efforts of the Infrastructure Working Council;
- Continue to work with the State Fire Marshall and other emergency response officials to create a comprehensive ZEV emergency response training program;
- Maintain the commitment to observe the activities of the U.S. Advanced Battery Consortium; and
- Support the development and implementation of reasonable incentive programs that enhance the near-term marketability of ZEVs.

An update on the progress made by auto manufacturers and ARB towards meeting the requirements of the MOAs is presented in Chapters 2 and 3 below.

2.0 PROGRESS OF AUTO MANUFACTURERS

All seven of the major auto manufacturers submitted annual and biennial reports on time. These reports outline the progress made towards meeting the requirements of the MOAs. Most of the auto manufacturers also included tentative plans for the future. The following information is based on the manufacturers submittals as well as private meetings and phone conversations with manufacturers.

2.1 National Low-Emission Vehicle (NLEV) Program

The NLEV program was included in the MOAs to offset the emission reductions associated with the revised ZEV program in 1998 through 2002 thereby maintaining the integrity of ARB's SIP. The benefits associated with the NLEV program result from the reduction in emissions associated with cleaner vehicles that either travel through or relocate to California from other states. By 2010, ARB staff's analysis indicates that the NLEV program will result in emission reductions that are equivalent to those that would have occurred had the ZEV program production requirement for 1998 through 2002 remained in place. The seven largest auto manufacturers were given the opportunity to opt in to the NLEV program beginning in 2001 or use alternative means to reduce emissions by the same amount subject to the approval of the Executive Officer.

All seven of the major auto manufacturers have opted in to the NLEV program beginning in 2001. The auto manufacturers will begin the NLEV program with the 1999 model year in most of the Northeast States. Four of the Northeast states, New York, Massachusetts, Maine and Vermont, did not agree to participate to the NLEV program because they have adopted California's LEV program with it's more stringent requirements. The NLEV program will begin in the remainder of the United States beginning with model year 2001, three years earlier than could be required under federal law.

2.2 Market-Based ZEV Launch in 1996, 1997 and 1998

The first electric vehicles to be made available in California arrived in December 1996. Following are summaries of each manufacturer's vehicle launches.

2.2.1 General Motors

The first purpose built electric vehicles were introduced to the general public in December of 1996 when General Motors began leasing the EV1 in the Los Angeles area, San Diego and Arizona. General Motors has since increased the market area of the EV1 to include Sacramento and the San Francisco Bay Area. According to ARB range tests, the EV1 has a combined city/highway range of approximately 75 miles per charge. The EV1 is currently equipped with conventional lead acid batteries. However, General Motors has indicated that they will make the EV1 available with nickel-metal hydride (NiMH) batteries by late 1998. Nickel-metal hydride batteries are expected to approximately double the range.

General Motors is leasing the EV1 through a three year program described as a "worry-free" lease. The lease price of an EV1 in California is $399 per month plus tax. This price includes a 220 volt wall mount charger, maintenance, repairs, and road-side assistance. While offered for lease only, the vehicle lease price is based on a retail price of $33,995. These figures are calculated using a federal tax credit and local clean air incentives and are subject to change.

In 1996, General Motors placed 65 EV1s in service in California. In 1997, 159 EV1s were placed in California. An additional 41 EV1s were placed in other states. As mentioned above, all of the EV1s placed in California use lead-acid batteries. Thus, they are not eligible for MOA ZEV credit.

General Motors also introduced the Chevy S-10 pickup truck in 1997. The S-10 is marketed to fleet operators in California and selected cities elsewhere in the country. As of December 1997, 111 S-10s were placed in California. One of these vehicles is equipped with NiMH batteries with specific energy of 60.4 W-hr/kg. Thus, under the terms of the Technology Development Partnership, General Motors is eligible for 2.0 MOA ZEV credits. In addition to the S-10s placed in California, 250 S-10s were placed in other states; six of these are equipped with NiMH batteries. According to ARB range testing, the S-10 has a combined city/highway range of approximately 40 miles per charge using conventional lead-acid batteries. General Motors has indicated that they will make more S-10s available with NiMH batteries in late 1998. These batteries are expected to approximately double the range.

Although lead-acid battery-powered EV1s and S-10s are not eligible for MOA ZEV credit, they do address the requirement in the MOAs to introduce ZEVs in accordance with market demand and they will apply to the requirement for ten percent ZEVs in 2003. Additionally, General Motors' considerable financial support of infrastructure programs designed to make recharging equipment widely available has increased public awareness and improved the range capabilities of EVs. General Motors has been actively involved with EV1 owners and has worked with them to promote the car. These efforts are necessary for a wider EV market.

2.2.2 Honda

Honda introduced the EV PLUS in May 1997. According to ARB range testing, the three-door, four-passenger EV PLUS has a combined city/highway range of approximately 125 miles per charge. The EV PLUS uses NiMH batteries and gives Honda the distinction of being the first manufacturer to introduce an advanced battery-powered EV available to the retail market in California. The EV PLUS has been marketed in the Los Angeles area, San Diego, Sacramento, and the San Francisco Bay Area and has been targeted toward the consumer market although it is also available to fleets. Because the EV PLUS uses advanced batteries, Honda is receiving MOA ZEV credit for placing advanced battery-powered ZEVs.

Honda established the Charter Lease Program to encourage market acceptance, promote infrastructure availability and minimize technology risk. To encourage market acceptance, the lease terms include unlimited mileage, vehicle collision and comprehensive insurance and 24 hour roadside assistance. To promote infrastructure availability Honda contracted with Edison EV to provide equipment and installation know-how and service. Finally, to minimize technology risk, Honda provides all service and repairs free of charge and offers a free rental car when the EV PLUS is being serviced or repaired for any reason.

Consistent with the lease demonstration program, Honda has launched a marketing effort. The effort includes brochures, newspaper articles, magazine articles, and television promotions. Honda intends to continue to develop and improve their marketing strategy to increase the interest in their EV PLUS and encourage sales.

As of December 1997, Honda placed 104 EV PLUS vehicles in California. All of these vehicles are equipped with NiMH batteries with specific energy of 59.0 W-hr/kg. Thus, under the terms of the Technology Development Partnership, Honda is eligible for 1.9 MOA ZEV credits per vehicle for a total of 198 credits. In addition to the EV PLUS vehicles placed in California, 10 were placed in other states.

The demonstration program is intended to provide Honda with valuable information regarding the attributes customers require in an electric vehicle as well as any problems that need to be corrected. The attributes consumers find most desirable will be integrated into the future generations of EVs. Additionally, Honda has been keeping very close track of issues that have arisen during the demonstration program and has established procedures to handle such issues. This strategy is intended to ensure Honda's readiness for the full market launch in 2003.

2.2.3 Toyota

As of October 1997, Toyota began offering an electric RAV4. The RAV4 EV is a five-door, four-passenger sport utility-like vehicle powered with NiMH batteries. According to ARB range testing the RAV4 has a combined city-highway range of approximately 125 miles. Because the RAV4 EV is powered by NiMH batteries, it is eligible for MOA ZEV credit. Toyota is making the RAV4 EV available to fleet operators only. At this time, even servicing is being provided through selected and trained fleet operators. Current plans are to produce up to 700 vehicles that would be available in the Northeast and in California.

In 1997, Toyota placed 52 electric RAV4s in California that are eligible for MOA ZEV credit. These vehicles are equipped with NiMH batteries with specific energy of 62.7 W-hr/kg. Thus, under the terms of the Technology Development Partnership, Toyota is eligible for 2.1 MOA ZEV credits per vehicle for a total of 109 credits. In addition to the electric RAV4s placed in California, 17 electric RAV4s were placed in other states.

Toyota's marketing efforts have focused on fleet purchasers. Due to the late placement of the RAV4s in 1997, very little feedback is available from the MOA vehicles at this time. It is anticipated that Toyota will have additional information available for the 1998 annual report. Toyota has visited numerous locations throughout the U.S. and has given interviews with the press in an effort to market the RAV4 EV to fleet costumers. Toyota has indicated its intent to offer the RAV4 EV to the general public by 2000. However, Toyota maintains that the fleet market is an appropriate place to begin the market launch of its EV.

2.2.4 Chrysler

Chrysler placed 17 Electric Powered Interurban Commute (EPIC) minivans in demonstration fleets in California during 1997. Fourteen of the EPICs were placed in military base fleets; three were placed in utility fleets. The EPIC uses advanced lead acid batteries with specific energy of 41 W-hr/kg allowing one MOA ZEV credit per vehicle in 1998. According to Chrysler (ARB has not yet completed range testing), the EPIC has a range of about 60 miles. At this time the EPIC is only available to fleet customers. In addition to the EPICs placed in California, two EPICs were placed in other states.

2.2.5 Ford

Ford introduced the Ranger EV pickup truck as a 1998 model year vehicle. The Ranger is powered by lead-acid batteries. According to Ford data, the Ranger EV has a range of approximately 50 to 60 miles. Ford believes this range may be sufficient under a plan it has to provide high voltage charging stations that would recharge cars in a relatively short time. Ford will make the Ranger EV available to fleet operators throughout California and the rest of the country, not limiting sales or leases to specified markets. Additionally, unlike other manufacturers, Ford plans to make the Ranger EV available for sale. It is anticipated that Ford will offer a Ranger EV that uses NiMH batteries in late 1998. Preliminary information from Ford indicates that the NiMH battery-powered Ranger will have a specific energy of 62 W-hr/kg and, therefore, would receive multiple ZEV credits under the MOA.

As of December 1997, three electric Rangers were placed in California. An additional seven electric Rangers were placed in other states. As mentioned above, all of the Rangers placed in California use lead-acid batteries. The use of lead-acid batteries in the current model Ranger EV makes it ineligible for MOA ZEV credit. However, lead-acid battery-powered Rangers address the requirement in the MOAs to introduce ZEVs in accordance with market demand and they would apply to the requirement for ten percent ZEVs in 2003. Additionally, similar to General Motors marketing strategy for 1997, Ford is establishing a market for EVs and is supporting development of infrastructure while battery development continues.

2.2.6 Nissan

Nissan is the first automaker to offer an electric vehicle powered with lithium-ion batteries. Nissan’s Altra EV, first shown publicly at the 14th International Electric Vehicle Symposium, and the Los Angeles Auto Show in late 1997 will be made available to fleet operators in Japan in 1998. The expected range of the five-door, four-passenger, station wagon style Altra is 120 miles city and 107 highway. To meet Nissan’s MOA commitment, a limited number of Altra EVs will be leased to fleet operators in California during 1998. Nissan has provided an estimate of specific energy for the Altra of 83 W-hr/kg which would allow Nissan to accumulate 2.8 MOA ZEV credits per vehicle.

2.2.7 Mazda

Mazda has stated its intention to purchase credits from Ford to meet its MOA obligations.

2.3 ZEVs Available in 1999 to 2003

Because information about manufacturer product plans is highly confidential, discussion of vehicles anticipated in the 1999 to 2003 time-frame will be general and non-manufacturer specific in nature.

Each of the auto manufacturers has laid out a plan for meeting the MOA requirements for 1999 through 2002 in their 1997 biennial progress report submittal. In most cases these plans include retail and fleet placements of the vehicles currently being demonstrated. Although not committed to in the November progress reports, vehicles with additional advanced battery technologies may become available to the California market during the MOA period if the new battery technologies prove successful. None of the auto manufacturers indicated plans to introduce new electric vehicle platforms during the MOA demonstration years, instead committing to production of currently available vehicles through the 2000 model year. More specific production plans are expected to be included in the year 2000 reports and review.

Plans for expanded development of the EV market with additional vehicle platforms and advanced battery technologies were discussed during the meetings staff conducted with manufacturers and reflected in several of the confidential progress reports. Most auto manufacturers have indicated that a marketing program including more than one vehicle platform would be needed to meet the ten percent market requirement in 2003. Several manufacturers are developing four-door, four- or five-passenger EVs for the ramp-up to the 2003 requirement. However, as with any technological challenge, some companies appear better prepared to meet the ZEV challenge than others. It is necessary for all auto manufacturers to recognize the importance of indicating preparation and product plans for the ten percent requirement in 2003 in their annual and biennial reports. ARB staff will continue to follow manufacturer progress toward the 2003 requirement to ensure that product plans are in place in a timely manner.

2.4 Intermediate Auto Manufacturers' Progress

Although not subject to the commitments of the MOA demonstration program, intermediate volume auto manufacturers have begun development of ZEVs in preparation for the 2003 ten percent market requirement. Some of the intermediate manufacturers have developed small purpose-built EVs that could be used as station cars or in other special applications. Others have opted to plan for conversion of a conventional vehicle or are developing purpose-built vehicles for the marketplace. Finally, four of the intermediate auto manufactures have stated that they will either purchase credits from the major auto manufacturers or consider proposed modifications to our regulations (scheduled for the November 1998 Board hearing) that would allow them to meet the 2003 ZEV requirement with very low-emitting hybrid-electric vehicles.

3.0 AIR RESOURCES BOARD ACTIVITIES

As part of the MOA, ARB committed to a number of tasks aimed at making California ready for the ZEV market. These included facilitation of purchase or lease of EVs by state and local governments, addressing infrastructure issues such as insurance rates, financing, battery recycling, public charging and emergency response and supporting reasonable incentives. Following is a summary of the activities that the ARB has undertaken or supported to meet the commitments of the MOA.

3.1 Purchase/Lease of EVs by State and Local Governments

The MOAs specify that ARB has the obligation to "Facilitate the purchase of ZEVs for appropriate applications in state fleets by working with the California Department of General Services and the California Energy Conservation and Development Commission to establish vehicle specifications for the State Bid List and by working with the Department of General Services Office of Fleet Administration to ensure the sale or lease of ZEVs to selected state agencies."

The Department of General Services has executed Master Service Agreements with the General Motors Acceptance Corporation (for the EV1) and American Honda Motor Co., Inc. (for the EV PLUS). These Master Service Agreements allow all state agencies, as well as the University of California, California State University, the Community Colleges, and local governments, to lease ZEVs according to pre-defined and pre-approved terms, conditions and lease rates. This greatly simplifies the leasing process and allows for more rapid acquisition of vehicles. Additional Master Service Agreements with Toyota Motor Company (for the RAV4), Ford Motor Company (for the EV Ranger) and General Motors Acceptance Corporation (for the Chevrolet S-10) are currently being developed.

Under these Master Service Agreements and prior agreements, as of February 27, 1998, ZEVs have been leased and are in service at the Department of General Services, the Air Resources Board, the Department of Water Resources, the California Energy Commission and Caltrans. Additional vehicles have been ordered by the Department of Forestry and Fire Protection, the Department of Justice, the California Highway Patrol, and the Department of Parks and Recreation. The Air Resources Board is also co-funding, with the South Coast Air Quality Management District, the purchase of 16 vehicles that would be housed in state garages in a number of locations throughout California and used in the EV Loan Program discussed below.

To further encourage state agency leasing of ZEVs, in February 1998 ARB dedicated additional staff resources to work directly with senior managers at other Boards and Departments to facilitate the purchase and use of EVs. Working in cooperation with the Department of General Services, ARB will make ZEVs, and the associated parking and recharging facilities, available to these agencies for no-cost short-term loans. This EV Loan Program will allow a wide variety of agencies to determine if the available vehicles meet their specific needs, and will help familiarize senior managers across the state with current ZEV technology, costs, and capabilities. As with any new technology, there is apprehension associated with the purchase of EVs. Loaned use of EVs will provide fleet operators and users the opportunity to recognize that EVs perform as well or better than conventional vehicles and can satisfy most of their driving needs. Initial efforts will focus on

Sacramento and Los Angeles. However, when the program is in full operation, the EVs will be housed at state garages in Los Angeles, Van Nuys, Sacramento, San Diego, San Francisco and Oakland.

Participation in the EV Loan Program has been approved by the South Coast Air Quality Management District, the Department of General Services and the California Energy Commission. The South Coast Air Quality Management District governing board has approved funding to lease eight EVs in Southern California. The eight vehicles approved have been ordered (four GM EV1s and four Honda EV PLUS vehicles). Installation of charging infrastructure at state garages commenced in June 1998. Additional EVs will be leased in Fall 1998, once Master Service Agreements are completed and vehicles are available.

3.2 Insurance and Financing

To date, issues of insurance rates or financing have not presented obstacles to further expansion of the EV market. Insurance issues have been addressed by at least one manufacturer, Honda, by including comprehensive and collision insurance in the lease package. Financing has not presented a problem for retail consumers because auto manufacturers are only leasing the vehicles to consumers with lease programs that are competitive with high-end conventional vehicles. The decision to lease EVs to consumers rather than sell the vehicles has not been based on concerns about financing availability. Auto manufacturers have indicated that offering lease programs to consumers protects customers from risks associated with investing in new, quickly changing technology. ARB staff will continue to monitor these areas to ensure any future issues that arise are dealt with in a timely manner.

3.3 Battery Recycling

ARB contracted with Acurex Environmental to assess battery recycling technology and the health impacts of battery recycling. Task 1: “Assessment of Recycling Technology”, was completed in March 1995. The purpose of Task 1 was to examine the ten most promising candidate EV battery technologies. The results of Task 1 will assist in determining where efforts should be focused in establishing new recycling facilities and developing cleaner technologies. In general, the report recommended that a deposit of $100 to $150 should be levied on light-duty vehicle batteries to ensure that these batteries are returned for recycling. There do not appear to be any overwhelming obstacles to the recycling of any of the most promising battery technologies expected to be used in EVs. However, it will likely be necessary to build new recycling plants for certain battery types, such as lithium-ion, to accommodate their use in large quantities of EVs. Fortunately, any new recycling facilities would be required to meet stringent air quality and environmental regulations that would minimize any adverse effects of the recycling processes.

Task 2: “Assessment of Health Impacts” is expected to be finalized later in 1998. Task 2 will establish the level of risk associated with various battery technologies. Preliminary information indicates that for established recycling facilities risk is minimal due to very stringent control technology. Risk associated with new technology is also expected to be low because any new recycling facilities would be subject to stringent local and state regulatory requirements that severely limit the allowable emissions.

3.4 Public Infrastructure

California currently has well over 500 electric vehicle charging outlets at locations in greater Los Angeles, Sacramento, San Francisco and San Diego. ARB is working with local utilities and electric vehicle infrastructure providers to assess charging station implementation issues and ensure that convenience charging facilities are developed as needed. The California Energy Commission, ARB and other government agencies have also assisted with modification and adoption of electrical and building codes that meet the needs of charging stations. This group instigated and coordinated the development of training for building officials involved with permitting and inspection of infrastructure installations. These activities resulted from California Energy Commission and ARB staff participation in the National Electric Vehicle Infrastructure Working Council.

3.5 Infrastructure Installation Considerations

The California Energy Commission formed the Building Codes Working Group with ARB, the California Building Officials, the California Electric Transportation Coalition, California utilities, General Motors, and Hughes Power Systems to address issues associated with installation of EV chargers, especially related to building codes, electrical codes and training of permitting and inspection personnel. The Building Codes Working Group developed revisions to the California Building Standards to allow for safe installation of electric vehicle charging systems. The Building Code changes, effective in 1996, defined EV charging equipment, added safety requirements, clarified the definition of refueling and added ventilation requirements. The Building Codes Working Group also modified the California Electric Code to include a requirement to use approved or listed EV charging equipment.

In an effort to provide a national standard for building code requirements related to EV charging systems, the Building Code Working Group focused much of its efforts through 1997 on preparing modifications to the National Electric Code. Changes suggested by the Building Code Working Group were forwarded to the National Infrastructure Working Council for approval and submittal to the National Electric Code governing organization.

Following adoption of new California code revisions, a training program was developed for building officials which covered the following:

- The new Building Code and Electric Code provisions governing EVs;
- Plan check and inspection techniques for the new regulation;
- An overview of current and emerging EV technologies including automotive, batteries and charging equipment;
- An opportunity to see and drive current production vehicles; and
- Hands-on experience with charging system equipment.

Additional activities of the Building Code Working Group included development of Interim Disabled Access Guidelines for Electric Vehicle Charging Stations in cooperation with the State Architect. Since EV charging stations are offered as a service to the general public, they are required to be accessible to those with disabilities. The guidelines give potential public infrastructure providers guidance on making installations accessible to those with disabilities.

The final project undertaken by the Building Code Working Group was the development of an informational brochure for building officials, contractors and consumers. The brochure provides information about permitting and inspection requirements, cites appropriate building and electric codes and gives phone numbers for agencies that can provide further information.

3.6 National Infrastructure Working Council

ARB staff has attended the Infrastructure Working Council's meetings, observing and participating in the Health and Safety Committee, the Connector and Connecting Stations Committee and the Connector Standardization Subcommittee of the Bus and Non-Road Committee. ARB's participation in the Health and Safety Committee has been focused on assistance with the proposed modification of the National Electric Code. ARB and California Energy Commission staff have observed and provided comments to the Connector and Connecting Stations Committee. This Committee recently made a recommendation that the Society of Automotive Engineers adopt a single standard for the butt-type conductive connector such as is used by Honda and Ford. It appears that the Society of Automotive Engineers will likely follow this recommendation in September 1998 following the full approval process. ARB staff has also observed the early work of the Bus and Non-road committee and has been asked to participate in the Connector Standardization Subcommittee as it works to determine the need for connector standardization for buses and non-road vehicles.

3.7 Emergency Response

Similar to the Building Code Working Group, the California Energy Commission formed the Emergency Response Working Group with ARB, the California Office of the State Fire Marshal, the California Highway Patrol, utilities, auto manufacturers and industry organizations such as the California Electric Transportation Coalition. The purpose of the working group was to develop training designed to inform emergency response personnel about EVs and the differences in response procedures for incidents involving EVs.

Early this year the Emergency Response Working Group completed the development of a training program consisting of material to train instructors, an instructor's manual and compact disc and slide teaching materials and student manuals. Train-the-trainer courses were taught throughout the state and, to date, at least 25 trainers have registered to teach the class to emergency response personnel and over 200 students have taken the class. Interest in the training materials has expanded beyond California. Through the Infrastructure Working Council, the complete package of training materials has been distributed to every state Fire Marshal Office in the United States.

3.8 Observe Activities of the U.S. Advanced Battery Consortium (USABC)

ARB staff has attended the Technical Advisory Committee meetings of the USABC on a quarterly basis. By attending these meetings staff is able to monitor the progress of USABC contracts with various battery developers and gain insight on their progress from the technical discussions of the committee. ARB staff has found the group to be very cooperative and has learned much from the frank and open discussions that take place during the meetings. Much of the information gathered is confidential and, therefore, cannot be discussed in this report. Issues and progress related to battery development will, however, be presented in Chapter 4.

3.9 Reasonable Incentives

There are a number of federal, state, local and private incentive programs currently available. Because ZEVs are a new technology and are currently produced in very limited quantities, they are more expensive than conventional vehicles. Once ZEVs are mass produced and the technology has been learned out, it is expected that ZEVs will be comparably priced to conventional vehicles. However, to enhance marketability in the near term, it is vital to provide support, monetary and non-monetary, in the form of incentives. The following is a list of incentives that are currently available.

3.9.1 Federal Incentives

- Tax credit for 10% of the cost of an EV, up to $4,000. This incentive will be in place through 2004 but will be reduced by 25% in 2002, 50% in 2003 and 75% in 2004.
- Business tax deduction of $100,000 for electric recharging sites.
- The Energy Policy Act of 1992 includes a ten year $50 million EV demonstration program and a fifteen year $40 million cooperative program between government and industry to research, develop and demonstrate EV infrastructure.
- Elimination of the luxury tax for alternative-fueled vehicles.

3.9.2 State of California Incentives

- The California Energy Commission funded 50 conductive recharging units for approximately $1,500 each. This incentive program was utilized by customers purchasing the Honda EV PLUS and is no longer available.
- The California Energy Commission will provide funding assistance to the EV Loan Program (discussed in section 3.1) for chargers and installation of infrastructure.
- Up to $5,000 (cap of $200,000) of the incremental cost of a ZEV for fleets located in Clean Cities (Bay Area, Orange, Riverside, Sacramento, San Bernardino, San Diego, Santa Barbara, Ventura and Yolo-Solano) provided by California Energy Commission and the U. S. Department of Energy.

3.9.3 Local Incentives

- The South Coast Air Quality Management District offers a $5,000 rebate per EV sold before 1999.
- The San Diego Air Pollution Control District offers $5,000 for the purchase of an EV sold before 1999.
- The Los Angeles Airport offers free parking and charging for EVs in its Central Terminal Area. Ten charging stations were installed at the Los Angeles Airports as part of the Quick Charge Los Angeles EV program. The program was created in 1997 when the City of Los Angeles received an $862,500 grant from the Mobile Source Air Pollution Reduction Review Committee, under its Electric Vehicle Corridor Communities Program, to install 194 EV charging stations at 42 high-profile locations throughout the city.

3.9.4 Utility Incentives

- Edison International has an employee incentive program that allows $3,600 towards the lease or purchase of a qualifying EV. This program is funded by the corporation's shareholders and combines a cash buy-down with special packages from four major auto manufacturers to make daily use of an EV easier for employees.
- Los Angeles Department of Water and Power provides discounts of $0.025 per kilowatt hour (kWh) for electricity used to recharge EVs.
- San Diego Gas and Electric offers a discount rate of $0.036/kWh for electricity used to recharge EVs during off-peak time periods.
- San Diego Gas and Electric also has a total of $50,000 in seed money to help local businesses and governments install charging stations in its service area.
- Southern California Edison offers a discount rate of $0.041/kWh for electricity used to recharge EVs during off-peak time periods.
- Sacramento Municipal Utility District offers a discount rate of $0.04187/kWh for electricity used to recharge EVs during off-peak time periods.
- Pacific Gas and Electric offers a discount rate of between $0.044/kWh to $0.051/kWh for electricity used to recharge EVs during off-peak time periods.

In addition to these incentives, the ARB has been working cooperatively with government agencies, auto manufacturers and other stakeholders to determine the most effective way to support the introduction of ZEVs into the marketplace. New monetary as well as non-monetary incentives have been discussed in addition to possible extensions of the incentives that currently exist. Many of these existing incentives were put into place prior to the 1996 amendments to the ZEV program and it would be appropriate to extend them in order to foster the proliferation of ZEVs during the market-based introductory period.

3.10 Additional Activities

ARB has instigated and/or been involved in a number of outreach programs, events and research contracts in addition to those addressed in the MOAs. Board members and staff have participated in local outreach as well as attending conferences and exhibitions promoting the use of zero-emission vehicles.

3.10.1 ARB Test Fleet

The ARB has acquired a test fleet of EVs, three GM S-10s, three GM EV1s, and two Honda EV PLUS vehicles, with two Toyota RAV4 EVs expected soon. In an effort to gather information about the vehicles, their usage patterns and issues associated with everyday EV use, ARB has set up a system to allow state employees to take the vehicles for a minimum of two days up to a week. Employees are selected based on their willingness to do outreach to schools and other local groups. Selected employees are given a specific vehicle to drive for a week or a weekend and are encouraged to use the vehicle for as much of their normal driving as possible. Employees are then required to fill out a log that indicates usage pattern and any suggestions regarding vehicle usability and accessibility. This system has been very successful and gives ARB and users the opportunity to gain valuable experience with EVs and infrastructure. Based on discussions with employees and entries in the EV log books, these experiences are typically very positive and users find that the vehicle meets practically all their driving needs. ARB has also been able to provide feedback to other fleet managers and infrastructure providers that will facilitate the smooth transition of EVs into the marketplace.

In addition, Board members and staff have been very proactive in conducting public outreach to their children's schools, community events, community groups, friends and family. These outreach events have been very successful at a "grass-roots" level. Typically, a Board or staff member is accompanied by a member of the Zero-Emission Vehicle Implementation Section who may give a presentation or participates in a demonstration of the vehicle. The children and/or adults attending the event get up-close experience with a vehicle they may otherwise have never seen. In addition, because the person demonstrating the vehicle may be familiar or may live in the community, the attendants get to see just how close zero-emission vehicles are to the mainstream.

3.10.2 Participation in Conferences and Exhibitions

ARB has participated in a number of conferences and exhibitions including the North American Electric Vehicle Infrastructure Conference, the 14th Annual Electric Vehicle Symposium, the World Electric Vehicle Expo and various Clean Cities Conferences. ARB has attended, contributed papers and/or purchased booth space at these and other gatherings. In addition, Board members and staff have participated in ride and drive programs, public relations events and technical advisory groups.

3.10.3 Research Activities

ARB has an ongoing contract to evaluate fuel cell technology. The Fuel Cell Technical Advisory Panel (Panel) was established by ARB in 1996. The Panel is composed of four scientists who are recognized experts in fuel cell and power system technologies. The objective of the Panel is to provide expert and independent assessment of the current status and future prospects of fuel cells as the primary power sources for EVs. The Panel has collected and critically evaluated information on fuel cell technologies that are being researched and developed worldwide for electric transportation applications. This contract, as well as those mentioned above, will provide ARB knowledge of the status of EV technology, improvements necessary and consumer demands as they relate to the EVs and infrastructure. The Panel's final report will be available this summer.

ARB is also actively involved in research regarding electric vehicles and infrastructure. ARB and South Coast Air Quality Management District are funding a study to evaluate full fuel cycle emissions of electric vehicles relative to other alternative fuels. This information may be used to determine partial ZEV credit under the proposed modifications to the Low-Emission Vehicle regulations. These modifications are scheduled for the November 1998 Board meeting. ARB is also involved with research to determine usage patterns and consumer needs as they relate to charging infrastructure. This research will help ARB and others to determine where charging stations would be best utilized and the kind of service necessary to support the stations. The success of the ZEV program depends largely on the necessary infrastructure being available and operational.

4.0 PROGRESS IN ADVANCED BATTERY DEVELOPMENT

The 1996 biennial review identified the need for improved battery performance, efficient battery manufacturing and reduced battery cost. In order to assess the progress of advanced battery development since 1996, the staff finds it instructive to review the USABC battery performace goals and the findings of the 1995 Battery Technical Advisory Panel report.

4.1 USABC Battery Performance Goals

The United States Advanced Battery Consortium (USABC) was formed in 1991 to identify the requirements of advanced batteries for EV applications, evaluate promising technologies, and support further development of these technologies. The USABC is a partnership of General Motors, Ford, Chrysler, and the Electric Power Research Institute (EPRI) with participation of the U.S. Department of Energy (DOE) and some electric utilities.

The USABC established desirable primary and secondary battery characteristics for EV applications. Using these characteristics, the USABC identified Mid-Term, Commercialization, and Long-Term criteria, or performance goals. The performance levels reflect what the members believe would be necessary to initiate an EV market, maintain minimal production levels, and sustain significant EV sales, respectively. The Battery Report focused on the USABC Mid-Term goals in its determination of likely battery candidates for EV applications in the near term, and relied on the most important battery characteristics.

Table 4 USABC Criteria			
Parameter	**Mid-Term Criteria**	**Commercialization Criteria**	**Long-Term Criteria**
Price ($/kWhr)	<$150/kWhr	<$150/kWhr ($75 desired)	<$100/kWhr
Cycle Life	600 @ 80% DOD	1000 @ 80% DOD 1600 @ 50% DOD 2670 @ 30% DOD	1000 @ 80% DOD
Lifetime Range (miles)	100,000	100,000	100,000
Calender Life	5 years	10 years	10 years
Power Density	250 W/l	460 W/l	600 W/l
Energy Density	135 Wh/l	230 Wh/l	300 W/l
Specific Power	150 W/kg	300 W/kg	400 W/kg
Specific Energy	80 Wh/kg	150 Wh/kg	200 Wh/kg
Regenerative Sp. Pwr.	75 W/kg	150 W/kg	200 W/kg
End of Life (EOL)	20% of rated power and capacity spec.	20% of rated power and capacity spec.	20% of rated power and capacity spec.
Operating Performance	-30 to +65 deg C	20% loss at extremes of -40 and +50 deg C	-40 to +85 deg C
Normal Charge	6 hrs., 20-100% SOC	6 hrs., 20-100% SOC	3-6 hrs., 20-100% SOC
High Rate Charge	<15 min., 40-80% SOC	<30 min. @ 150 W/kg, 20-70% SOC	<15 min., 40-80% SOC
Efficiency at EOL	75%	80%	80%

Table 4 provides a summary of the USABC Mid-Term, Commercialization, and Long-Term criteria. This table represents only the primary criteria requirements. Additional secondary requirements are not presented here, but include requirements for minimal battery efficiency, maintenance, abuse tolerance, and thermal losses. These performance and cost goals are believed by the USABC to be necessary to ensure EV commercialization can take place. While this update is not intended to review each of the USABC goals and current progress toward meeting these goals, it will cover many of the required battery characteristics for EV application.

4.2 EV Performance Based on USABC Goals

By meeting the Mid-Term, Commercialization, and Long-Term USABC battery criteria, manufacturers believe that EVs would offer various minimal levels of cost and performance characteristics. These levels are necessary to support different stages of new vehicle technology market introduction and consumer acceptance.

As indicated above, meeting the USABC Mid-Term goals would allow a manufacturer to introduce EVs at the prototype level and initiate EV demonstration programs. Assuming a battery pack capacity of 30 kWhrs, performance characteristics of a Mid-Term technology EV would offer a driving range of approximately 100-150 miles, acceleration from 0 to 60 miles per hour (mph) of 15-

18 seconds, and a realistic battery expected life of over 50,000 miles. Assuming cost goals are met, a Mid-Term battery pack would have a cost of $4,500 to the vehicle manufacturer if sized to provide 30 kWhrs of energy (although this is unlikely at initial low volumes).

USABC members also indicated that by meeting the USABC Commercialization criteria, advanced batteries would allow manufacturers to initiate and maintain minimal production levels of EVs. Meeting these goals would allow for a smaller, lighter battery pack that for the same capacity of 30 kWhrs could offer a longer driving range than a midterm vehicle. With improved power capability and lower weight, 0-60 mph acceleration times would be reduced to 11-14 seconds. If commercialization cost goals are eventually met, battery pack cost to the manufacturer would still be about $4,500.

Finally, meeting the USABC Long-Term goals would offer a battery pack with further performance and cost improvements. These improvements, according to the USABC, could promote a significant EV market and relatively high production volumes. In terms of vehicle performance, Long-Term battery characteristics, particularly a specific energy of 200 Wh/kg, would reasonably offer an EV with a driving range of a couple hundred miles on a single battery charge. Acceleration performance could rival that of conventional gasoline vehicles. Cycle life for an advanced battery meeting the USABC Long-Term goals would be the same as that for Commercialization level performance, but because of the higher specific energy, useful life in terms of miles driven should improve.

4.3 Battery Technical Advisory Panel (BTAP)

In order to gain a better understanding of the current status of advanced battery development and the likelihood for success in meeting the 1998 goal of two percent ZEV sales in California, ARB funded the creation of a Battery Technical Advisory Panel, or BTAP, in the Summer of 1995. The Battery Panel was comprised of four individuals with extensive experience in battery technology, development, and manufacturing. The BTAP was given the task of independently meeting with battery developers and experts from around the world and producing a final report detailing the progress in battery development in order to assist ARB with the ZEV program. In December, 1995, the BTAP delivered to ARB their final report entitled, “Performance and Availability of Batteries for Electric Vehicles: A Report of the Battery Technical Advisory Panel.” This report will be referred to as the Battery Report.

The Battery Report focused on the USABC Mid-Term goals in its determination of likely battery candidates for EV application in the near term, and primarily considered only the most important battery characteristics. Relying on vehicle manufacturer expertise in the design and production of new technology vehicles, the BTAP applied standard industry practice in new technology development to ZEV technology. Using standard development schedules for new technology, the BTAP assessed probable ZEV production scale-up scenarios given likely battery performance levels, manufacturing technologies, and potential investment strategies.

At the March, 1996, Board Hearing, ARB approved a decision to modify the ZEV requirement for California. In making their decision, the Board relied significantly on the findings of the Battery Technical Advisory Panel (BTAP) report entitled, ”Performance and Availability of

Batteries for Electric Vehicles: A Report of the Battery Technical Advisory Panel." Over a 5-month period, the Battery Panel met with or solicited written information from 20 battery manufacturers and developers.

4.4 BTAP Final Report

The BTAP final report provided ARB with the needed information to support modifications to the ZEV regulation. Based on expert technical information regarding EV performance, production, and market potential, as well as battery technology advancements and the minimal qualifications of meeting the USABC Mid-Term criteria, the BTAP final report became the cornerstone for ARB's decision to modify the original 1990 ZEV regulation.

4.4.1 BTAP Main Conclusions

BTAP produced their final report in December, 1995. The main conclusions of the report are summarized below:

- Improved lead-acid and nickel-cadmium batteries will be available in 1998. Automakers do not believe they could market and sell EVs using these technologies to meet the 2 percent ZEV requirement.

- Major development efforts in Europe, Japan, and the U.S. indicate promise to satisfy USABC mid-term goals.

- Prototypes of several advanced battery technologies have been tested in laboratories and on vehicles. Good performance has encouraged further development, investment in manufacturing, and increased interest from automakers in electric vehicle testing.

- The key steps in the next few years are increased production of advanced batteries with improved manufacturing processes, high quality, and good economics, and to permit the evaluation of the performance, reliability, safety, and life of these batteries under realistic vehicle driving conditions.

- Commercial-scale battery production (10,000-40,000 battery packs per year) will begin only after commitments are made from car makers to buy these batteries. Once this decision is made, 2 years will be required to construct the plant and achieve production.

- In a complete success scenario, EVs with commercially available advanced batteries could become available in 2000 or 2001.

- The California ZEV regulation has substantially accelerated the development of advanced batteries. Most developers believe that an orderly, stable program is needed to foster the introduction of EVs with advanced batteries.

Within the Battery Panel report, several battery characteristics were identified as significant in the design and performance of electric vehicles. The report focused on general battery requirements instead of reviewing all the detailed technical characteristics for realizing a successful EV battery candidate. In general, before considering a particular battery electrochemistry for EV application, the technology must meet all pertinent safety requirements associated with all possible vehicle operating conditions. With acceptable safety, the candidate battery must also meet minimal performance levels in terms of energy capacity, power availability, and cycle life. Finally, the candidate battery must meet cost goals, in terms of raw material make-up as well as manufacturing processes, which will allow for acceptable battery pricing to the vehicle manufacturer and ultimate consumer. Once a candidate battery is determined to meet these general requirements, a more thorough assessment of the battery's performance and qualities can be conducted.

4.4.2 BTAP Identified Battery Technologies

The Battery Panel identified likely advanced battery candidates for EV application within the 1998-2003 time frame. After consideration of battery performance characteristics and level of development, several advanced battery technologies were selected. Energy capacity, in terms of specific energy and energy density, is related to EV driving range and was perhaps the most important performance characteristic reviewed. Battery power capability, in terms of specific power and power density, relates to acceleration performance and was also reviewed. The third important performance characteristic reviewed was battery life, measured in charge/discharge cycles as well as calendar life.

The level of development for a particular battery technology was also assessed to consider likely availability in the near future. Prior to realizing high production to achieve acceptable cost levels, battery pack development must complete basic pre-production steps in engineering, quality control, testing, and volume manufacturing. As determined in the Battery Panel findings, only those technologies capable of meeting Mid-Term requirements in performance, cost, and level of development can be considered to have a realistic chance for volume production in support of EV commercialization in the 1998-2003 time frame.

Of the many battery technologies currently under development, the Battery Panel concluded that four advanced technologies had good potential to meet most of the required characteristics necessary to support EV production and sales. The four most promising technologies identified in the final report were nickel-metal hydride (Ni-MH), sodium-sulfur (Na-S), Lithium-Ion (Li-Ion), and sodium-nickel chloride (Na-NiCl). At the time of the final report, these four technologies showed the most promise for meeting the USABC performance goals in the post 2000 timeframe.

4.4.3 Staff Assessment of Current Battery Candidates

With over two years of ongoing battery development since the Battery Panel report, staff believes three of the four technologies, and one additional technology, continue to show the most promise for meeting the goals needed to support EV commercialization. It appears that nickel-metal hydride (Ni-MH), sodium-nickel chloride (Na-NiCl), lithium-ion (Li-Ion), and lithium-polymer (Li-Poly) technologies continue to show the greatest promise for meeting USABC goals for EV application. Currently, Ni-MH is being developed by more companies worldwide than any of the competing advanced battery technologies. Na-NiCl is a high temperature battery (operating at 300 deg C) and offers proven energy capacity and cycle life. The Battery Panel had also determined that sodium-sulfur (Na-S) could be a viable high temperature technology, but the main developers of this technology have since discontinued their work. Because the Battery Panel review occurred at a time when Li-Poly performance data were not yet available to assess its longer term likelihood for success, this technology was not included on their "most promising" list. Since the Battery Report, Li-Poly technology has undergone substantial development and has demonstrated performance characteristics (at the module level) that indicate promise for EV applications. Both Li-Ion and Li-Poly are at an earlier stage of development, but show promise of surpassing the other technologies in some aspects of performance. These four technologies hold the most promise for achieving levels of development sufficient to support ZEV requirements beginning in 2003.

4.5 Current EV Battery Performance

Since the March 1996 Board Hearing, EV battery technology has continued to improve. Some of the battery technologies described in the BTAP report have since progressed from the laboratory stage of development and are now integrated onboard vehicles for field testing. As evaluated by the vehicle manufacturers, candidate batteries must meet minimal performance levels for acceptable EV operation.

Following is a brief review of advanced battery technology improvements over the past two years with respect to energy capacity, power availability, and cycle life. In addition to ultimate battery cost, these three battery characteristics are considered to be the most critical performance figures for assessing battery suitability for EV application.

4.5.1 Battery Energy Capacity

Energy capacity is a measurement of a battery's ability to provide driving range. Given a standard size battery pack, in terms of weight and volume, the higher the energy capacity, the greater the driving range for a given vehicle size. Energy capacity is typically determined by measuring specific energy (Watt-hours per kilogram) and energy density (Watt-hours per liter) under standard test procedures. While the driving range needed to ensure public acceptance of EVs is speculative, the USABC has identified the three criteria levels of energy capacity that battery manufacturers should meet. Table 5, provides a summary of the USABC energy capacity criteria.

Table 5
USABC Goals for Energy Capacity

	Mid-Term	Commercialization	Long-Term
Specific Energy (Whr/kg)	80	150	200
Energy Density (Whr/liter)	135	230	300

Of the four advanced battery technologies expected to become available within the next 5 years, Li-Ion and Na-NiCl currently meet the mid-term goals for specific energy at the battery pack level, while Ni-MH is somewhat behind. Only Li-Poly shows significant promise of meeting the specific energy commercialization goals, but with continued development success Na-NiCl and Li-Ion could achieve around 120 Whr/kg. In terms of energy density (higher values allow for a more compact pack) Ni-MH and Li-Poly are close to the commercialization goal. At present, no battery technology appears to have the level of performance to realize the long-term energy goals by 2003.

Table 6 below provides a summary of the level of progress made in energy storage for the four candidate advanced batteries. These entries represent the best energy performance results within the laboratory from prototype packs (except Li-Poly, for which module values are available). To the best of staff's knowledge, there were no lithium-ion battery packs available in 1996, so there are no entries for that year. Additionally, there is no increase in energy capacity for Na-NiCl because recent efforts have focused on improving power while maintaining energy capability. To date, no Li-Poly battery packs have been evaluated. However, Li-Poly module performance is provided to indicate the current level of reported progress. Li-Poly battery packs are expected to become available in early 1999.

The performance estimates represent technology averages. For Ni-MH, several manufacturers from various countries are developing EV batteries and the performance levels of each specific approach will vary from the figures shown. On the other hand, staff believes Na-NiCl is being developed by primarily one company, AEG. For lithium-based technologies, only Sony has publicly announced their level of performance for full-size Li-Ion EV battery packs.

Table 6
Progress in Advanced Battery Energy Capacity

	1996 Whrs/kg	1998 Whrs/kg	1996 Whrs/liter	1998 Whrs/liter
Ni-MH	60	70	150	200
Na-NiCl	86	86	149	149
Li-Ion	-	90	-	160
Li-Poly[a]	-	155	-	220

[a] At the module level, no battery pack level figures releasable; full battery pack values will be lower.

The four technologies under review are at various stages of demonstration for EV applications. Each of these technologies is, or will soon be, in vehicles and part of demonstration programs in the U.S. and abroad. If advanced battery-powered EVs are offered in 2003 at a reasonable price, with reliable and acceptable performance, the ARB believes they will be a success in the marketplace. ARB will be monitoring the progress closely to determine any action needed to ensure the success of ZEVs in the marketplace.

Perhaps the most visible demonstration vehicles are being evaluated in California. The Honda EV PLUS and the Toyota electric RAV4 both use advanced Ni-MH battery packs. Each is equipped with approximately 30 kWhr packs demonstrating over 60 Whrs/kg. Similar in size and capable of carrying four passengers, these EVs provide a "real world" driving range of 80-100 miles. While this driving range will not satisfy all consumers, average daily driving data suggest this range would satisfy perhaps a majority of California drivers. Given the likelihood of achieving the goal of 80 Whrs/kg by 2003, these same vehicles would offer typical driving ranges of 110-135 miles.

4.5.2 Advanced Battery Power Characteristics

In reviewing the progress made in battery power capacity, the key measurements within the industry are specific power (Watts per kilogram) and power density (Watts per liter). In general, battery power capacity is an indicator of how well a battery can provide an EV with acceleration and hill-climbing performance. As with energy capacity, the USABC has established target criteria for EV battery pack power capacity. Table 7 summarizes the USABC power criteria.

Table 7
USABC Criteria for Power Capacity

	Mid-Term	Commercialization	Long-Term
Specific Power (W/kg)	150	300	400
Power Density (W/liter)	250	460	600

Table 8 provides a general summary of the progress made by the four candidate advanced battery technologies in power capacity. Except for Li-Poly, to the best of staff's knowledge these values represent performance levels for full-size battery packs under standard USABC test procedures. As can be seen in Table 8, USABC Mid-Term goals have already been met by all technologies. The numbers shown are for power at 20 percent battery State-of-Charge (SOC), or 80 percent Depth-of-Discharge (DOD). In general, batteries exhibit a loss of power as the SOC is reduced. By evaluating power at the lower SOC, manufacturers can be certain that EV performance will not diminish as battery pack SOC is reduced.

Table 8
Progress in Battery Pack Power Capacity

	1996 W/kg	**1998 W/kg**	**1996 W/liter**	**1998 W/liter**
Ni-MH	180	230	250	400
Na-NiCl	76	150	130	256
Li-Ion	-	300	-	300
Li-Poly[a]	-	315	-	450

[a] At the module level, no battery pack level figures releasable

From initial customer feedback in the cases of the Honda EV PLUS and the Toyota RAV4 EVs, it appears they are providing satisfactory acceleration, hill-climbing, and generally good performance under normal driving conditions. Under ARB test programs, both of these vehicles exhibited consistent acceleration performance at various battery pack SOCs. Typically, these vehicles offer 0-50 mph acceleration in 14 seconds and 0-60 mph acceleration in 18 seconds.

4.5.3 Advanced Battery Cycle Life Performance

Battery useful life is also an important characteristic for EV applications. The USABC evaluates two components of battery life - calender life and cycle life. Calender life refers generally to a battery technology's ability to maintain its usefulness over a length of time, typically in calender years. Calender life does not necessarily mean the battery pack is not used, or remains idle. However, if not in use over a period less than a specified calender life, the battery pack should provide the performance characteristics close to those exhibited prior to storage. In general, cycle life is a measure of the useful life for a battery in terms of total available energy and number of possible charge/discharge cycles before reaching End-of-Life conditions. The USABC has established several discharge and charge test procedures as well as standard conditions for the measurement of battery cycle life. The ideal candidate battery would offer a high enough cycle life to offset any initial high cost to the EV manufacturer and consumer. In Table 9 below are the three USABC criteria levels for EV battery life performance goals.

Table 9
USABC Life Cycle Criteria

	Mid-Term	Commercialization	Long-Term
Calender Life	5 years	10 years	10 years
Cycle Life	600 @ 80% DOD	1000 @ 80% DOD	1000 @ 80% DOD

The characteristic of battery life is not only important to minimize battery replacement intervals for EV consumers. Battery cycle life is also critical in determining the actual cost of maintaining an EV. For example, an EV battery providing 1,000 charge/discharge cycles with each cycle providing 100 miles could offer up to 100,000 miles of useful life. If, however, a battery pack offers only 500 cycles with each cycle providing 50 miles of driving, a total useful life of only 25,000 miles is realized. If 10,000 miles are driven each year for both examples (assume 50 miles driven per day for 200 days), one battery would last ten years versus two and one-half years for the other. Given that a new battery pack would likely cost the consumer several thousand dollars, a longer life battery pack is necessary. Table 10 provides a brief summary of the general progress made in battery life for three of the four candidate advanced battery technologies.

Table 10 Progress in Calendar and Cycle Life for Advanced Batteries				
	1996 Calender Life	**1998 Calender Life**	**1996 Cycle Life**	**1998 Cycle Life**
Ni-MH	> 5 years	> 5 years	250	500-1000
Na-NiCl	> 5 years	> 5 years	500	> 800
Li-Ion	-	> 5 years[a]	-	1000

[a] Current Li-Ion designs may only achieve 3 years based on recent data.

Thus, at least two of the candidate technologies shown should meet the Mid-Term goal for calender life and all should achieve the cycle life goal. Li-Poly life characteristics are not provided because no data are available at the module or pack levels for the latest designs. It should also be noted that while these performance figures are for full-sized battery packs, each of these technologies demonstrates considerably higher cycle life at the cell and module levels. This is an important point when one considers the prospects for future improvements. Considerable work has begun in the past two years to better manage some battery packs through monitoring and control of each individual module. By compensating for differences in temperature, quality, age, charge/discharge acceptance, and other factors between each of the modules (where applicable), studies have shown that a better pack balance is realized. Through the use of "active" battery management, cycle life is expected to improve further.

4.5.4 Other Battery Considerations

Because some of these technologies have been integrated into vehicles and ARB has acquired some experience with operating and testing these advanced technologies, staff believes it is important to review a few other key battery characteristics. Since overall energy use of electric vehicles is directly related to electricity generation and power plant emissions, it is important that a candidate EV battery technology minimize energy losses and maximize efficiency. For Ni-MH battery systems, thermal management energy use, self-discharge losses, and overall battery efficiency are important characteristics to consider. Similarly, for Na-NiCl battery systems, thermal management energy use, off-tether energy losses, and battery efficiency are of particular interest. As ARB staff gains experience with Li-Ion and Li-Poly battery EVs, it appears that these characteristics will also be of considerable importance.

Some of the early Ni-MH battery packs demonstrated high self-discharge losses and the need for considerable thermal management control. Self-discharge is a measurement of the characteristic for a battery to lose some stored energy without performing useful work over a specific time period under standard conditions. For example, the USABC Mid-Term goal for self-discharge is less than 15 percent of total energy for a fully charged battery pack over a 48-hour period. The USABC Long-Term self-discharge goal is less than 15 percent in 30 days. Thermal management systems are typically required by all battery technologies, including Ni-MH. Because any given battery technology operates at optimal performance only when its temperature is maintained within a certain range, thermal management systems are required to ensure peak performance and achieve expected battery life. Some technologies, such as lead-acid, typically require minimal thermal management. For Ni-MH, thermal management control may be needed during high ambient temperature (above 100 degrees F), during high power demands for acceleration or hill-climbing, or during charging activities (immediately following a discharge cycle or during end of charge). Thermal management includes heating and cooling systems with varying energy demands and utilize either air, liquid, or other cooling mediums. Because excessive thermal management consumes useful energy, either from the battery itself or from the wall plug, it may significantly impact the total energy and emission benefits of EVs.

Current Ni-MH designs now exhibit fairly low self-discharge losses due to improvements in battery design and system control. Current Ni-MH self-discharge losses measured at ARB are approximately five percent over a 48 hour period. This compares favorably relative to Ni-MH technology in 1995, which exhibited self-discharge losses on the order of 15 percent over the same period. It must be noted that the majority of self-discharge losses for Ni-MH occur in the first 48 hours after charge completion with only minimal losses observed after two days. In the area of thermal management, Ni-MH has also exhibited improvement over the past two years. In measuring thermal management energy requirements, ARB measured total recharge energy, including thermal management losses, over several days of testing. On average, earlier Ni-MH EVs required as much as three kilowatt-hours (kWhrs) of additional energy for thermal management per day under standard vehicle test conditions. For today's Ni-MH EVS, ARB testing indicates a typical need for less than 0.5 kWhrs of thermal energy per day.

As a high temperature battery, the Na-NiCl technology requires that its internal temperature be maintained at approximately 315 degrees C (600 degrees F) in order to operate in an EV application. When not in use, the Na-NiCl technology typically requires being plugged into a wall plug, or tethered, in order to be ready for use when needed. The AEG ZEBRA technology has been evaluated at the ARB and some measurements have been made on the additional energy required to maintain the battery at the required elevated temperature. Of particular importance is the amount of AC wall plug energy required for the Na-NiCl battery pack when not in use over a given period of time. Fortunately, if additional energy from a wall plug is not provided over an extended period of time and the battery pack is allowed to shutdown, or "freeze," the pack will not be damaged. If shut down, a reheating process must be initiated that typically requires about one to two days to bring the battery pack up to temperature and fully charge the battery. This reheating time can vary depending on the battery SOC at the time of shutdown, battery temperature, and available power used for reheating. If shutdown of the battery is desired, three to four days are typically required for a fully charged battery to lose significant heat with the battery disconnected from the wall plug.

The effects of thermal management energy requirements for the ZEBRA technology depend largely on the use patterns of the EV. If the EV is used on a daily basis, the amount of additional energy required to maintain battery temperature is minimized. For example, if a ZEBRA-powered EV is driven as a commute vehicle for one hour in the morning and one hour in the late afternoon, followed by overnight charging, the additional energy required for thermal management is less than 1.5 kWhrs per day. If the EV is driven more, this energy requirement is further reduced. The reason for this is that while the Na-NiCl battery operates, it also generates heat that increases its internal temperature. Therefore, after some operation the Na-NiCl battery is typically at the upper limit of its operating temperature range with additional latent heat stored internally. Several hours of nonoperation are needed before external energy, or heat, is needed to maintain a minimal internal temperature. On the other hand, if the ZEBRA-powered EV is left on charge (on-tether) over multiple days, approximately 3.0 kWhrs of AC wall plug energy would be required per day to maintain battery temperature. If this vehicle were not required to be operated for a long period of time, over a two week period or more, it would make sense to shut down the battery until it was needed again. Given these Na-NiCl characteristics, staff believes this technology best serves consumers with high daily use requirements. Discussions with AEG representatives indicate further improvements continue to be made, such as improved insulation materials, which will be incorporated in future ZEBRA batteries to further reduce thermal energy consumption. AEG expects up to a 50 percent reduction in total thermal management energy needs prior to 2003.

While thermal management needs for the high temperature ZEBRA technology are not ideal for EV applications, there are some positive characteristics this technology has demonstrated when compared to ambient temperature battery systems. Because the Na-NiCl battery operates at above 300 degrees C, there are no detrimental effects resulting from use at extreme cold or hot ambient temperatures. For more conventional battery systems, extreme temperatures require more elaborate thermal management or result in reduced battery performance. Additionally, because a ZEBRA battery pack includes all of the necessary cells within the pack as well as all of the monitoring systems and control logic, there is no need for additional compensation circuitry to control a given number of modules. Whereas other technologies must carefully protect against excessive variations between individual modules within a battery pack, the ZEBRA technology does not have this concern. The ZEBRA system also includes the necessary charging logic and control to offer over 90 percent charging efficiency. Most other technologies require an additional charging system at an additional cost. Finally, because of its high temperature operation, Na-NiCl allows for the use of latent heat for fast cabin heating or window defrosting. Up to three kWhrs of additional energy is available from the ZEBRA battery after being fully charged and unplugged from the wall plug. This additional latent heat would be particularly useful for cold climate operation. In all, staff has observed that the ZEBRA technology offers many additional benefits for EV application despite its drawback of operating at a higher temperature. Also, while previous cell designs have demonstrated long life, the new high power cell design is now undergoing life cycle testing to confirm similar results

Overall, advanced battery development for each of the four technologies has been steadily progressing. Staff discussions with battery manufacturers and other experts have provided ARB with valuable information and have allowed staff to project possible advanced battery performance characteristics for the year 2003. If manufacturer development and cost goals are met, 2003 battery technology will have improved significantly relative to 1998 performance. With sustained EV battery development, performance levels identified in Table 11 could be possible by 2003.

Table 11 Staff Estimates of 2003 Battery Performance Characteristics								
	Ni-MH		Na-NiCl		Li-Ion		Li-Poly	
	1998	2003	1998	2003	1998	2003	1998	2003
Energy (Wh/kg)	70	80	86	100	90	120	-	150
Power (W/kg)	230	300	150	200	300	300	-	315
Cycle Life	500-1000	1000	800	1000	1000[a]	1000	-	< 1000

[a] Calendar life is of concern (current test data indicate 2-3 years)

4.6 Battery Availability and Cost

Staff developed availability and cost estimates for the four candidate battery technologies based on discussions with battery manufacturers and available public information. As a starting point, the Battery Panel report provided estimates of battery availability and cost data as a result of direct communications with manufacturers. Although staff was unable to visit each of the battery manufacturer facilities, staff participates in Technical Advisory Committee meetings of the USABC and visited with some advanced battery developers in order to gain a reasonable assessment of advanced battery availability and cost in the 2003 timeframe.

4.6.1 1995 BTAP Battery Availability Estimates

The Battery Panel in its 1995 report outlined a general, yet widely accepted, EV battery development schedule. This schedule includes five phases that would likely require nine years for developing a battery system from a “cell level” concept to qualified production status. Table 12 below is a summary version of the Battery Panel table on EV battery development (Table II-3, page II-6). A more complete explanation of each of the battery development phases is provided in the Battery Report.

Table 12 EV Battery Development (from BTAP Report)					
Program Year	**0------ 1 -----**	**2------ 3 -----**	**4------ 5 -----**	**6------ 7 -----**	**8------ 9 -----**
Phase	**Cell Development**	**Prototype**	**Prototype -> Pilot**	**Pilot**	**Production**
Focus	**Cell Development**	**Battery Development**	**Pilot Plant Operation**	**Test Pilot Batteries, Design Production Plant**	**Production Plant Construction**
Key Milestones	**Freeze cell design at 2 years**	**Commit to pilot plant investment at 4 years**	**Complete pilot plant at 5 years**	**Commit to production plant investment at 7 years**	**Production plant qualified at 9 years**

Although Table 12 only provides general guidelines for battery development, staff believes it offers a reasonable tool to measure the current level of progress in the development of the four candidate batteries as well as a good estimate of the development status for these technologies for the 2003 time frame. Using the above schedule, the Battery Panel estimated the status of each of the candidate advanced batteries as of December 1995. At that time, the Panel reported that Ni-MH technology was between the third and fifth year of development, or about the start of building and operating a pilot plant. The program status for Na-NiCl was also placed at about the start of the fourth year, or committed to a pilot plant. Li-Ion and Li-Poly were determined by the Panel to be further behind. While Li-Ion was considered to be at the second phase of building prototype modules and batteries, the Panel believed Li-Poly was still at the cell development phase. Table 13 provides a review of the Panel's estimate of battery availability for the four candidate technologies (from Table. III-3 of BTAP Report, page III-47).

Table 13
Battery Panel's Estimate of Battery Availability

Technology	Pilot Production (hundreds/year)	Production (10,000-40,000/year)
Ni-MH	1996-97	1999-2001
Na-NiCl	1996-97	2000
Li-Ion	1998-2001	2001-02
Li-Poly	1999	2002

4.6.2 Projections for Advanced Battery Availability

With two years having passed since the Battery Report was released, there has been significant progress in the development of the four candidate battery technologies. For Ni-MH technology, two vehicle manufacturers have already introduced small fleets of EVs, mostly in California, while three additional manufacturers are expected to introduce Ni-MH EVs by the end of 1998. Honda first introduced the EV PLUS in the Spring of 1997. Then, Toyota began delivery of their RAV4 EV in the Winter of 1997. GM and Ford are expected to introduce Ni-MH versions of their currently available lead-acid models and Chrysler will soon introduce their Ni-MH-powered EPIC Minivan. As for Na-NiCl, AEG has recently initiated pilot production of their ZEBRA battery packs with improved power capability. Depending on negotiations with various vehicle manufacturers, AEG has informed staff that production levels of 7,500-30,000 battery packs per year could be realized as early as 2001. For the Li-Ion technology, Nissan and Sony announced the introduction of the Nissan Altra EV powered by a Sony Li-Ion battery pack. The Li-Ion powered EV is scheduled to be introduced in California by the end of 1998. Finally, the USABC announced in December, 1997, that the 3M-Hydro-Quebec Li-Poly technology showed promise at the module level to meet the USABC commercialization goals and that full-size battery packs for initial evaluation are expected to be delivered in early 1999.

Given the current status of these advanced batteries and using the BTAP EV battery development time line, Table 14 below is staff's best estimate of the development levels for the four candidate technologies for 2003.

Table 14
Staff Estimates of 2003 Advanced Battery Development Status

Technology	2003 Potential Status	Status Highlights
Ni-MH	Production	Production of 20-100K batteries per year. Life and performance qualified and full warranty provided.
Na-NiCl	Production	Production capability of up to 30K batteries per year. Life and performance qualified and full warranty provided.
Li-Ion	Pilot Production	Several thousand fully qualified batteries per year. Production plant construction initiated.
Li-Poly	Pilot Production	Hundreds of battery packs under vehicle evaluation. Pilot plant capable of production levels of 2-5K per year. Decision to be made on full production.

In comparing Tables 13 and 14, current staff estimates are more conservative than the acknowledged optimistic ones offered by the Battery Panel in December, 1995. In particular, Li-Ion and Li-Poly technologies are presently not expected to reach full production status by the 2002 model year. However, if progress continues with both lithium-based technologies, staff believes the original BTAP estimates of realizing a 2002 production status are still possible.

4.6.3 Advanced Battery Cost

Assessing the progress in battery cost and estimating cost to the vehicle manufacturer is not a straightforward process. As with the Battery Panel report, a detailed examination of battery cost is beyond the scope of this technology update. However, staff is able to provide some general analysis of future cost scenarios using a number of resources from battery and manufacturing industries. Information directly from battery developers was the primary source of cost estimates for the Battery Panel as well as for this staff review.

Fortunately, working with the USABC, staff was able to more closely examine advanced battery technology cost methodologies and determine the likelihood of meeting developer cost objectives. Table 15 presents the USABC goals for EV battery cost. For the staff's analysis, as with the Battery Report and the USABC, battery cost is defined as the cost paid by the vehicle manufacturer to the battery manufacturer.

Table 15 USABC Goals for EV Battery Cost and Derived Life Cycle Cost			
	Mid-Term	**Commercialization**	**Long-Term**
Price ($/kWhr)	**< 150**	**< 150**	**< 100**
Cycle Life (to 80% DOD)	**600**	**1000**	**1000**
Life Cycle Cost (¢/kWhr-cycle)	**25**	**15**	**10**

Included in Table 15 are derived life cycle costs, defined as cents per kilowatt-hour-cycle (¢/kWhr-cycle). The use of life cycle cost is important because it includes the two major components of EV battery replacement cost - initial cost and useful life. For example, some lead-acid batteries are currently available at a cost of approximately $150/kWhr and offer a cycle life of about 200 cycles. Using these numbers, this lead-acid example results in a life cycle cost of 75 ¢/kWhr-cycle. Similarly, an advanced battery, for example a Ni-MH battery available in 2001, may cost $300/kWhr and offer a 900 cycle life. The hypothetical Ni-MH battery option would have a life cycle cost of 33 ¢/kWhr-cycle. Taking this scenario further, the lead-acid powered EV uses a 400 kg battery pack (costing $1,800) and provides about a 50 mile driving range per charge. The Ni-MH EV also has a 400 kg battery pack (costing $8,400) and offers a 120 mile range. Assuming each vehicle is driven 10,000 miles per year, the lead-acid pack would require one replacement per year (50 miles x 200 cycles = 10,000 miles). The Ni-MH pack would require replacement about once every ten years (120 miles x 900 cycles = 108,000 miles). In this example, the annualized replacement cost would be $1,800 for the lead-acid option and $840 for the Ni-MH option.

Table 16 includes the reported cost estimates and availability of advanced batteries as presented in the Battery Report (from Table. III-4 of the BTAP report, page III-48). Considerable variance in production cost estimates exists for all four candidate battery technologies. Most of this variability is attributed to the actual level of battery production volumes. While material cost and manufacturing processes also play a role in battery price determination, battery demand, or more precisely, battery purchase orders, play the most significant role in final product pricing.

Keep in mind that in providing these cost estimates staff is not including an analysis of cycle life and its relationship to battery life cycle cost. As discussed earlier, initial battery cost may be high, but when a battery technology exhibits a relatively high cycle life, the initial purchase cost is partially offset by longer battery life. The use of long life EV batteries could be greatly enhanced with the implementation of creative purchase and leasing agreements based on the expected durability of the better advanced battery technologies.

Table 16 Earliest Availability and Prospective Cost (from BTAP)				
	Pilot Scale (hundreds per year)		Production Scale (10,000-40,000 per year)	
Battery Type	**Year**	**$/kWhr**	**Year**	**$/kWhr**
Ni-MH	1996-97	450-550[a]	1999-01	250[b]-350 (→150[c])
Na-NiCl	1996-97	1,000-3,000	2000	345→230 (→175[d])
Li-Ion	1998-01	1,000-3,000	2001-02	≤ 200[e] (→150-180)[f]
Li-Poly	1999	750-1,500	2002	175[g] (125)

[a] For learned-out pilot production of 2,000 batteries/year (GM-Ovonic)
[b] For mature production from ~20,000 batteries/year plant (2001)
[c] For advanced technology, mature production from ~20,000 batteries/year plant (GM-O)
[d] For mature production from ≥ 100,000 batteries/year plant
[e] Preliminary estimates for mature production from ~20,000 batteries/year plant
[f] Ultimate potential estimated for large volume production
[g] For mature production from 20,000 batteries/year plant (2004)

For the four candidate battery technologies, Table 17 provides staff estimates of potential advanced battery cost, cycle life, and life cycle cost for 2003. Table 17 estimates require that considerable progress be made by the developers and manufacturers of the four candidate technologies. The cost estimates are especially significant given the current high cost of these technologies. However, these cost estimates rely largely on production volumes that require orders from vehicle manufacturers. In order to achieve the cost estimates identified in Table 17, battery manufacturers require purchase orders to support annual production levels in excess of 20,000 batteries per year. If high production volumes are realized, life cycle cost estimates could achieve levels near the USABC Mid-Term goals.

Table 17 Staff Estimates for 2003 Advanced Battery Costs to Manufacturers			
Battery	**Price ($/kWhr)**	**Cycle Life**	**Life Cycle Cost (¢/kWhr-cycle)**
Ni-MH	250	1,000	25
Na-NiCl	250	1,000	25
Li-Ion	300	1,000[a]	30
Li-Poly	< 250	< 1,000	> 25

[a] Calendar life may be an issue.

4.7 Additional Comments

The development and commercialization of electric vehicles and advanced batteries are likely to benefit other industries in addition to pure battery-powered ZEVs . In the automotive field, hybrid electric vehicles, or HEVs, also utilize battery packs in order to offer limited electric range and/or improved emissions and fuel economy in combination with some form of heat engine, or auxiliary power unit (APU). In a series HEV, a larger battery pack with high energy density is typically used to offer more all-electric driving range. In a parallel HEV, a smaller battery pack with high power density is typically used to combine with the APU to provide additional power under acceleration, hill-climbing, and other high power driving scenarios. In both series and parallel HEV designs, the battery pack is also typically used to recapture regenerative braking energy. Should interest in HEVs support significant production levels of these vehicles, demand for battery packs would likely benefit the production of pure EV batteries and reduce overall battery production costs.

Fuel cell vehicles may also benefit from EV and battery development. With the increased investment worldwide in fuel cell vehicle development, EV and battery technology offers many benefits to reduce potential risks for fuel cell vehicles. Since fuel cell vehicles require the use of electric motors and electronic controls, current EV systems, minus the battery pack, could also be used with fuel cell systems. Fuel cell vehicles could also utilize advanced batteries to reduce high operational demands of the fuel cell. As with some HEVs, batteries could provide the energy requirements for vehicle start-up, acceleration demands, and hill-climbing needs for a fuel cell vehicle. This type of fuel cell hybrid vehicle has already been demonstrated at the prototype level by Toyota. Thus, the technologies being developed for battery-powered EVs should benefit the fuel cell vehicle industry, and vice versa.

Improvements in advanced battery energy and power storage capabilities are also opening up opportunities for other applications. Portable equipment, such as lawnmowers, golf carts, portable energy storage systems, and more, appear to offer a considerable market for advanced batteries. Electric scooters and smaller neighborhood electric vehicles, or NEVs, may also develop into markets, with potential to achieve significant annual production volumes. To the extent these new technologies achieve sizeable market levels, EV battery availability and cost should become more favorable in supporting EV production and consumer EV cost.

4.8 Conclusions

At this point in time, Ni-MH batteries provide good overall performance and are fairly space efficient in terms of packaging. Areas needing improvement are battery cost (but due to the high cost of materials, significant improvements are unlikely) and improved specific energy to permit a lighter battery pack weight for improved vehicle range and dynamic handling.

Li-Ion batteries provide fairly high driving range for their weight, but calendar life is currently too short, and achieving acceptable safety will increase cost and weight. Cost is also high due in large part to the use of relatively expensive materials in the best performing designs. However, work is underway to reduce the material cost of Li-Ion batteries.

The Na-NiCl battery is overall a very good performer with potential for relatively low cost in high production volumes since material costs are relatively low for this design, and manufacturing costs can be brought down as volume and learning increase. Its only real drawback is its high temperature operation that requires it to be connected to a power outlet most of the time and the associated energy costs with maintaining battery temperature.

Li-Poly offers the promise of high energy capacity with little associated weight and again the potential for low cost because of low material costs and availability of efficient manufacturing processes. Safety is also good. At this time, cycle life still needs improvement and battery pack system development needs to be completed and optimized. This battery may eventually be a very good performer.

Thus, over the last two years battery development efforts and cost reduction programs have made steady gains. Staff expects these improvements to continue, and will revisit further progress in 2000 as the next milestone toward implementation of the 2003 ZEV requirement.

5.0 REFERENCES

Some information for this staff report was derived from the following confidential documents:

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