State of California
California Environmental Protection Agency

AIR RESOURCES BOARD

STAFF REPORT

LOW-EMISSION VEHICLE AND ZERO-EMISSION VEHICLE PROGRAM REVIEW

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I. OVERVIEW

A. Introduction

In September 1990, the Air Resources Board (ARB or "Board") adopted the Low-Emission Vehicle and Clean Fuels regulations. These regulations require automobile manufacturers to introduce progressively cleaner light- and medium-duty vehicles with more durable emission controls. The regulations established stringent emission standards for four new classes of light- and medium-duty vehicles. Also, for the first time, an increasingly stringent annual fleet average emission requirement was established to provide a flexible mechanism for phasing-in low-emission vehicles. In order of increasing stringency, the new classes of vehicles are: transitional-low-emission vehicles (TLEVs), low-emission vehicles (LEVs), ultra-low-emission vehicles (ULEVs), and zero-emission vehicles (ZEVs). Auto manufacturers may produce any combination of TLEVs, LEVs, ULEVs, and ZEVs as long as the fleet average requirement is met. However, beginning in 2003, 10 percent of the largest manufacturers' light-duty vehicle fleets must be comprised of ZEVs. At this time, electric or fuel cell vehicles are most likely to meet the ZEV requirement.

Because of the long-term nature and technological challenges presented by the Low-Emission Vehicle regulations, the Board directed staff to provide an update at least biennially on the status of implementation of the regulations and to propose any appropriate modifications. Since adoption of the Low-Emission Vehicle regulations in 1990, there have been three subsequent program implementation updates (June 1992, May 1994, and October-December 1995). At the last update in October-December 1995 only the ZEV requirement was reviewed because of impending production decision timing constraints. The regulations have also been modified several times, most recently at the March 1996 hearing when the Board approved regulatory modifications to eliminate the 1998 through 2002 model year percentage ZEV requirements while maintaining the 2003 and subsequent requirements.

B. Background

Despite considerable improvement, California continues to experience the worst air pollution in the United States. Five of the seven worst areas for ozone in the United States are located in California. Although there has been substantial progress in reducing air pollution, many areas of California still fail to meet federal and state ambient air quality standards. Increases in the state's population, the number of miles motorists travel, and the increasing number of vehicle trips significantly contribute to California's air quality problem. Atmospheric modeling shows that for California to meet ambient air quality standards, and thus provide its citizens with healthful air, emissions from mobile sources must be reduced to near-zero levels.

A major component of California's plan to reduce mobile source emissions is the Low-Emission Vehicle program. This program, which was adopted in 1990, requires vehicle manufacturers to phase-in progressively cleaner light- and medium-duty vehicles, culminating in the introduction of ZEVs.

The program applies to light- and medium-duty vehicles. The four emission standard categories and the 50,000 mile emission standards applicable for passenger car and light-duty trucks less than 3751 pounds are shown in Table I-1.

Table I-1

Low-Emission Vehicle Emission Standards (grams/mile)			
Category	non-methane organic gases (NMOG)	carbon monoxide (CO)	oxides of nitrogen (NOx)
TLEV	0.125	3.4	0.4
LEV	0.075	3.4	0.2
ULEV	0.040	1.7	0.2
ZEV	0	0	0

Provisions are also included in the regulations that provide considerable compliance flexibility to the manufacturers. Instead of requiring the phase-in of a fixed percentage of low-emission vehicle categories at specified times, the LEV program relies on a categorized fleet averaging system. This allows vehicle manufacturers to meet the program requirements with any combination of vehicles certified to any of the low-emission vehicle categories, as long as they meet the overall fleet average requirement. For light-duty vehicles, the fleet average requirements begin in 1994 and decline each year through 2003. The fleet average schedule for passenger cars and light-duty trucks less than 3751 pounds is shown in Table I-2. The only instance where implementation of a specific category is required is the introduction of zero-emission vehicles in 2003.

Since adoption of the Low-Emission Vehicle regulations in 1990, emission control technologies have continued to evolve rapidly and will be less complex than the staff's initial projections. This is because both emission performance and durability of some familiar emission controls have significantly improved. In the years since 1993 when the first TLEVs were introduced, the number of vehicles certified to the TLEV standards has continued to increase. In the 1996 model year, TLEVs consisted of over 26% of the new light-duty vehicles certified for sale in California and will be a higher percentage of new vehicles in 1997. In meeting these stringent standards, the TLEVs did not require the use of new, sophisticated emission controls as some had predicted. Instead, refinements of Tier I technologies that have been utilized for years on some vehicles were employed. The more stringent LEV requirements are expected to be met with additional refinements to technology approaches that are already well known and are also being introduced on schedule. For the 1997 model year, six LEV engine families have already been certified and more are expected to be certified by the end of the model year.

Table I-2

Fleet Average Requirements for Passenger Cars and Light-duty Trucks (0-3750 pounds loaded vehicle weight) (grams/mile)	
Model Year	Fleet Average NMOG
1994	0.250
1995	0.231
1996	0.225
1997	0.202
1998	0.157
1999	0.113
2000	0.073
2001	0.070
2002	0.068
2003 and subsequent	0.062

C. Conclusions and Recommendations

The ARB staff has found that the technologies needed to comply with the Low-Emission Vehicle program are available and being utilized on many current vehicles. Vehicle manufacturers have successfully introduced numerous TLEVs in the past several years and are currently introducing LEVs. Many of the basic emission control approaches incorporated by these low-emission vehicles have been utilized on new vehicles for several years to meet less stringent emission standards. The most significant improvements have been to traditional catalysts, which now warm up very rapidly and are substantially more durable than past technology, and to fuel control, which is much more precise and accurate than previous systems. Although some of the more difficult to control vehicles may need additional advanced emission control technologies to meet the stringent ULEV requirements, it is projected that the lead-time available will allow manufacturers to successfully develop and implement new technologies on schedule. Based on the successful implementation of low-emission vehicles to date and the progress of emission control development, the ARB staff believes that the Low-Emission Vehicle program is progressing on schedule and that no changes to the program's implementation schedule are currently needed.

II. LOW-EMISSION VEHICLE PROGRAM UPDATE

A. Technology Assessment

When the Low-Emission Vehicle regulations were first adopted in September, 1990, ARB staff projected that gasoline vehicles meeting the more stringent standards (i.e., the LEV and ULEV emission standards) would require the use of emerging new technologies such as electrically-heated catalysts (EHCs) and heated fuel preparation systems. Staff had also believed that alternative-fueled vehicles would have an increasing presence in the light-duty vehicle fleet as the emission standards became more stringent. However, in the six years since these initial projections, it seems that the staff's original projections were overly conservative. Low-emission vehicles are being introduced generally with refinements of existing technology and it appears that few vehicles will require the use of completely new technologies or other "add-on" components. Ford, Geo, Honda, Nissan, and Toyota are some of the manufacturers which will have gasoline LEVs available for the 1997 model-year. None of these vehicles utilizes technology that is much different from the previous year's model.

Although alternative-fueled vehicles have been certified to the LEV and ULEV standards, it appears that gasoline vehicles will continue to dominate the light-duty vehicle fleet since gasoline vehicles can be built to meet these standards at a lower cost. Alternative-fueled vehicles, such as those powered by compressed natural gas (CNG), however, are expected to show a more significant presence in the medium-duty vehicle sector (i.e., trucks and vans) because of the potential life-cycle cost (e.g., fuel and vehicle maintenance costs) savings these vehicles may provide over gasoline vehicles coupled with energy policy requirements and low emission incentives which may apply to some fleets.

Since gasoline vehicles are projected to be the dominant vehicle type in the light-and medium-duty vehicle sector, the remainder of this report will focus on the emission control technologies of gasoline vehicles and their associated costs.

1. Emission Control Technology

While reducing emission levels of current vehicles can be achieved through various means, there are four basic aspects of current emission control systems that vehicle manufacturers have been improving to achieve low-emission levels. These are more precise fuel control, better fuel atomization and delivery, improved catalytic converter performance and reduced base engine-out emission levels.

The following descriptions provide a more detailed overview of the technologies needed to meet the most stringent low-emission vehicle standards. With the exception of a few technologies such as EHCs, all of these technologies are already in use in many current model-year vehicles. Manufacturers are expected to take existing control systems and improve various components to comply with the requirements. The projected emission control technologies for low-emission vehicles are listed in Table II-1a. It is important to note that low-emission vehicles will not require the use of all of these technologies. The list just provides the current projections of potential low-emission technologies. The choices and combinations of low-emission technologies that will ultimately be utilized by vehicle manufacturers are dependent on the current engine-out emission levels of the vehicle, the effectiveness of the existing emission control system, and individual manufacturer preferences.

Table II-1a

Low-Emission Vehicle Technologies	
Dual Oxygen Sensors	Engine Calibration Techniques
Universal Exhaust Gas Oxygen Sensors	Leak-Free Exhaust Systems
Individual Cylinder Air-Fuel Control	Increased Catalyst Loading
Adaptive Fuel Control Systems	Improved High-Temperature Washcoats
Electronic Throttle Control Systems	Electrically-Heated Catalysts
Reduced Combustion Chamber Crevice Volumes	Electric Air Injection
Sequential Multi-Point Fuel Injection	Full Electronic Exhaust Gas Recirculation
Air-Assisted Fuel Injectors	Hydrocarbon Adsorber Systems
Improved Induction Systems	Engine Designs to Reduce Oil Consumption
Close-Coupled Catalysts	
Heat-Optimized Exhaust Pipes	

Technologies for Improving Fuel Control

a. Dual Oxygen Sensors

Maintaining the air-fuel ratio (A/F) at stoichiometric (where the amount of air is just sufficient to completely combust all of the fuel) is an important factor in achieving lowest engine emissions. In order for the emission control system to operate most efficiently, the A/F must remain within a very narrow range (less than 1% deviation) around stoichiometric. Modern vehicles have traditionally performed fuel control with a single oxygen sensor (O2S) feedback system. While this fuel control system is capable of maintaining the A/F with the required accuracy under steady-state operating conditions, the system accuracy is challenged under rapidly changing throttle conditions and is reduced as the sensor ages. Therefore, to improve fuel control and in-use emission performance at high mileage, most low-emission vehicles are expected to incorporate improved control algorithms combined with dual-oxygen sensors.

Since an O2S may not perform as accurately when it has aged, a second O2S placed downstream of one or more catalysts in the exhaust system can be used to monitor and adjust for deterioration of the front, primary sensor, thereby maintaining precise fuel control. Should the front O2S, which operates in a higher temperature environment, begin to exhibit slow response or drift in its calibration point, the secondary O2S is relied upon for modifying the fuel system controls to compensate for these aging effects. By placing the second sensor further downstream from the hot engine exhaust where it is also less susceptible to poisons, the rear sensor would not be likely to age significantly over the life of the vehicle. In this way, a dual O2S system would maintain good fuel control -- and attendant low emissions -- as a vehicle ages. Because of their effectiveness, most current model year gasoline powered light-duty vehicles now utilize dual oxygen sensors for fuel control. Manufacturers have also elected to use dual oxygen sensors on all new vehicles to accomplish the catalyst monitoring requirement of California's On-Board Diagnostic II regulation.

b. Universal Exhaust Gas Oxygen Sensors (UEGOs)

Vehicles that employ lean A/F control strategies (i.e., use less fuel than required to achieve a stoichiometric ratio) may utilize one or more UEGOs for fuel control in lieu of conventional oxygen sensors. This is because conventional oxygen sensors cannot accurately measure A/Fs other than stoichiometric. Conventional oxygen sensors are "limit" switches in that they can only determine that the engine's A/F is higher or lower than stoichiometric; they do not have the capability of recognizing specific A/Fs. In contrast, UEGOs are capable of recognizing a wide-range of A/F since the voltage output of the UEGO is "linear" (i.e., each voltage value corresponds to a certain A/F). Therefore, maintaining a lean A/F is attainable with the use of UEGO sensors. Since operating lean of stoichiometric during cold-start situations can assist the heating of the catalysts, an increasing number of low-emission vehicles will be expected to incorporate these sensors. In addition to their capability of maintaining a tight lean A/F, some manufacturers claim UEGOs will also allow the fuel control system to maintain a tighter band around stoichiometric. In this way, UEGOs will assist vehicles in achieving very precise control of the A/F. It is projected that some ULEVs and a small percentage of LEVs will rely on the use of UEGOs.

c. Individual Cylinder A/F Control

In order to further improve fuel control, some ULEVs are expected to utilize software algorithms to perform individual cylinder fuel control. While dual O2S systems are capable of maintaining A/F ratios within a narrow range, some vehicle manufacturers believe that even more precise control will be needed for ULEVs and are developing individual cylinder control systems. On current vehicles, fuel control is modified whenever the O2S determines that the combined A/F of all cylinders in the engine or engine bank is “too far” from stoichiometric. The needed fuel modifications (i.e., inject more or less fuel) are then applied to all cylinders simultaneously. Although this fuel control method will maintain the "bulk" A/F for the entire engine or engine bank around stoichiometric, it would not be capable of correcting for individual cylinder A/F deviations that can result from differences in manufacturing tolerances, wear of injectors, or other factors. With individual cylinder fuel control, A/F variation among cylinders will be diminished, thereby further improving the effectiveness of the emission controls. By modeling the behavior of the exhaust gases in the exhaust manifold and using software algorithms to predict individual cylinder A/F, a feedback fuel control system for individual cylinders can be developed. Except for the replacement of the conventional front O2S with a UEGO sensor and a more powerful engine control computer, no additional hardware is expected in order to achieve individual cylinder fuel control. Software changes and the use of mathematical models of exhaust gas mixing behavior will be required to perform this operation. Based on information provided to staff, the first application of this technology will occur on a 1998 ULEV Honda Accord. ULEVs are most likely to utilize individual cylinder A/F control as a more cost-effective means of achieving these low emission levels than resorting to more expensive catalyst technology.

d. Adaptive Fuel Control Systems

In order to maintain good driveability, responsive performance, and optimum emission control, fluctuations of the A/F must remain small under all driving conditions including transient operation. Virtually all current fuel systems incorporate an adaptive fuel control system that automatically adjusts the system for component wear, varying environmental conditions, varying fuel composition, etc., to more closely maintain proper fuel control under various operating conditions. For most fuel control systems today, this adaptation process affects only steady-state operating conditions (i.e., constant or slowly changing throttle conditions). However, an increasing number of vehicles are being introduced with adaptation during "transient" conditions (e.g., rapidly changing throttle, purging of the evaporative system).

Accurate fuel control during transient driving conditions has traditionally been difficult because of the inaccuracies in predicting the air and fuel flow under rapidly changing throttle conditions. Because of air and fuel dynamics (fuel evaporation in the intake manifold and air flow behavior) and the time delay between the air flow measurement and the injection of the calculated fuel mass, temporarily lean A/F ratios can occur during transient driving conditions that can cause engine hesitation, poor driveability and primarily an increase in NOx emissions. However, by utilizing fuel and air mass modeling, vehicles with adaptive transient fuel control will be more capable of maintaining accurate, precise fuel control under all operating conditions. Adaptive transient fuel control is already being utilized by some manufacturers across their entire product line. Virtually all LEVs and ULEVs are expected to incorporate adaptive transient fuel control software.

e. Electronic Throttle Control ("Drive-By-Wire") Systems

As mentioned above, the time delay between the air mass measurement and the calculated fuel delivery presents one of the primary difficulties in maintaining accurate fuel control and good driveability during transient driving conditions. For vehicles which utilize a conventional mechanical throttle control, quick throttle openings can result in a lean A/F spike in the combustion chamber. Although air and fuel modeling algorithms can be developed to compensate for these time delay effects, some manufacturers may instead choose to incorporate electronic throttle control to better synchronize the air and fuel flow to achieve proper fueling during transients (e.g., the driver moves the throttle, but the fuel delivery is momentarily delayed to match the inertial lag of the increased airflow). A limited number of higher end vehicles are expected to utilize this technology in the next few years.

Technologies for Improving Fuel Atomization and Delivery

f. Sequential Multi-point Fuel Injection

Unlike conventional multi-point fuel injection systems that deliver fuel continuously or to paired injectors at the same time, sequential fuel injection can deliver fuel precisely when needed by each cylinder. With less than optimum fuel injection timing, fuel puddling and intake manifold wall wetting can occur, both of which hinder complete combustion. Use of sequential fuel injection systems is expected to especially help in reducing cold start emissions when fuel puddling and wall wetting are more likely to occur and emissions are highest. Because of the emission reductions and other performance benefits "timed" fuel injection offers, sequential fuel injection systems are seeing increased usage in many current vehicles. In the current model year, virtually all light-duty vehicles incorporate sequential multi-point fuel injection.

g. Air-Assisted Fuel Injectors

In addition to maintaining a stoichiometric air-fuel ratio, it is important that a homogeneous air-fuel mixture is delivered at the proper time and that the mixture is finely atomized to provide the best combustion characteristics and lowest emissions. Poorly prepared air-fuel mixtures, especially after a cold-start and during the warm up phase of the engine, show significantly higher emissions of unburned hydrocarbons since combustion of the mixture is less complete. To further encourage a homogeneous mixture, air-assisted fuel injectors can be used. By providing better fuel atomization, more efficient combustion can be attained which should aid in improving fuel economy and reducing emissions. Since achieving good fuel atomization is difficult when the air flow into the engine is low, air-assisted fuel injection can be particularly beneficial in reducing emissions at low engine speeds. This technique improves idle smoothness, thereby permitting a lower engine idle speed and reduced fuel consumption. Further, industry studies have shown that the short burst of additional fuel needed for responsive, smooth transient maneuvers can be reduced significantly with air-assisted fuel injection due to a decrease in wall wetting in the intake manifold. The ARB is aware of at least three manufacturers that currently utilize these systems on some of their vehicles (Audi, Honda, and Toyota). A majority of LEVs and ULEVs are eventually expected to utilize air-assisted fuel injection.

h. Improved Induction Systems

Vehicle manufacturers are also incorporating improvements to the air induction system to enhance air-fuel mixing. Through the use of technologies such as variable intake systems and variable valve timing, the amount of swirl, turbulence, and velocity of the intake charge can be increased, especially during cold-start and low load operating conditions where sufficient swirl and turbulence tend to be lacking. By providing a strong swirl formation in the combustion chamber, the air-fuel mixture can mix sufficiently; smooth, complete combustion can be achieved even under lean air-fuel conditions, thereby reducing emissions. Some TLEVs, and all LEVS and ULEVs are projected to incorporate improved air induction systems.

Technologies for Improving Catalyst Performance

I. Close-Coupled and Underfloor Catalysts

Three-way catalytic converters traditionally utilize rhodium and platinum as the catalytic material to control the emissions of all three major pollutants (hydrocarbons (HC), CO, NOx). Although this type of catalyst is very effective at converting exhaust pollutants, rhodium, which is primarily used to convert NOx, tends to thermally deteriorate at temperatures significantly lower than platinum. Recent advances in palladium-only three-way catalyst technology and tri-metal (i.e., palladium-platinum-rhodium), however, have improved both the light-off performance and high temperature durability over previous catalysts. These recent improvements in catalysts are perhaps the most significant development that will enable manufacturers to meet the LEV and ULEV standards at relatively low cost.

With the improvements in light-off capability, catalysts may not need to be placed as close to the engine as previously thought. However, if placement closer to the engine is still required for better emission performance, these improved catalysts would be more capable of surviving the higher temperature environment without deteriorating. Currently, many vehicles already utilize close-coupled catalysts. In the future, increasing numbers of vehicles are expected to utilize this technology as the emission standards become more stringent since close-coupling the catalysts to the engine can provide more heat, allowing them to become effective quickly. As previously mentioned, catalytic converter manufacturers have improved catalysts to be more resistant to the deteriorating effects of the high temperature environment to which close-coupled systems are subjected. They have done this by increasing the level of palladium that tends to be more durable at high temperatures and through improvements to the washcoat. These improved washcoats will prevent unwanted sintering and alloying of precious metals, thereby increasing the high temperature durability and effectiveness of catalysts.

Because of the improved performance of three-way catalysts, the majority of light-duty vehicles are projected to use this technology without the need for other aftertreatment devices such as electrically-heated catalysts. Through discussions with vehicle manufacturers coupled with research of current vehicle technology and low-emission vehicle prototypes, staff was able to assemble a projection of the exhaust system configurations that will be utilized for low-emission vehicles. The various exhaust configurations are shown in Figures II-1 through II-3.

j. Heat-Optimized Exhaust Pipe

Improving insulation of the exhaust system is another method of furnishing heat to the catalyst. Similar to close-coupled catalysts, the principle behind insulating the exhaust system is to conserve the heat generated in the engine for aiding catalyst warm-up. Through the use of laminated thin-wall exhaust pipes, less heat will be lost in the exhaust system, enabling quicker catalyst light-off. As an added benefit, the use of insulated exhaust pipes will also reduce exhaust noise. Some manufacturers are also considering utilizing air-gap exhaust manifolds (i.e., manifolds with metal inner and outer walls and an insulating layer of air sandwiched between them) for further heat conservation. All LEVs and ULEVs are projected to utilize heat-optimized exhaust pipes.

k. Engine Calibration Techniques

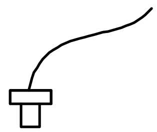
Besides the hardware modifications described above, low-emission vehicles will also utilize engine calibration changes such as a brief period of substantial ignition retard, increased cold idling speed, and leaner air-fuel mixtures to quickly provide heat to a catalyst after cold-starts. Since only software modifications are required, engine calibration modifications provide manufacturers with an inexpensive method to quickly achieve light-off of catalytic converters. When combined with close-coupled catalysts and the other heat conservation techniques described above, engine calibration techniques can be quite effective at providing the required heat to the catalyst for achieving ULEV emission levels without auxiliary heating devices such as EHCs. Merely two years ago, the ARB projected that all ULEVs and some LEVs would require the use of EHCs to meet the requirements, but it now appears that most vehicles will be able to achieve ULEV emission levels without requiring the assistance of an EHC. Heat producing engine calibrations such as described above are already in production and are projected to be incorporated on all low-emission vehicles.

l. Leak-Free Exhaust System

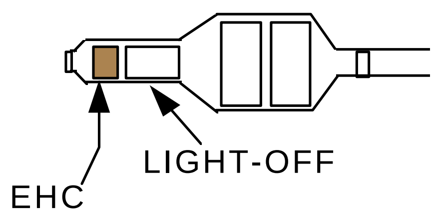
Improving exhaust systems to be leak-free would also reduce emission levels. Air leaks in the exhaust system can cause an oxidation environment in the three-way catalyst at low speeds that would lead to an increase in NOx emissions. Also, should air leaks occur upstream or near the oxygen sensors, fuel control could be erratic and/or overly rich in response to the leaking unmetered air. This would not only affect driveability but also would increase emission levels.

Legend

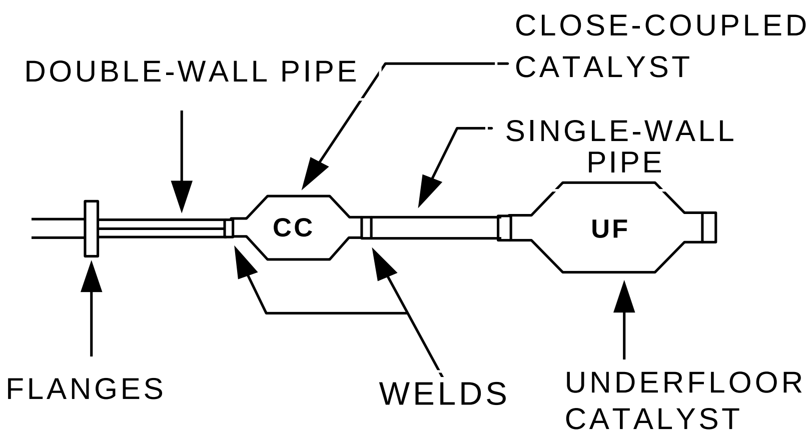
AIR INJECTION PUMP



OXYGEN SENSOR



EHC CASCADE SYSTEM



OTHER GENERAL COMPONENTS

Exhaust System Configurations
4-cylinder Engines

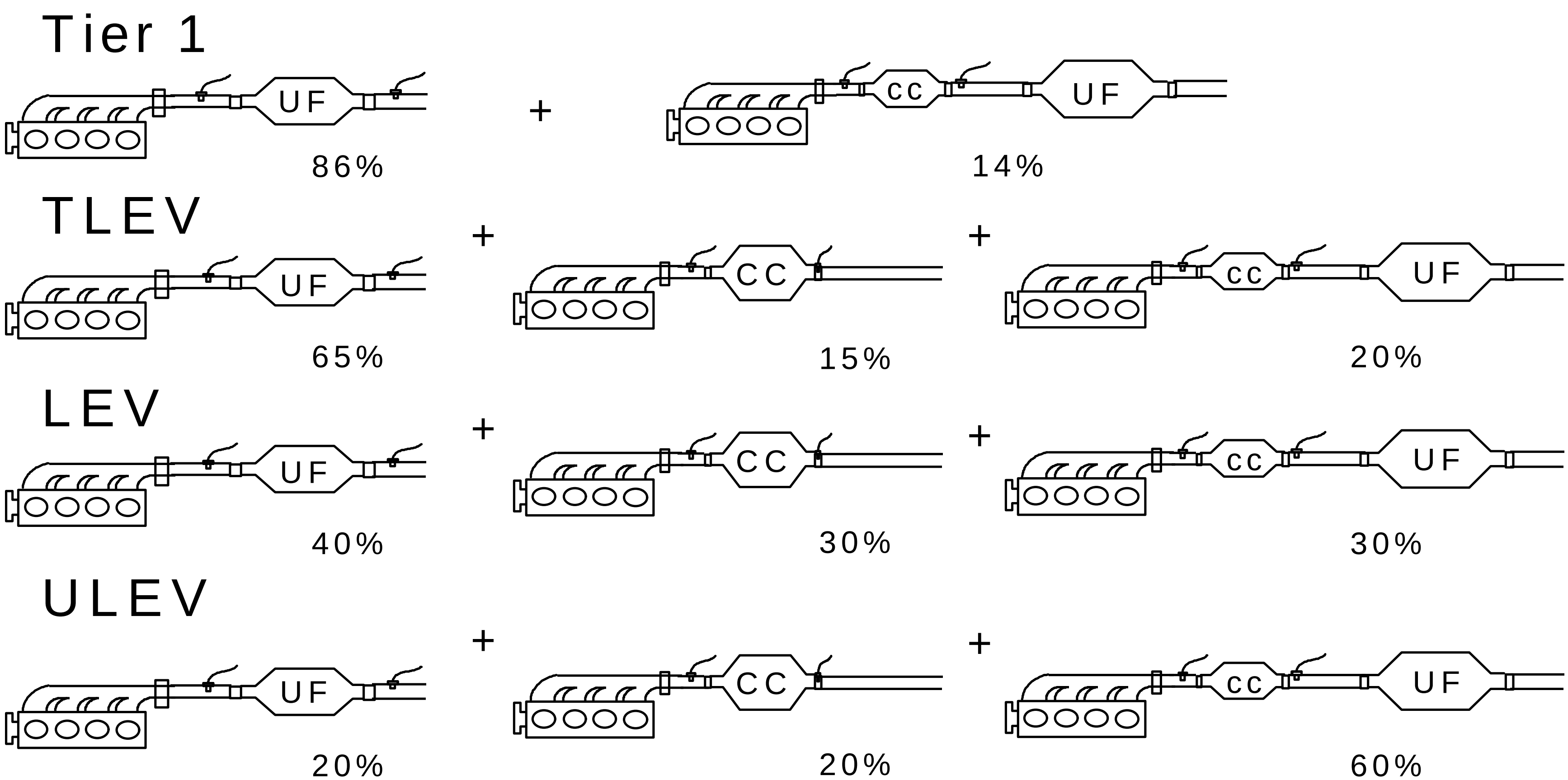


Figure II-1

Exhaust System Configurations
6-cylinder Engines

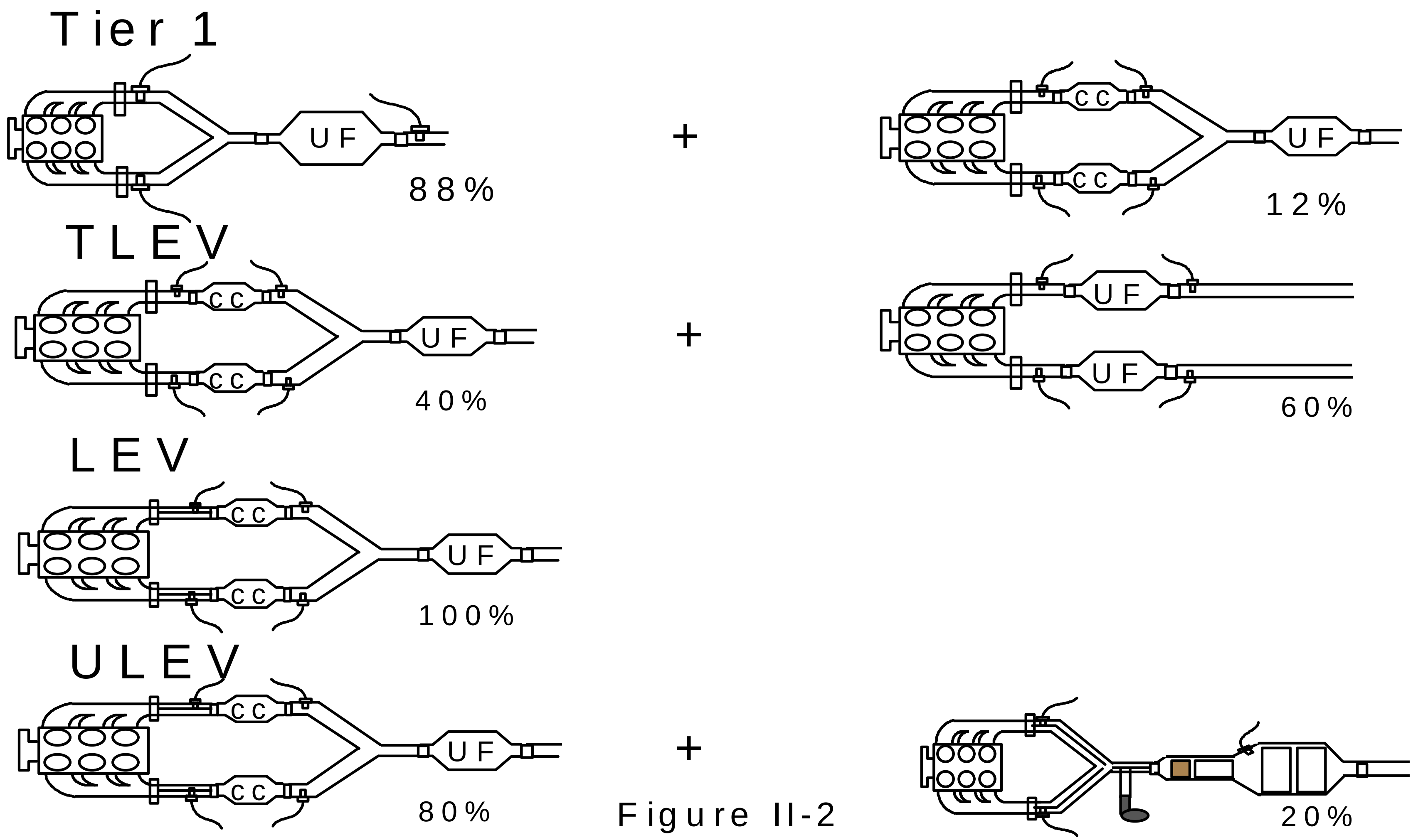


Figure II-2

8-cylinder Engines

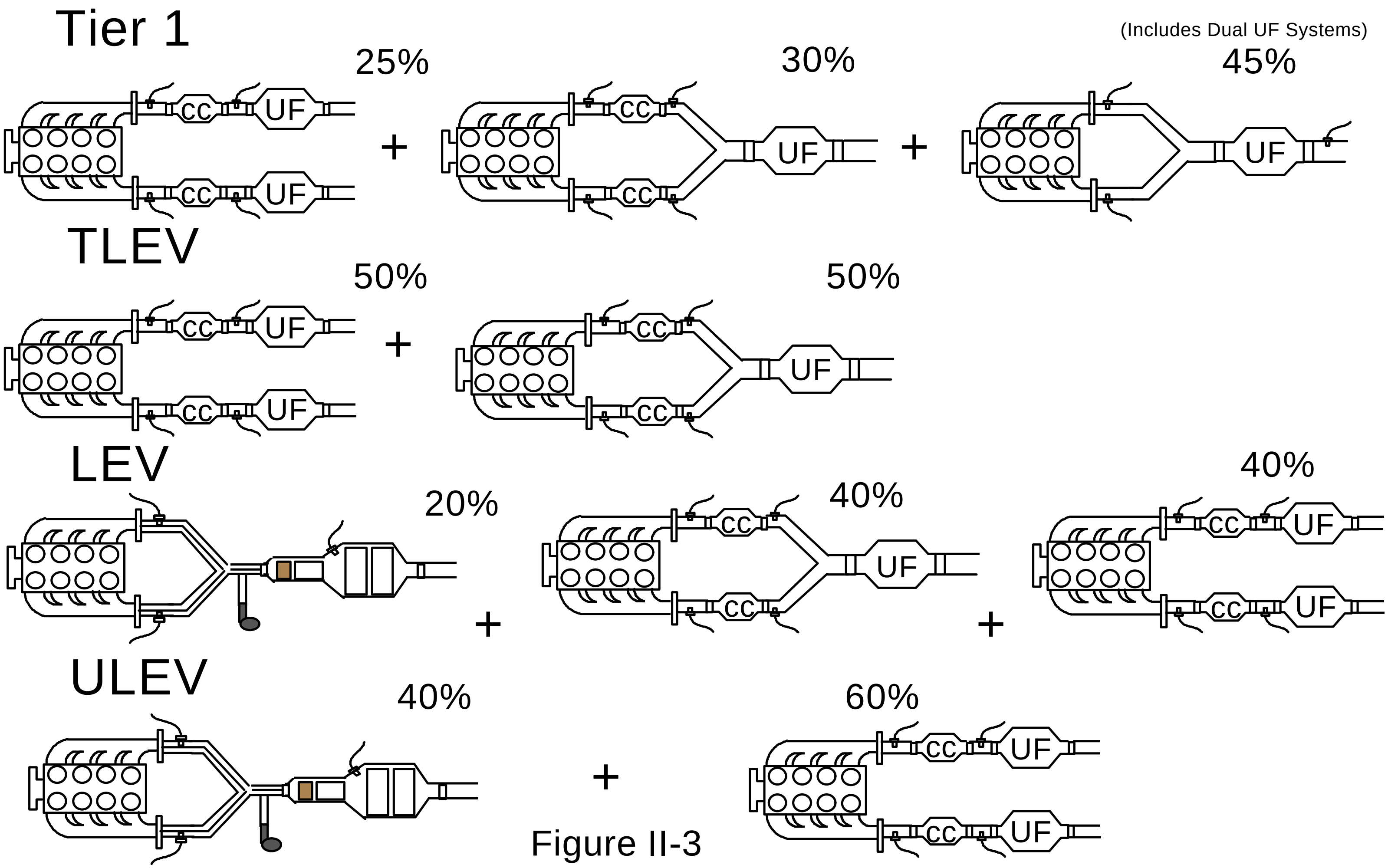


Figure II-3

Because of their emission benefits, vehicle manufacturers will continue incorporating leak-free exhaust systems as the emission standards become more stringent.

The system is expected to consist of an improved exhaust manifold/exhaust pipe interface plus a corrosion-free flexible coupling inserted between the exhaust manifold flange and the catalyst to reduce stress and the tendency for leakage to occur at this joint. This system is already incorporated on many vehicles. Use of this type of system, assuming use of corrosion-free steel, can also reduce warranty costs due to customer complaints of noise from leaking joints. Further, improvement in the welding process for catalytic converter canning would assure less air leakage into the converter and provide reduced emissions. Virtually all low-emission vehicles are expected to incorporate leak-free exhaust systems.

m. Electrically-Heated Catalysts

While the techniques described above will allow more heat to be provided quickly to the catalyst, some larger vehicles or those with tightly packaged engine compartments that require catalysts be placed underfloor may need additional help from auxiliary heating devices to achieve ULEV emission levels. Various strategies have been proposed to provide additional heat to the catalyst such as electrically-heated catalysts, exhaust gas burners, and energy storage devices. Of all these strategies, the electrically-heated catalyst has received the most attention since the technology has been shown to be feasible, cost-effective, and is ready to be introduced commercially.

In the early years of EHC development, there was concern that the electrical energy and power requirements needed to provide the heat energy necessary for ULEV emissions would require major upgrades to a vehicle's electrical system, including alternator upgrades, a separate dedicated battery to power the EHC and other electrical improvements. Recent advancements in EHC designs, however, have substantially reduced this concern. Most vehicles which utilize EHC systems will likely power the EHC directly from the alternator, or solely from the vehicle's battery, or from a combination of power from the vehicle battery and alternator.

As mentioned previously, most vehicles are projected to meet the ULEV requirements without the use of EHCs. However, for some of the more difficult to control vehicles (e.g., larger vehicles or vehicles where underhood space limitations prohibit the close-coupling of catalysts), EHCs will allow the vehicles to comply with the ULEV requirements.

n. Electric Air Injection

Although most ULEVs are expected to operate lean of stoichiometric or near stoichiometric after a cold-start, there will be some vehicle applications where this will not be possible because of driveability concerns. For these vehicles, a brief period of cold operation with a rich A/F mixture will be necessary. Although operating with a rich A/F mixture provides more stable combustion and better driveability when the engine is cold, it would also increase emissions of unburned HC and CO out of the engine. In order to control these emissions, vehicles that incorporate a rich cold-start fueling strategy are expected to include an electric air injection system to inject air upstream of the three-way catalyst so that a stoichiometric A/F ratio at the catalyst can be achieved for optimum emission performance.

The use of air injection also appears likely on some EHC-equipped vehicles. With EHC systems, substantial reductions in HC and CO emissions can be achieved with air injection because the EHC can reach light-off temperature in about 3 seconds after starting the engine. Since NOx emissions are not a problem with a cold engine, the excess air that air injection provides should not significantly increase these emissions.

Unlike previous air injection systems that are powered by pumps driven by the engine, future air injection pumps will likely be electrically powered. Advantages of using electric air pumps include higher overall efficiencies, lower costs, increased reliability, and the ability to be turned off when not needed.

Technologies to Reduce Engine-out Emission Levels

o. Reduced Crevice Volumes

Emission performance can also be improved by reducing crevice volumes in the combustion chamber. Unburned fuel can be trapped momentarily in crevice volumes before being subsequently released. Since trapped and re-released fuel can increase engine-out emissions, the elimination of crevice volumes would be beneficial to emission performance. To reduce crevice volumes, vehicle manufacturers are designing engines to include pistons with reduced top "land heights” (the distance between the top of the piston and the first ring). Although reducing the top land height could reduce the durability of the piston, improved design and materials will allow moving the ring higher on the piston. Mainly vehicles that are fitted with larger more difficult to control engines are expected to incorporate reduced crevice volume modifications to their engines.

p. Reduced Oil Consumption

Lubrication oil which leaks into the combustion chamber also has a detrimental effect on emission performance since the heavier hydrocarbons in oil do not oxidize as readily as those in gasoline and some components in lubricating oil may tend to poison the catalyst and reduce its effectiveness. Also, oil in the combustion chamber may trap HC and later release them unburned. To reduce oil consumption, vehicle manufacturers are tightening the tolerances and improving the surface finish on cylinders and pistons, improving piston ring design and materials, and improving exhaust valve stem seals to prevent excessive leakage of lubricating oil into the combustion chamber. Virtually all low-emission vehicles with newly redesigned engines will also incorporate features to reduce oil consumption.

q. Electronic Exhaust Gas Recirculation (EGR)

One of the most effective emission controls for reducing NOx emissions is exhaust gas recirculation. By recirculating spent exhaust gases into the intake manifold to reenter the engine, peak combustion temperatures are lowered and NOx emissions are thus reduced.

Many EGR systems in today's vehicles utilize a control valve that requires vacuum from the intake manifold to regulate the EGR flow rate. Under part-throttle operation where EGR is needed, engine vacuum is sufficient to open the valve. However, during throttle applications near or at full-throttle, engine vacuum is too low to open the EGR valve. While EGR operation only during part-throttle driving conditions has been sufficient to control NOx emissions for most vehicles in the past, the more stringent NOx standards for LEVs and ULEVs and emphasis on controlling off-cycle emission levels may require more precise EGR control and additional EGR during heavy throttle operation to reduce NOx emissions. Vehicle manufacturers are expected to utilize electronic EGR valve actuators in order to provide more precisely-controlled EGR rates for low emission levels. Therefore, using these electronic systems will allow engines to receive the optimal amount of EGR for all driving conditions. All LEVs and ULEVs are projected to incorporate electronic EGR systems.

r. Hydrocarbon Adsorber Systems

If the limiting factor for a vehicle to comply with the low-emission vehicle requirements is the control of HC, one possible solution could be HC adsorber systems. There have been several different types of HC adsorber systems proposed for use in motor vehicles over the past several years. Some of these systems are very complex with multiple valves, pipes, and heat exchangers while some are simpler in design and do not utilize any valves or other moving parts. Nonetheless, these systems all operate on the same principle. They are designed to trap the HC while the catalyst is cold and unable to convert the HC by utilizing an adsorbing material which holds onto the hydrocarbons. Once the catalyst is warmed up, the trapped HC are released from the absorption material and directed to the fully functioning downstream three-way catalyst. While this principle sounds simple, the technical solution is not uncomplicated, because the adsorption and desorption of the HC need to be timed correctly to prevent premature release of the unburned HC (i.e., the HC must be released only after the catalyst has warmed-up). Staff has been informed by some manufacturers that HC adsorbers may be used on some LEVs and ULEVs which have severe underhood space constraints. One HC adsorber system has recently received tentative approval for incorporation of an adequate monitoring strategy for meeting On-Board Diagnostics II requirements.

2. Status of Technology Development

Meeting the low-emission vehicle standards over the 100,000 mile interval will require utilization of many of the technologies discussed above. Many low-emission vehicles have already been introduced with these technologies in the past few years. In the 1996 model year, 26% of all gasoline light-duty engines were certified to the TLEV standard and one engine certified to the more stringent LEV standard. For the 1997 model year, six gasoline engine families have already been certified to the LEV standard (several of which are high volume engines) and many more will likely follow before the end of the model year. All of the initial LEVs are powered by 4-cylinder engines, which was expected since the smaller 4-cylinder engines' emission levels tend to be easier to control. The technologies most frequently utilized by these early LEVs are listed in Table II-1b.

As Table II-1b indicates, for the LEV category, staff expects that only some of the technologies which have been described in this report are likely to be utilized when most LEVs are introduced around 1999. With continued improvements in catalyst washcoat and design, engine combustion improvements, and more precise fuel control, future LEVs are projected to be capable of meeting the requirements with a similar hardware approach as is currently utilized on Tier I and TLEV vehicles. Some vehicles may require new emission control components to meet the more stringent ULEV requirements; however, progress in developing these components is on track. Overall, the ARB is very encouraged with industry's ability to comply with the standards with a limited amount of new technology and added hardware.

Table II-1b

Projected Low-Emission Vehicle Technologies		
Low-Emission Vehicle Technologies	**Typical Usage on 1996-7 LEVs**	**Projected Usage on 1999 LEVs**
Dual Oxygen Sensors	X	X
Universal Exhaust Gas Oxygen Sensors		
Individual Cylinder Air-Fuel Control		
Adaptive Transient Fuel Control Systems	X	X
Electronic Throttle Control Systems		
Reduced Combustion Chamber Crevice Volumes		X
Sequential Multi-Point Fuel Injection	X	X
Air-Assisted Fuel Injectors	X	X
Improved Induction Systems	X	X
Close-Coupled Catalysts	X	X
Heat-Optimized Exhaust Pipes	X	X
Engine Calibration Techniques	X	X
Leak-Free Exhaust Systems	X	X
Increased Catalyst Loading	X	X
Improved High-Temperature Washcoats	X	X
Electrically-Heated Catalysts		
Electric Air Injection		
Full Electronic Exhaust Gas Recirculation		X
Hydrocarbon Adsorber Systems		
Engine Designs to Reduce Oil Consumption		X

B. Costs of the Program

The ARB staff has updated the comprehensive cost analysis of the TLEV, LEV, and ULEV requirements of the Low-Emission Vehicle program presented in the "1994 Low-Emission Vehicle and Zero-Emission Vehicle Program Review" staff report. Similar to the approach adopted in the 1994 staff report, the ARB cost estimates assume a horizontally integrated company, i.e., one that relies heavily on suppliers to assist in the development of vehicles from the initial concept stage through the final production processes, and incorporates platform teams for product development. Also, ARB's cost estimates emphasize long-term stabilized costs, yet still account for the up-front extra expense by spreading this cost over a realistic number of years of production. From this updated analysis, the following conclusions were drawn:

* The incremental retail costs of low-emission vehicles compared to Tier I vehicles continues to be reasonable.

Emission Category	1994 Estimate	1996 Estimate
TLEV	$66	$72
LEV	$120	$120
ULEV	$227	$145

* Current estimates indicate that manufacturers will utilize less sophisticated after-treatment technology than was estimated in 1994. Considerable emphasis is being placed on technology aimed at reducing engine-out emissions such as improved precision fuel control, full electronic EGR and engine modifications.

* 1996 cost estimates are not significantly different from the 1994 estimates. This is a result of two opposing trends. Costs decreased significantly due to a reduction in the complexity of catalyst technology required to meet the various emission standards, including Tier I vehicles. On the other hand, significant costs were added for system upgrades including the use of universal exhaust oxygen sensors on some vehicles and movement to full electronic EGR control, and more engine modifications.

* The cost-effectiveness of low-emission vehicles relative to Tier I vehicles will also be very favorable, averaging less than $1.00 per pound of pollutants reduced. Even the incremental cost-effectiveness of ULEVs relative to LEVs is very reasonable at $1.15 per pound of pollutants reduced. Motor vehicle control measures typically range up to $5 per pound of pollutants reduced while stationary source controls range up to $10 per pound of pollutants reduced.

1. Cost Methodology

The cost methodology used in this analysis is essentially the same as described in detail in the “1994 Low-Emission Vehicle and Zero-Emission Vehicle Program Review” staff report. In this section, the staff describes the changes in current technology and cost estimates compared with the 1994 estimates.

a. Total Variable Costs

1) Cost of Part

Tables II-1-3 and Figures II-1-3 provide a detailed breakdown of component usage and costs for all of the emission control systems. The following discussion summarizes the basis used by staff in deciding the changes to the cost entries in Tables II-1-3 in this update.

Universal Exhaust Oxygen Sensor (UEGO)

20 percent of LEVs and 50 percent of ULEVs have been projected to use a UEGO sensor instead of a conventional oxygen sensor ahead of the front catalyst. Suppliers indicated that the incremental cost of UEGOs over conventional oxygen sensors would be approximately $10.

Leak Free Exhaust system

In the 1994 staff report, a leak-free exhaust system was expected to include a corrosion free coupling and two flat flange gaskets, plus improved welding of catalyst assemblies. However, examination of current production systems and discussions with manufacturers do not indicate plans to generally utilize flat flange gasket systems. Therefore, staff lowered the cost of a leak-free exhaust system by $5 for four cylinder engines, and $10 for six and eight cylinder engines.

Full Electronic EGR system

Discussions with manufacturers have indicated that virtually all LEVs and ULEVs will utilize full electronic EGR systems in place of vacuum-assist EGR systems. Unlike vacuum-assist EGR systems, these will utilize electronic actuators which will provide more precise control of EGR even under full-throttle conditions. Accordingly, staff estimated that this system would add $10 relative to the cost of conventional EGR systems.

Engine Modifications

Manufacturers have indicated that they are improving emission performance by making engine modifications such as reducing crevice volumes in the combustion chamber, improving piston ring design and materials, revising head gasket designs and others. Accordingly, staff estimated an additional cost for these improvements of $10 for six cylinder engines and $15 for eight cylinder engines.

Close-Coupled, Underbody, and Electrically-Heated Catalysts

Figures II-1-3 show the revised estimates of catalyst technology that will be utilized on low-emission vehicles and Tier I vehicles. Overall, compared to the 1994 estimates, it appears that the level of catalyst technology needed has dropped significantly. This is due to the development of more durable catalysts with improved light-off characteristics and increased experience with these advanced technologies.

Air-Injection (Electric)

In 1994, staff estimated that virtually all applications utilizing EHCs would also use secondary air-injection. However, some manufacturers have recently indicated that it would not be necessary on some EHC applications. Accordingly, staff has revised its estimates to show 50 percent of EHC applications using air-injection.

2) Cost of Assembly, Shipping and Warranty

No significant changes have been made to the assembly, shipping and warranty costs since the 1994 update.

b. Support Costs

1) Research Costs

Based on discussions with manufacturers, staff has doubled the engineering cost for the development of improved precision fuel control (Table II-4). Otherwise, the costs remain the same as detailed in the 1994 update.

2) Legal and Administrative costs

No changes have been made to the legal and administrative costs since the 1994 update.

c. Investment Recovery

This portion of the cost analysis includes accounting for machinery and equipment to manufacture the part, assembly plant changes (automation), vehicle development (engineering), and cost of capital recovery. The costs under this category remain the same as in the 1994 update.

d. Dealership costs

Dealership costs include accounting for recovery of operating costs and the cost of capital recovery. The methodology used in this analysis to calculate dealership costs is the same as the one used in the 1994 update.

2. Incremental Cost and Cost-Effectiveness of the Low-Emission Vehicle Program

Table II-5 contains a summary of the incremental costs of TLEVs, LEVs and ULEVs relative to Tier I vehicles, based on the status of technology development in 1996. The cost-effectiveness of the various categories of the Low-Emission Vehicle program relative to Tier I vehicles continues to be less than $1.00 per pound which compares favorably with other emission control programs. Even the incremental cost-effectiveness of ULEVs is lower compared to 1994 estimates, ranging from $0.37 per pound to $1.15 per pound.

Incremental cost of TLEV compared to a Tier I vehicle

Emission Control Technology	4-Cylinder (45%) Tech. cost est. (in dollars)	% of Tier I vehs. that use tech.	%TLEV that will req. tech.	Inc. cost over tier 1	6-Cylinder (47%) Tech. cost est. (in dollars)	% of Tier I vehs. that use tech.	%TLEV that will req. tech.	Inc. cost over tier 1	8-Cylinder (8%) Tech. cost est. (in dollars)	% of Tier I vehs. that use tech.	%TLEV that will req. tech.	Inc. cost over tier 1
Sequential fuel injection (a)		100	100	0		100	100	0		100	100	0
Universal Exhaust Gas Oxygen Sensor (b)	10	0	0	0	20	0	0	0	20	0	0	0
Improved fuel preparation (c)	8	4	15	0.88	12	9	0	-1.08	16	0	0	0
Improved precision fuel control (d)	0	10	15	0	0	10	15	0	0	10	15	0
Heat optimized exhaust pipe (e)		0	0	0		0	0	0		0	0	0
Leak-free exhaust system (f)	10	50	50	0	20	50	50	0	20	50	50	0
Greater catalyst loading + improved washcoat (g)	0	0	50	0	0	0	50	0	0	0	100	0
Close-coupled catalyst	55	14	35	11.55	55	0	0	0	55	0	0	0
Underbody or main catalyst	80	100	85	-12	80	100	40	-48	80	60	50	-8
Dual close-coupled catalyst		0	0	0	90	12	40	25.2	110	55	100	49.5
Dual underbody or main catalyst		0	0	0	160	0	60	96	160	40	50	16
EHC (w/o prec. metal + light-off catalyst)	112	0	0	0	112	0	0	0	112	0	0	0
EHC(with prec. metal + light-off catalyst)	132	0	0	0	132	0	0	0	132	0	0	0
Dual-EHCs (with prec. metal+light-off catalyst)	237	0	0	0	237	0	0	0	237	0	0	0
Air injection(electric) (h)	50	0	0	0	50	0	0	0	65	0	0	0
Total incremental cost				0.43				72.12				57.50

(a) Sequential fuel injection will be utilized on all Tier I vehicles and therefore, cost will not be ascribed to the LEV program.
(b) Dual O2 sensor compensation cost has been ascribed to the OBD II regulation.
(c) Air assisted injection requires minor redesign of the idle air control valve at no additional cost and addition of an adaptor to each injector at a cost of $2 each.
(d) Improved precision fuel control constitute software changes only, at no additional hardware cost.
(e) Length of heat optimized exhaust pipe required is estimated to be one foot for 4-cylinder engines, four feet for six-cylinder engines, and six feet for eight-cylinder engines, at a cost of $1 per foot incremental.
(f) Leak-free exhaust system includes corrosion free flexible coupling, plus improved welding of catalyst assemblies.
(g) Greater catalyst loading cost will be offset by increased palladium use.
(h) Cost of Air injection includes an electric air pump with integrated filter and relay, wiring, air shut-off valve with integral solenoid, check valve, tubing and brackets.

Incremental cost of TLEV compared to Tier I vehicle = 38.69

Table II-1

Incremental cost of a LEV compared to a Tier I vehicle

Emission Control Technology	4-Cylinder (45%)				6-Cylinder (47%)				8-Cylinder (8%)			
	Tech. cost est. (in dollars)	% of Tier I vehs. that use tech.	%LEV that will req. tech.	Inc. cost over tier 1	Tech. cost est. (in dollars)	% of Tier I vehs. that use tech.	%LEV that will req. tech.	Inc. cost over tier 1	Tech. cost est. (in dollars)	% of Tier I vehs. that use tech.	%LEV that will req. tech.	Inc. cost over tier 1
Sequential fuel injection (a)		100	100	0		100	100	0		100	100	0
Universal Exhaust Gas Oxygen Sensor (b)	10	0	20	2	20	0	20	4	20	0	20	4
Improved fuel preparation (c)	8	4	100	7.68	12	9	100	10.92	16	0	100	16
Improved precision fuel control (d)	0	10	100	0	0	10	100	0	0	10	100	0
Heat optimized exhaust pipe (e)		0	100	1		0	100	4		0	100	6
Leak-free exhaust system (f)	10	50	100	5	20	50	100	10	20	50	100	10
Greater catalyst loading + improved washcoat (g)	0	0	100	0	0	0	100	0	0	0	100	0
Engine modifications	0	0	0	0	10	0	100	10	15	0	100	15
Full electronic EGR	10	0	100	10	10	0	100	10	10	0	100	10
Close-coupled catalyst	55	14	60	25.3	55	0	0	0	55	0	0	0
Underbody or main catalyst	80	100	70	-24	80	100	100	0	80	60	60	0
Dual close-coupled catalyst		0	0	0	90	12	100	79.2	110	55	80	27.5
Dual underbody or main catalyst		0	0	0	160	0	0	0	160	40	40	0
EHC (w/o prec. metal + light-off catalyst)	112	0	0	0	112	0	0	0	112	0	20	22.4
EHC(with prec. metal + light-off catalyst)	132	0	0	0	132	0	0	0	132	0	0	0
Dual-EHCs (with prec. metal+light-off catalyst)	237	0	0	0	237	0	0	0	237	0	0	0
Air injection(electric) (h)	50	0	0	0	50	0	0	0	65	0	10	6.5
Total incremental cost				26.98				128.12				117.40

(a) Sequential fuel injection will be utilized on all Tier I vehicles and therefore, cost will not be ascribed to the LEV program.
(b) Dual O2 sensor compensation cost has been ascribed to the OBD II regulation.
(c) Air assisted injection requires minor redesign of the idle air control valve at no additional cost and addition of an adaptor to each injector at a cost of $2 each.
(d) Improved precision fuel control constitute software changes only, at no additional hardware cost.
(e) Length of heat optimized exhaust pipe required is estimated to be one foot for 4-cylinder engines, four feet for six-cylinder engines, and six feet for eight-cylinder engines, at a cost of $1 per foot incremental.
(f) Leak-free exhaust system includes corrosion free flexible coupling, plus improved welding of catalyst assemblies.
(g) Greater catalyst loading cost will be offset by increased palladium use.
(h) Cost of Air injection includes an electric air pump with integrated filter and relay, wiring, air shut-off valve with integral solenoid, check valve, tubing and brackets.

Incremental cost of a LEV compared to a Tier I vehicle = 81.75

Table II-2

Incremental cost of a ULEV compared to a Tier I vehicle

Emission Control Technology	4-Cylinder (45%) Tech. cost est. (in dollars)	% of Tier I vehs. that use tech.	%ULEV that will req. tech.	Inc. cost over tier 1	6-Cylinder (47%) Tech. cost est. (in dollars)	% of Tier I vehs. that use tech.	%ULEV that will req. tech.	Inc. cost over tier 1	8-Cylinder (8%) Tech. cost est. (in dollars)	% of Tier I vehs. that use tech.	%ULEV that will req. tech.	Inc. cost over tier 1
Sequential fuel injection (a)		100	100	0		100	100	0		100	100	0
Universal Exhaust Gas Oxygen Sensor (b)	10	0	50	5	20	0	50	10	20	0	50	10
Improved fuel preparation (c)	8	4	100	7.68	12	9	100	10.92	16	0	100	16
Improved precision fuel control (d)	0	10	100	0	0	10	100	0	0	10	100	0
Heat optimized exhaust pipe (e)		0	100	1		0	100	4		0	100	6
Leak-free exhaust system (f)	10	50	100	5	20	50	100	10	20	50	100	10
Greater catalyst loading + improved washcoat (g)	0	0	100	0	0	0	100	0	0	0	100	0
Engine modifications	0	0	0	0	10	0	100	10	15	0	100	15
Full electronic EGR	10	0	100	10	10	0	100	10	10	0	100	10
Close-coupled catalyst	55	14	80	36.3	55	0	0	0	55	0	0	0
Underbody or main catalyst	80	100	80	-16	80	100	100	0	80	60	40	-16
Dual close-coupled catalyst		0	0	0	90	12	80	61.2	110	55	60	5.5
Dual underbody or main catalyst		0	0	0	160	0	0	0	160	40	60	32
EHC (w/o prec. metal + light-off catalyst)	112	0	0	0	112	0	0	0	112	0	0	0
EHC(with prec. metal + light-off catalyst)	132	0	0	0	132	0	20	26.4	132	0	40	52.8
Dual-EHCs (with prec. metal+light-off catalyst)	237	0	0	0	237	0	0	0	237	0	0	0
Air injection(electric) (h)	50	0	0	0	50	0	10	5	65	0	20	13
Total incremental cost				48.98				147.52				154.30

(a) Sequential fuel injection will be utilized on all Tier I vehicles and therefore, cost will not be ascribed to the LEV program.
(b) Dual O2 sensor compensation cost has been ascribed to the OBD II regulation.
(c) Air assisted injection requires minor redesign of the idle air control valve at no additional cost and addition of an adaptor to each injector at a cost of $2 each;
(d) Improved precision control constitute software changes only, at no additional hardware cost.
(e) Length of heat optimized exhaust pipe required is estimated to be one foot for 4-cylinder engines, four feet for six-cylinder engines, and six feet for eight-cylinder engines, at a cost of $1 per foot incremental.
(f) Leak-free exhaust system includes corrosion free flexible coupling, plus improved welding of catalyst assemblies.
(g) Greater catalyst loading cost will be offset by increased palladium use.
(h) Cost of Air injection includes an electric air pump with integrated filter and relay, wiring, air shut-off valve with integral solenoid, check valve, tubing and brackets.

Incremental cost of an ULEV compared to a Tier I vehicle = 103.72

Table II-3

Support Costs

(A) Advanced Engineering Development Cost of Advanced Vehicle Technology (Research)

Emission Control Technology	Eng. Staff for Tech. Dev.		Eng. Staff Cost (a)	Dev. vehicles cost (b)	Addtl. equipment	Cost/vehicle(c)
	(person yrs.)	(person hrs.)	(in dollars)	(in dollars)	(in dollars)	(dollars/veh.)
Improved precision fuel control	8	16,640	998,400	0	0	1.25
Air-assist Fuel Injection	6	12,480	748,800	250,000	0	1.25
RAF development	9	18,720	1,123,200	300,000	60,000	1.85
Advanced Pd Catalysts	12	24,960	1,497,600	1,000,000	0	3.12
EHCs (durability & development) (d)	15	31,200	1,872,000	1,500,000	0	4.22
Total						11.69

(B) Legal and Administrative costs

	No. of Staff required	Number of years	Staff cost (in dollars)	Cost/vehicle (c) (dollars/vehicle)
Legal	2	3	1,200,000	1.50
Administrative	4	3	1,497,600	1.87

(a) Development cost includes personnel, overhead and other miscellaneous costs at a total rate of $60/hr.
(b) Prototype development vehicles are estimated to cost 100,000 dollars each (except Air Assist Fuel injection @ $50,000).
(c) Cost has been distributed over 100,000 vehicles per year for a total of 8 years.
(d) For advance engineering work in contrast to vehicle calibration/certification effort.

Table II-4

r cost of a TLEV compared to Tier I vehicle

		4-cylinder (45%) (in dollars)	6-cylinder (47%) (in dollars)	8-cylinder (8%) (in dollars)
Variable costs	Component	0.43	72.12	57.50
	Assembly	1.00	1.00	1.00
	Warranty	0.00	0.00	0.00
	Shipping	0.00	0.00	0.00
Support costs	Research	11.69	11.69	11.69
	Legal	1.50	1.50	1.50
	Administrative	1.87	1.87	1.87
Investment recovery costs	Mach. & equipment	0.00	0.00	0.00
	Assembly plant changes	0.00	0.00	0.00
	Vehicle development	10.27	10.27	10.27
Capital recovery		1.61	5.91	5.03
Dealership costs	Operating costs	0.85	3.13	2.67
	Cost of capital recovery	0.43	1.58	1.34
Total cost		29.65	109.06	92.87

cost of a TLEV compared to Tier I vehicle= 72.03

er cost of a LEV compared to Tier I vehicle

		4-cylinder (45%) (in dollars)	6-cylinder (47%) (in dollars)	8-cylinder (8%) (in dollars)
Variable costs	Component	26.98	128.12	117.40
	Assembly	1.00	1.00	1.00
	Warranty	0.04	0.04	0.13
	Shipping	0.00	0.05	0.25
Support costs	Research	11.69	11.69	11.69
	Legal	1.50	1.50	1.50
	Administrative	1.87	1.87	1.87
Investment recovery costs	Mach. & equipment	0.00	0.00	0.00
	Assembly plant changes	0.00	0.00	0.00
	Vehicle development	10.27	10.27	10.27
Capital recovery		3.20	9.27	8.65
Dealership costs	Operating costs	1.70	4.91	4.58
	Cost of capital recovery	0.85	2.48	2.31
Total cost		59.10	171.20	159.65

cost of a LEV compared to Tier I vehicle= 119.83

r cost of a ULEV compared to Tier I vehicle

		4-cylinder (45%) (in dollars)	6-cylinder (47%) (in dollars)	8-cylinder (8%) (in dollars)
Variable costs	Component	48.98	147.52	154.30
	Assembly	1.00	1.00	1.00
	Warranty	0.04	0.14	0.24
	Shipping	0.25	0.25	0.25
Support costs	Research	11.69	11.69	11.69
	Legal	1.50	1.50	1.50
	Administrative	1.87	1.87	1.87
Investment recovery costs	Mach. & equipment	0.00	0.00	0.00
	Assembly plant changes	0.00	0.00	0.00
	Vehicle development	10.27	10.27	10.27
Capital recovery		4.54	10.45	10.87
Dealership costs	Operating costs	2.40	5.54	5.76
	Cost of capital recovery	1.21	2.79	2.90
Total cost		83.75	193.03	200.65

cost of a ULEV compared to Tier I vehicle= 144.46

Table II-5

Cost-effectiveness of the LEV program

Incremental cost of Low Emission Vehicles compared to a Tier I vehicle
(in dollars)

Category	Incremental cost estimate in 1994
TLEV	72.03
LEV	119.83
ULEV	144.46

Emission reductions from a Low Emission Vehicle compared to a Tier I vehicle

Category	Life-time ROG Emissions (in lbs.)	Life-time NOx Emissions (in lbs.)	Life-time CO Emissions (in lbs.)	ROG+ NOx Emiss. Red. (in lbs.)	ROG Emiss. Red. (in lbs.)	ROG+ NOx+ CO/7 Emiss. Red. (in lbs.)
Tier I	85.14	141.1	1258.5			
TLEV	45.55	141.1	914.5	39.59	39.59	88.74
LEV	23.90	70.6	823.1	131.74	61.24	193.93
ULEV	13.17	70.6	427.1	142.47	71.97	261.24

Cost effectiveness of Low Emission Vehicles compared to a Tier I vehicle
(in dollars/pound)

Category	ROG+ NOx (a)	ROG(a)	ROG+ NOx+ CO/7 (b)
TLEV	0.91	0.91	0.81
LEV	0.45	0.98	0.62
ULEV	0.51	1.00	0.55

Incremental cost effectiveness of Low Emission Vehicles
(in dollars/pound of pollutants reduced)

Category	ROG+ NOx (a)	ROG(a)	ROG+ NOx+ CO/7 (b)
TLEV	0.91	0.91	0.81
LEV	0.26	1.10	0.45
ULEV	1.15	1.15	0.37

Assumption:
(a) one-half of the added cost is allocated towards
criteria pollutant reductions and other half towards toxic air contaminant reductions.
(b) based on "California Clean Air Act : Cost-effectiveness Guidance" document dated Sep. 1990

Table II-6

III. ZERO-EMISSION VEHICLE PROGRAM UPDATE

The requirement that automakers produce specific percentages of zero-emission vehicles (ZEVs) was included in the 1990 Low-Emission Vehicle regulations. Under the original ZEV requirement, beginning in 1998, two percent of the vehicles produced and delivered for sale in California by the seven largest automakers were required to be ZEVs. That percentage increased to five percent in 2001 and ten percent in 2003.

As directed in 1990, staff provided ZEV technology updates to the Board in 1992 and 1994. The primary conclusion of these updates was that the technology needed for the successful commercialization of ZEVs beginning in 1998 was continuing to show good progress. In preparation for the more critical 1996 ZEV update, staff embarked on a rigorous assessment of ZEV technology and marketability. As part of this effort, a panel of independent battery experts, the Battery Technical Advisory Panel, was commissioned to evaluate the state of advanced battery development worldwide. In addition, staff held eight forums to solicit input regarding a variety of ZEV issues including infrastructure, marketability, and benefits and costs.

As a result of the information collected, ARB concluded that modifications to the existing regulations were necessary to ensure a successful launch of ZEVs in California. This conclusion was based on three main factors:

- The battery technology available for use in commercial 1998 electric vehicles (EVs) would provide relatively low driving ranges, limiting the potential market for EVs. Particularly from a consumer standpoint, the risk of weak market acceptance was too great, as it is important for early consumer experiences with EVs to be positive in order to gain long-term success.

- The Battery Technical Advisory Panel found that advanced batteries, which could double or triple EV range and eliminate the need for costly battery replacements, could be available around the turn of the century. Vehicles powered by advanced batteries would appeal to a larger market and expand battery options for consumers, thereby increasing the likelihood of a successful launch.

- By modifying the program to allow time for advanced batteries to be further demonstrated and developed, a more gradual, market-based introduction would increase the chances of a successful vehicle launch.

With these technology considerations and market-based principles in mind, the Board voted unanimously at their March 1996 Board meeting to eliminate the ZEV requirements from 1998 through 2002 while retaining the ten percent requirement for 2003 and beyond. By suspending the percentage requirements for five years, ARB has attempted to capitalize on market competition and ensure the successful launch of a sustainable ZEV market that will provide air quality benefits in California through 2010 and beyond.

At the March 1996 meeting, ARB also directed the staff to enter into Memoranda of Agreement or "MOAs" with the seven largest automakers to ensure that progress on ZEV technology continued, and that air quality in California will not be adversely affected. More specifically, the MOAs formalize the automakers' commitment to participate in a Technology Development Partnership to accelerate the commercialization of advanced-battery vehicles by placing up to 3,750 demonstration vehicles in California using advanced batteries in 1998, 1999, and 2000. The automakers also committed to continued funding of ZEV-related technology research and development.

In addition, the MOAs formalize the automakers' enforceable commitments to introduce LEVs nationwide in 2001, three years earlier than can be required under federal law. With the migration of vehicles from other states into California, the emission reductions gained by this measure will offset those associated with the 1998-2002 ZEV requirements, plus a premium. Thus, California's commitments under the State Implementation Plan will be met. All MOAs have now been signed and are legally binding contracts.

Automakers have responded well to the additional flexibility offered by the modified ZEV program. Three automakers have indicated plans to introduce EVs prior to 1998. Also, it is apparent that automakers will offer battery/vehicle combinations distinct from other automakers, each with its own "selling points". This indicates a highly competitive approach to the EV market that is necessary for technology and market growth. The following summarizes the activities to date of each automaker in meeting its MOA obligations:

Chrysler

Chrysler has announced plans to commercially introduce an electric version of their Dodge Caravan in time to meet 1998 MOA obligations. The "EPIC" is a five-passenger vehicle that will use sealed advanced lead-acid batteries developed by Texas-based Electrosource. These batteries currently provide a vehicle range of 60 miles per charge, a top speed of 80 miles per hour, and an acceleration from 0 to 60 miles per hour in roughly 16 seconds. Between 1993 and 1995 Chrysler sold first generation EVs to fleets nationwide to acquire experience and customer feedback to improve performance and reduce costs for the EPIC minivans.

Ford

Ford is now offering an electric-powered Ranger pickup truck through a partnership with Troy Design and Manufacturing (TDM) in Michigan. TDM will install the motor and advanced lead-acid batteries in "gliders" provided by Ford. The vehicles are projected to have a range of 50 miles, a top speed of 75 miles per hour, and cost approximately $33,990 (does not include air conditioning or charger). Ford has also announced plans to produce an in-house electric Ranger beginning in November 1997. Ford continues to evaluate EV technology through its fleet of Ecostars, an electric version of the European Escort.

General Motors

General Motors announced its introduction of the EV1, an efficient two-seat EV sports car, at Saturn dealerships in Los Angeles, San Diego, Phoenix and Tucson beginning in Fall 1996. The EV1, a production model based on the Impact EV prototype, will be sold or leased to customers using lead-acid batteries to achieve a range of 70 to 90 miles. EV1 accelerates from 0 to 60 miles per hour in just 8 seconds. Future models may be upfitted with advanced batteries. General Motors has also announced plans to introduce an electric version of their S-10 truck in 1997 nationwide.

Honda

Honda has announced plans to market a highly refined production model EV that uses advanced nickel-metal-hydride batteries. The Honda EV has been designed from the ground up to be an electric vehicle. The EV is projected to have a range of 125 miles per charge, a governed top speed of 80 miles per hour, and an acceleration of 0 to 60 miles per hour in 18 seconds. About 300 Honda EVs will be leased over the next few years beginning in the spring of 1997. The lease program will cover maintenance, insurance, and roadside assistance. EVs will be placed in the Sacramento and Southern California areas where selected dealers will lease and service the vehicles. As part of the Technology Development Partnership, Honda plans to evaluate infrastructure requirements, customer acceptance of EVs, and “real-world” use of the nickel-metal hydride battery**.**

Mazda

Mazda is evaluating EV technology with a lead-acid battery Miata roadster. No future plans have been announced.

Nissan

Nissan has announced plans to offer an EV using lithium-ion batteries to fleet users in California beginning in 1998. One year earlier in 1997, Nissan will introduce a lithium-powered EV, named Prarie Joy, in Japan. The lithium-ion battery for the Prarie Joy has an energy density three times greater than a conventional lead-acid battery, providing the vehicle with a range exceeding 120 miles. Prairie Joy has a governed top speed of 75 miles per hour and an acceleration of 0 to 60 miles per hour in 17 seconds. Through demonstration program activities in the United States, Nissan plans to optimize vehicles using advanced batteries for the California market.

Toyota

Toyota has announced plans to have an electric version of their popular RAV4 sport-utility vehicle available to fleet users in Fall 1997. The front wheel drive vehicle, which will use nickel-metal hydride batteries, has a range of roughly 120 miles per charge and a top speed of 79 miles per hour.

Since the focus of the ZEV requirement has shifted to a market-based approach in the early years, ARB staff has likewise shifted its resources toward ensuring a smooth implementation, including removing potential market barriers and improving infrastructure. ARB has established a ZEV Implementation Advisory Committee comprised of representatives from key stakeholder groups. These include automakers, dealers, electric utilities, environmental groups, vehicle users, and state and local government. The Committee is charged with two main goals: addressing potential market barriers for ZEVs, and establishing the necessary infrastructure.

ARB specifically committed to address a number of infrastructure and implementation issues to ensure a successful introduction of ZEVs under the MOAs. Based on these commitments, ARB staff has developed a plan to provide support for the following efforts: providing outreach to electrical contractors to ensure quick and safe EV charger installation, assessing convenience charging availability and needs, ensuring convenient ZEV registration, providing training curricula for ZEV maintenance technicians, assisting in the development of data for ZEV financing, promoting insurance industry awareness of ZEVs, facilitating state and local government ZEV purchases, supporting reasonable ZEV incentive programs, ensuring consumer protection regulations for ZEVs are enforced, providing outreach materials to enhance public awareness of ZEVs, ensuring a process is developed to recycle ZEV advanced batteries, and continuing support of emergency response training for ZEVs.

ARB staff is already participating in public/private partnerships to help prepare California for ZEVs. One example of such a partnership is a large working group to support the State Fire Marshal's Office in the development of an emergency response training program for fire and law enforcement officials. ARB staff plans to continue working with a number of stakeholders in upcoming years to ensure a smooth transition for ZEVs into the California marketplace.