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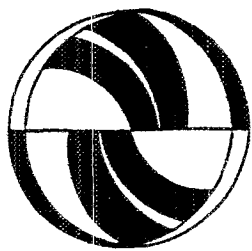
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# California's Partial ZEV Credits And LEV II Program

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## *Abstract*

In November 1998, the California Air Resources Board modified its Zero Emission Vehicle (ZEV) "mandate" so as to allow certain vehicles with measurable tailpipe emissions to earn partial credit toward the 10% requirement scheduled for 2003 and beyond. This change in the ZEV mandate provides automakers with a greater incentive to market a broad range of very low-emitting vehicles, and reduces the requirement for 'pure' zero-emission vehicles. Partial ZEV credits will be given to vehicles that have very low tailpipe emissions, all-electric driving capability, integrated advanced componentry, and use inherently clean fuels. Even very clean-burning gasoline vehicles can earn partial ZEV credit. This report describes the methods and conditions for granting partial ZEV credits, examines credit allocations to particular technology and fuel options, and explores the implications of the proposed changes. This report is an update of UCD-ITS-RR-98-5.

## *Why Zero-Emission Vehicles?*

The zero and low emission vehicle rules in California are the product of the California Air Resources Board. The mission of the California Air Resources Board is to “promote and protect public health, welfare and ecological resources through the effective and efficient reduction of air pollutants, while recognizing and considering the effects on the economy of the State.” This mission is dictated in part by national health-based ambient air quality standards set by the U.S. Environmental Protection Agency for six major pollutants. This mission does not include energy use, carbon dioxide, or other environmental impacts. The ZEV and LEV rules are therefore premised exclusively on air pollution.

The critical ambient pollutant, with respect to light duty vehicles, is tropospheric ozone, which is formed principally via a set of complex photochemical reactions involving oxides of nitrogen (NO<sub>x</sub>) and reactive organic gases (ROG). In urban areas, almost half of these emissions are from light duty vehicles. To meet national air quality standards, many areas in California would need major reductions in emissions. Emissions may be reduced by decreasing either vehicle use or vehicle emission rates. Because transportation planners have not been able to devise politically feasible strategies to reduce vehicle use, regulators now look primarily to technology as the best option for emissions reductions. Indeed, tested emissions per mile for new vehicles have been reduced to approximately 2% of uncontrolled levels through application of advanced emissions control technologies. But actual in-use emissions are often much higher than new-vehicle tested emissions, and a disproportionate share of total emissions comes from a relatively small number of vehicles.

Emissions control system deterioration is caused by a variety of factors, including emissions catalyst aging and poisoning, emissions control system malfunctions, user tampering, and the unresponsiveness of owners to the warnings of on-board diagnostic systems. Many argue that attention should be placed on in-use high-emitting vehicles. Why focus on new vehicles and ZEVs rather than on repairing the emissions control systems of high-emitting in-use vehicles? There are two reasons.

First, it is difficult and expensive to identify and repair high-emitting vehicles. This path is fraught with political land mines. Many owners of high-emitting vehicles are low income and would be economically burdened by repairs of vehicle emissions control systems, which can be expensive. In politics, equity concerns often trump environmental concerns. There is also a privacy issue. The primary strategy to identify high-emitting vehicles in a cost-effective manner is to measure emissions with a roadside device and photograph license plates of high-emitting vehicles. This type of governmental surveillance is seen by many as a violation of privacy.

A second reason for focusing on new cars is that repairing aging and malfunctioning emissions control systems on in-use vehicles is a relatively short-term solution to California's air quality problem. Zero-emission vehicles, on the other hand, have no possibility of emissions control deterioration. For this reason, zero-emission vehicles have been a key element of California's plan for reducing automobile air pollution.

## *LEV and LEV II*

In 1990, after a series of public hearings, the California Air Resources Board adopted a set of low emission vehicle (LEV) rules that have come to be known as LEV I. The new rules were a dramatic departure from the past, not only because emission standards were made far more stringent, but also because the program was made more flexible and included a zero emission requirement.

In the past, vehicle emissions were regulated using a uniform grams-per-mile standard for each vehicle class (cars, light trucks, etc.) that all vehicles in that class were required to meet. With the LEV I program, California identified four vehicle emissions levels for cars and light trucks, plus a zero emissions category. Vehicle manufacturers were required to certify vehicles offered for sale in California at one of these emissions levels. The mix of vehicles had to result in an average emissions level that was lower than an average non-methane organic gas (NMOG) emission level set by the State. This fleet average NMOG requirement was specified to decline in annual steps from the Tier I emissions level of 0.25 g/mile at the outset of the program in 1994 to 0.062 g/mile in 2003. Although only the NMOG emissions were directly regulated by the fleet average requirement, each NMOG certification level was accompanied by specific certification levels for other key pollutants. In this way, all emissions were regulated. By allowing manufacturers the flexibility to certify their vehicles at different levels (and comply with an average as opposed to a uniform standard), they introduced flexibility into the regulatory process. Further provisions allowing banking of credits and trading of emissions between vehicle suppliers, providing even more flexibility.

The other new component to the original Low Emission Vehicle ruling was the zero-emission vehicle rule. Known as the "ZEV mandate", this new regulation required auto manufacturers to offer specified numbers of zero-emission vehicles for sale. In LEV I, 2% of the vehicles made available for sale in California in 1998 by each of the seven largest vehicle suppliers were required to be zero emitting. The percentage increased to 5% in 2001, and 10% in 2003 and beyond. At that time in 1990, the only technology thought to be viable that would meet the definition of a zero-emission vehicle was the battery electric vehicle.

In early 1996, after another series of public hearings and considerable public debate, the California Air Resources Board amended the ZEV elements of the LEV program. The Board determined that battery electric vehicles expected to be offered for sale in California did not appear to have the range necessary for consumer acceptance, and therefore more research and development was needed. The Board removed the zero-emission vehicle requirements for the years 1998 through 2002 and replaced them with a Memorandum of Agreement with each of the seven major manufacturers. The agreements imposed a set of new requirements designed to ensure that the emissions benefits lost from the rollback of the zero-emission vehicle requirements would be offset, and that research and development of zero-emission vehicle technologies would continue. The principal offsetting requirement was early adoption of more stringent national emission standards by the seven manufacturers, thus reducing emissions from vehicles purchased outside the state and subsequently imported.

In November 1998, the Air Resources Board adopted even more extensive changes. The LEV II program alters a number of sections in the original regulation, including the zero-emission vehicle component. The remainder of this report will focus on this newest version of the zero-emission vehicle mandate and its implications for battery, hybrid and fuel cell electric vehicle introduction.

**Table 1: LEV and LEV II Standards for Light Duty Vehicles**

Vehicle Emission Category	Vehicle Miles Traveled	NMOG		CO		NOx		PM	
		LEV	LEVII	LEV	LEVII	LEV	LEVII	LEV	LEVII
Tier I	50,000	0.250	n/a	3.4	n/a	0.4	n/a	0.08	n/a
	100,000	0.310	n/a	4.2	n/a	0.6	n/a	n/a	n/a
TLEV	50,000	0.125	n/a	3.4	n/a	0.4	n/a	n/a	n/a
	100,000	0.156	n/a	4.2	n/a	0.6	n/a	n/a	n/a
LEV	50,000	0.075	0.075	3.4	3.4	0.2	<b>0.05</b>	n/a	n/a
	100,000	0.090	n/a	4.2	n/a	0.3	n/a	n/a	n/a
	120,000	n/a	0.090	n/a	4.2	n/a	<b>0.07</b>	n/a	<b>0.01</b>
	150,000*	n/a	<b>0.090</b>	n/a	<b>4.2</b>	n/a	<b>0.07</b>	n/a	<b>0.01</b>
ULEV	50,000	0.040	0.040	1.7	1.7	0.2	<b>0.05</b>	n/a	n/a
	100,000	0.055	n/a	2.1	n/a	0.3	n/a	n/a	n/a
	120,000	n/a	0.055	n/a	2.1	n/a	<b>0.07</b>	n/a	<b>0.01</b>
	150,000*	n/a	<b>0.055</b>	n/a	<b>2.1</b>	n/a	<b>0.07</b>	n/a	<b>0.01</b>
SULEV	120,000	n/a	<b>0.010</b>	n/a	<b>1.0</b>	n/a	<b>0.02</b>	n/a	<b>0.01</b>
	150,000*	n/a	<b>0.010</b>	n/a	<b>1.0</b>	n/a	<b>0.02</b>	n/a	<b>0.01</b>

Note: Shaded cells indicate LEV II changes to the original LEV standards.

The 1998 amendments add a new emission category and tighten standards in existing categories (see Table 1). The new standard category is called "super ultra low emission vehicle" (SULEV), and is the lowest emissions category (other than ZEV). The creation of the SULEV category (and tightening of other standards) reflects an observation that automotive engineers are making rapid progress in reducing the cost and magnitude of emission control technology – reinforced by announcements by Honda and other major automakers that they could soon be producing vehicles that beat the ULEV standard by a significant margin.

The original LEV certification levels are strengthened in LEV II by extending the 100,000 mile requirement to 120,000, lowering the NOx standards for the Low Emission Vehicle and Ultra Low Emission Vehicle categories, and creating new standards for particulate emissions. The Board also added an option to certify vehicles at 150,000 miles instead of 120,000 miles, in return for proportionally more weight in the calculation of fleet average NMOG compliance.

A second important departure from the original regulation is the merging of the standards for passenger vehicles with those of all light-duty trucks under 8500 pounds.



Gross Vehicle Weight Rating<sup>1</sup> Until this point, certain light-duty trucks were allowed to emit more than passenger cars based on the assumption that these vehicles were used primarily for work purposes<sup>2</sup> Work vehicles generally have larger load carrying capacity and often will be driven ‘harder’ than passenger vehicles However, in recent years it has become increasingly common for these vehicles to be used exclusively for simple passenger travel For this reason, the 1998 Low Emission Vehicle II regulation requires all vehicles rated under 8500 pounds – both passenger cars and light-duty trucks – to meet identical emissions standards To allow for the manufacture of some work trucks in this vehicle class, a special standard has been created in the Low Emission Vehicle category that has a slightly higher limit for NOx emissions than is required for passenger cars<sup>3</sup> Certification to this standard is limited to 4% of the light-duty trucks rated between 3751 and 8500 pounds sold by a manufacturer in California

### *Partial ZEV credits*

When the 1990 ZEV mandate was passed, the Air Resources Board expected huge strides to take place in battery electric vehicle development, and that zero-emission vehicles would be on the road in significant numbers by the end of the decade Huge strides were taken, but this technology is still far from competitive with conventional gasoline and diesel vehicles. Partly due to these shortcomings, automakers have stepped up their investment in a number of alternative technologies that achieve zero or near-zero emissions levels As originally conceived, the “ZEV mandate” did not provide any benefits or incentives to most of these other alternative technologies

In the original ZEV program, manufacturers were required to meet the 2%, 5%, and 10% levels by offering the appropriate number of vehicles for sale, or buying ZEV credits from other companies selling above their quota (including manufacturers other than the Big 7) That flexibility is retained in the new rules.

Under the new rule, partial ZEV credit can also be earned through production of near-zero emission vehicles Multiple ZEV credits can even be earned for a single zero emission vehicle with an exceptionally long range Vehicles eligible for partial ZEV credit include hybrid electric vehicles, reformer-equipped fuel cell vehicles, natural gas vehicles, and conventional gasoline vehicles with advanced emissions control systems

To preserve the initial intent of the ZEV program – to accelerate the introduction of vehicles with inherently and permanently low emissions – CARB introduced a rule that 40% of the 10% zero-emission credit requirement in the mandate must be met with actual zero-emission vehicles (i e ZEV credits from pure zero-emission vehicles must be equivalent to 4% of the total number of vehicles delivered for sale in California, starting

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<sup>1</sup> Gross Vehicle Weight Rating is defined as the curb weight of the vehicle plus the maximum payload that the vehicle is rated to carry

<sup>2</sup> All trucks rated over 6000 pounds GVW fall into this category. Trucks rated under 6000 pounds GVW but over 3750 lbs. loaded vehicle weight—curb weight plus 300 lbs —are also held to a less stringent standard under current rules

<sup>3</sup> The special work truck standard is not shown in Table 1.

in 2003) This 4% pure zero-emission vehicle requirement applies only to the seven “large-volume” manufacturers

### *Qualifying for Partial ZEV Credit*

The California Air Resources Board has divided the desirable characteristics of zero-emission vehicles into categories – low lifetime tailpipe emissions, low fuel cycle emissions, and long ZEV range. The Board has recognized that a variety of vehicle technologies may exhibit some of these characteristics and thereby deserve partial ZEV credit. In order to receive partial ZEV credit, a vehicle must meet all of the following requirements: 150,000 mile SULEV (Super Ultra Low Emission Vehicle) exhaust emission standards, “zero” evaporative emissions standards, on-board diagnostic requirements at 150,000 miles, and a 15 year or 150,000 mile performance and defects warranty. Vehicles that meet these criteria will receive 0.2 ZEV credits and will also be eligible to receive additional credit based on zero-emission range and fuel-cycle emissions. The next sections of this report detail the qualifications necessary to obtain additional ZEV credit.

### **Zero-Emission Range**

A number of technologies have been developed that result in vehicles producing zero tailpipe emissions when driven short distances, but some tailpipe emissions when driven longer distances. These technologies include charge-depleting hybrid electric vehicles<sup>4</sup> and some fuel cell vehicles. To encourage the development and sale of vehicles that operate with zero emissions, the Air Resources Board decided to give such vehicles partial ZEV credit according to the following formula:

$$\text{Partial ZEV Credits} = 0.6 \times \frac{\text{Zero - Emission Miles}}{\text{Total Miles Traveled Per Trip}}$$

Clearly, it is impossible to know in advance the ratio of zero-emission miles to total miles traveled for each vehicle. Therefore, the Air Resources Board created a simple relationship to specify a numerical value for the all-electric range of vehicles (see Table 2).

Manufacturers are free to propose alternative methodologies for determining the zero-emission range potential of a vehicle as a percent of total range, provided that an engineering evaluation “adequately substantiates” the zero-emission vehicle determination. The example given of a potential alternative methodology is the case of the vehicle that is zero-emission for one pollutant and not zero-emission for another, qualifying for a zero-emission range factor of 0.5, for 0.3 ZEV credits. Note that this example alternative methodology is not dependent on the all-electric range of the vehicle, but rather on the fact that the vehicle will never produce emissions of one pollutant. The highest possible zero-emission range factor is 1.0.

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<sup>4</sup> A charge-depleting hybrid electric vehicle is defined by the Board as a vehicle whose battery steadily depletes its charge as it is driven and ultimately falls low enough to diminish the acceleration performance of the vehicle.

**Table 2: Zero Emission Range Factors for Hybrid and Fuel Cell Vehicles**

Urban All-Electric Range	Zero-Emission Range Factors
< 20 miles	0 0
≥ 20 miles to < 100 miles	$\frac{30 + (0.5 \times \text{Urban All - Electric Range})}{80}$
≥ 100 miles	1 0

### **Off-Vehicle Charging**

In California, off-vehicle charging will produce fewer emissions than on-board charging of batteries with an internal combustion engine. This is largely due to the very low emissions from California's electricity generating powerplants. Most other regions do not have such a low-emitting mix of powerplants. To encourage the reduction in emissions that comes with off-vehicle charging, the partial ZEV regulation states that hybrid electric vehicles that have an urban all-electric range greater than 20 miles are eligible for an additional 0.1 ZEV credits if they are equipped with software and/or other strategies that promote the use of off-vehicle charging. However, hybrid electric vehicles may not receive more than 0.6 ZEV credits based on zero-emission range criteria (off-vehicle-charging credit is counted toward the zero-emission vehicle range allocation).

### *Transferability to Other States*

By federal law, states can require vehicles sold in their state to be California certified or nationally certified for emissions, but cannot choose any intermediate (third) certification level. This prohibition of a third level is problematic in transferring California's ZEV program to other states. That is because other states have a very different mix of electricity powerplants. California does not use coal for electricity generation and 72% of electricity generated in California in 1996 did not cause any smog-precursors to be emitted into the atmosphere. In comparison, over 50% of electricity generated nationwide is from (high polluting) coal.

Differences in electricity mix between California and other states result in greatly differing levels of emissions from off-board charging across states. Ideally, differing incentives would be offered in each state, depending on local emissions from grid electricity. With simple adoption of the off-vehicle charging aspect of the California ZEV program, most states would be giving incentives to produce more pollution.

### **Advanced ZEV Componentry**

Any vehicle that uses advanced ZEV componentry is contributing to the eventual replacement of conventional internal combustion engine vehicles with zero-emission vehicles. Increasing the production volumes of ZEV technologies and helping to bring their costs down is an important part of bringing zero emission vehicles to market. Using this logic, CARB grants 0.1 credits to any vehicle with an all-electric range of less than 20 miles (the threshold for ZEV range credits) – if it incorporates advanced zero-

emission vehicle components. Examples of qualifying technologies include batteries that are integral to the operation of the vehicle or an electric powertrain.

Charge-sustaining hybrid vehicles fit into this category. These vehicles would be powered by a power source such as an internal combustion engine or fuel cell, supplemented with a battery (or ultracapacitor). The power source operates to charge the battery. The energy stored in the battery is then used to drive an electric motor which, in turn, drives the vehicle. Although this method introduces an extra step to turn the potential energy in the fuel into kinetic energy at the wheels, it can also increase overall efficiency by allowing the power source to operate at a more optimal, constant level than if it were directly driving the wheels. Charge-sustaining hybrid vehicles are designed such that when the vehicle is turned on, the power source is also turned on most of the time. These vehicles tend to have relatively small battery packs and rarely (or never) have to recharge batteries from the electric grid. These vehicles have little or no all-electric range, but are eligible for credit under this section of the partial ZEV regulation.

### Low Fuel-Cycle Emissions

Even though a vehicle may have zero tailpipe emissions, there are emissions associated with production of the power that is used to drive the vehicle. In the case of a fuel-powered vehicle, these emissions occur upstream in the production and transportation of fuel. In the case of a battery electric vehicle, the emissions occur at the power plant when the vehicle is charged and in the production and transportation of the fuel powering the power plant. By considering the complete fuel cycle, the Air Resources Board can ensure that a fuel that is clean on-board the vehicle, but produces significant pollution elsewhere, does not gain undeserved credit. Alternatively, a fuel that is clean both on and off the vehicle is rewarded for its potential to improve air quality.

Accordingly, CARB decided to give partial ZEV credit to any vehicle that has a full fuel-cycle non-methane organic gas (NMOG) emission level at or below 0.01 grams per mile. This emissions level has been calculated to be that associated with the fuel-cycle emissions of a battery-powered electric vehicle in the South Coast Air Basin. The fuel cycle emissions of oxides of nitrogen (NO<sub>x</sub>) and carbon monoxide (CO) are not considered in the establishment of this credit because emissions of these pollutants associated with the production and distribution of likely automotive fuels are very low in comparison to tailpipe or power plant emissions.

**Table 3: Partial ZEV Fuel Cycle Credits**

Fuel	Probable Fuel-Cycle Credit
Gasoline	0.0
Diesel	0.0
Methanol	0.0 or 0.2
Compressed Natural Gas	0.2
Battery Electric	0.2

The maximum available credit for low fuel cycle emissions is 0.2 ZEV credits. A fuel will receive 0.2 ZEV credits if it has fuel-cycle emissions less than or equal to 0.01 grams of NMOG per mile. A particular vehicle will receive low fuel-cycle emissions credit in proportion to the percent of VMT using low fuel-cycle fuels. The burden is placed upon the manufacturers to prove that a particular fuel has fuel-cycle emissions that are low enough to meet these criteria. The probable allocation of the low fuel-cycle emissions credit for various automotive fuels is illustrated in Table 3.

It has not yet been determined whether methanol has fuel-cycle emissions lower than this limit of 0.01 grams of NMOG emissions per mile. With this fuel cycle credit, as with off-vehicle charging, there is an issue of transferability to other states.

### Multiple ZEV Credits

The partial ZEV credit regulation allows 'pure' zero-emission vehicles that have long ranges to earn multiple ZEV credits. A 'pure' zero-emission vehicle is defined as any vehicle that earns 1.0 ZEV credits under the partial ZEV credit criteria. Current technologies that meet this qualification are hydrogen fuel cell vehicles and battery electric vehicles with ranges of at least 75 miles. Range has been a major issue in battery electric vehicle development because consumers normally demand ranges upward of 100 miles. Table 4 indicates the number of ZEV credits that a 'pure' ZEV is eligible to receive depending on the model year and the range of the vehicle. 'Pure' zero-emission vehicles with ranges between 100 and 175 miles will earn ZEV credits according to a linear interpolation between the points given in the chart.

**Table 4: Partial ZEV Credits for All-Electric Range**

All-Electric Range, miles	Model Years 1999-2000	Model Years 2001-2002	Model Years 2003-2005	Model Years 2006-2007
100-175	6-10	4-6	2-4	1-2

The credit for long range diminishes over time because CARB believes it will be less costly to provide longer ranges in battery electric vehicles in future years. Hydrogen fuel cell vehicles and battery electric vehicles that have recharging/refueling times under 10 minutes will be considered infinite-range vehicles and will be eligible to receive the highest number of ZEV credits available for the model year in which they were produced.

### The ZEV and Partial ZEV Credit System

Table 5 presents the ZEV credits that could be earned by a number of representative vehicle technologies.

**Table 5: Partial ZEV Credits for Vehicle Technologies, Year 2003**

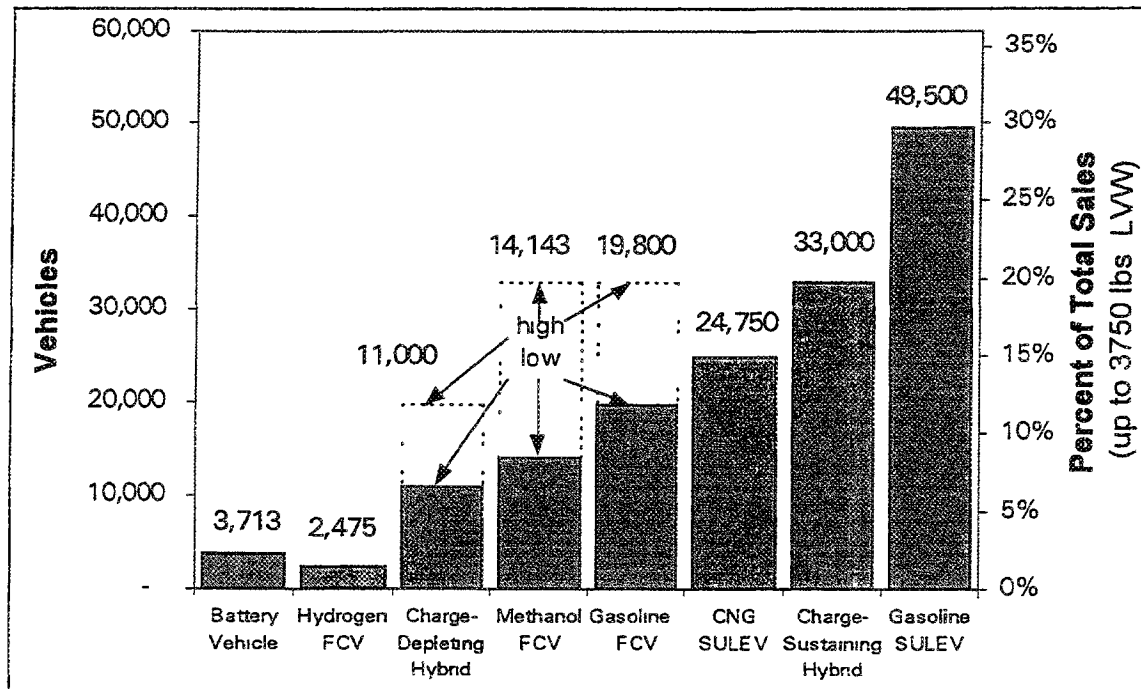
Technology	SULEV	ZEV Range	Low Fuel Cycle	ZEV credit
Gasoline SULEV	0.2	0.0	0.0	0.2
Compressed Natural Gas SULEV	0.2	0.0	0.2	0.4
Charge-Sustaining Hybrid (gasoline)	0.2	0.1	0.0	0.3
Charge-Depleting Hybrid (gasoline)	0.2	0.1-0.6	0.0+	0.3+ - 0.8+
Battery, Range<100 miles	0.2	0.1-0.6	0.2	0.5-1.0
Battery, Range>100 miles	n/a	n/a	n/a	2-4
Gasoline Reformate Fuel Cell	0.2	0.1-0.3	0.0	0.3-0.5
Methanol Reformate Fuel Cell	0.2	0.1-0.3	0.0-0.2	0.3-0.7
Hydrogen Fuel Cell	n/a	n/a	n/a	4

Because the new regulation offers the opportunities to earn partial ZEV credit for some vehicles and multiple ZEV credits for other vehicles as well as the flexibility to trade and bank ZEV credits, the exact number of vehicles cannot be ascertained. Although it is difficult to specify the number of 'pure' and partial zero-emission vehicles that will be on California's roadways in 2003 as a result of the new ZEV rules, the Air Resources Board has attempted to structure the regulation such that the reduction in pollutants associated with the partial ZEV credit rules should be roughly equivalent to what would have been achieved under the more rigid original version of the "ZEV mandate"

Although it is impossible to predict actual vehicle numbers, it is illuminating to see an example of possible vehicle sales combinations that could meet a large manufacturer's zero-emissions vehicle obligations. Consider a large manufacturer selling 165,000 light duty vehicles per year in California. In order for the manufacturer to fulfill the requirement that 40% of the ZEV credits be earned through 'pure' zero-emission vehicles, approximately 2500 battery electric vehicles,<sup>5</sup> 1650 hydrogen fuel cell vehicles, or some combination of the two must be offered for sale. Figure 1 provides an illustrative analysis of the number of vehicles of that a manufacturer could offer for sale in California to fulfill the remaining ZEV credit requirement (i.e., the other 6%). For simplicity, this chart (unrealistically) assumes that this portion of the ZEV credit obligation would be met with a single vehicle technology. For certain technologies, it is not clear how many ZEV credits will be earned for each vehicle produced. The dotted outlines of bars indicate the upper range for the number of vehicles with these technologies that would need to be offered for sale.

<sup>5</sup> Here, battery electric vehicles are assumed to have a range of 125 miles, which will earn 2.7 ZEV credits in 2003. Battery electric vehicles with shorter ranges would earn fewer ZEV credits and more of them would need to be sold.

**Figure 1: Alternative Strategies for a Large Manufacturer (165,000 sales per year) to Meet the 6% "Partial ZEV" Portion of the 2003 ZEV Mandate**



Adapted from unpublished analysis by Jason Mark, Union of Concerned Scientists

### *Some Issues and Implications*

The original intent of the ZEV mandate was to accelerate the development and commercialization of vehicles with permanently zero emissions. It was believed that California air pollution was so severe, and population growth so strong, that clean air could be attained only by switching to zero emitting vehicles (assuming that the upstream sources of pollution from very clean electricity-generating powerplants and other energy sources would be very low). The only known technologies that qualified as zero-emission vehicles were battery electric vehicles and hydrogen fuel cell vehicles. Unfortunately, these vehicles will not be competitive with internal combustion engine technology in cost or utility in the near future.

Recognizing the economic, political, and marketing barriers of pure ZEVs, in 1998 CARB developed the more flexible and inclusive partial ZEV credit system. Their strategy was to provide partial credits to vehicles that have very low emissions, incorporate some advanced ZEV technology, and that operate on very clean fuels (defined as fewer fuel-cycle emissions than a battery electric vehicle in the Los Angeles area). The complexity of the rules and uncertain manufacturer and consumer responses cause uncertainty about the actual air quality impact of the new rules. Below we explore some important issues.

### **Gasoline SULEVs and ZEV credits**

Allowing vehicles powered solely by internal combustion engines to earn ZEV credits is certainly the most fundamental proposed change to the principles of the ZEV mandate. It was a change motivated by recent successes with very clean vehicles. Indeed, future vehicles certified as SULEVs, with the required extension of the emissions control warranty, would be nearly as clean as a 'pure' zero-emission vehicle. Because a SULEV would not have the range limitations and inherently high cost of a battery electric vehicle, it would have the added attraction of possibly accruing more miles per car and probably selling in greater numbers. A SULEV could potentially clean up California's air *more* than a battery electric vehicle. But gasoline vehicles certified to the SULEV standard do not meet the main original goal of the ZEV mandate, to accelerate the development and commercialization of a new generation of inherently clean propulsion technology.

And so the Air Resources Board compromised and assigned 0.2 ZEV credits to vehicles meeting extended SULEV criteria. The implications of this compromise are uncertain. On the one hand, automakers will have to sell five vehicles meeting the extended SULEV criteria in order to receive one ZEV credit. These vehicles count not only toward meeting their ZEV credit quota, but also are counted in their fleet average NMOG calculation. Because the NMOG emissions difference between a vehicle qualifying as a SULEV and a 'pure' zero-emission vehicle is so small, the five SULEV vehicles will actually bring the NMOG average down significantly more than the single zero-emission vehicle.

One effect is to undermine the development of inherently clean propulsion technologies. That is because automakers will weigh the costs of producing five vehicles meeting the SULEV standard (estimated to be not more than a few hundred dollars per vehicle) against the cost of producing a single vehicle meeting the requirements for 'pure' zero-emission vehicles plus four vehicles which do not receive ZEV credit. Since the cost of producing zero-emission vehicles is high, it seems likely that the cost to automakers of producing five near-zero emission vehicles will be lower. In addition, automakers opting to produce five SULEV vehicles could offset some of their costs in doing so by certifying more vehicles to the less stringent TLEV and LEV standards. The incentive for SULEV vehicles here seems clear, but automaker behavior is difficult to predict (and will probably vary greatly across companies), in part because automakers have some motivation to develop and promote new "high-tech," green technologies that are likely to eventually replace internal combustion engine vehicles in the future.

### **Hybrids and ZEV credits**

An automaker can receive 0.7 ZEV credits for the manufacture of a charge-depleting hybrid vehicle with 20 miles of all-electric range that has the capacity for off-vehicle charging. The breakdown of these credits is 0.2 for meeting the extended SULEV criteria, 0.3 for having 20 miles of all-electric range, 0.1 for off-vehicle charging capability, and approximately 0.1 for low fuel-cycle emissions when running on the battery. In contrast, a charge-sustaining hybrid vehicle such as the Toyota Prius, which has less than 20 miles of all-electric range, will receive only 0.3 ZEV credits. The breakdown of these credits is 0.2 for meeting the extended SULEV criteria and 0.1 for incorporating advanced ZEV



componentry into the vehicle. The difference in the earned ZEV credits results entirely from the fact that one vehicle has 20 miles of all-electric range and the other does not

Both draw some of their power from an internal combustion engine that burns gasoline and both must meet the stringent extended SULEV requirements to be considered for any ZEV credits. In this way, both vehicle configurations meet similar near-zero emission criteria.<sup>6</sup> The discrepancy in ZEV credits is arguably justified by the difference in the contributions of the two vehicles to the long-term goal of developing 'pure' zero-emission vehicles. The difficult-to-answer question is: Do charge-depleting hybrids really bring zero-emission vehicles that much closer to production than charge-sustaining hybrids?

Another related issue is the incentive for manufacturers of charge-depleting hybrids to build them such that their all-electric range is slightly greater than 20 miles. This is due to the structure of the credit system. A hybrid with an all-electric range of less than 20 miles will receive 0.1 ZEV credits for this range under the advanced ZEV componentry section. A hybrid with 20 miles of all-electric range will receive 0.4 ZEV credits under the rule – 0.3 for the range itself and 0.1 for off-vehicle charging capability. To receive another 0.1 ZEV credits, the hybrid vehicle must have 47 miles of all-electric range.

A simple cost comparison makes it clear that it will be less expensive for a manufacturer to earn ZEV credits from many hybrid vehicles with 20 miles of all-electric range than from fewer hybrid vehicles with longer all-electric ranges. We estimate that the battery costs for a hybrid vehicle with 20 miles of all-electric range are \$2000.<sup>7</sup> We assume that the added cost for providing more range is solely the added battery costs (since the electric-drive components are in place). Thus, the cost for a hybrid with 47 miles of all-electric range should be \$4700, compared with \$2000 for the hybrid with 20 miles of all-electric range. The difference between these two vehicles is \$2700, 27 miles of all-electric range, and 0.1 ZEV credits. It is unlikely, at least as long as these battery cost attributes remain, that manufacturers will build many hybrid vehicles with all-electric ranges greater than 20 miles.

### **Battery Electric Vehicles and ZEV credits**

Under the original ZEV rules, any 'pure' zero-emission vehicle that met safety and other applicable standards would receive a full ZEV credit, regardless of its range. Under the ZEV II regulation, vehicles earn ZEV credit based on their range up to 100 miles.

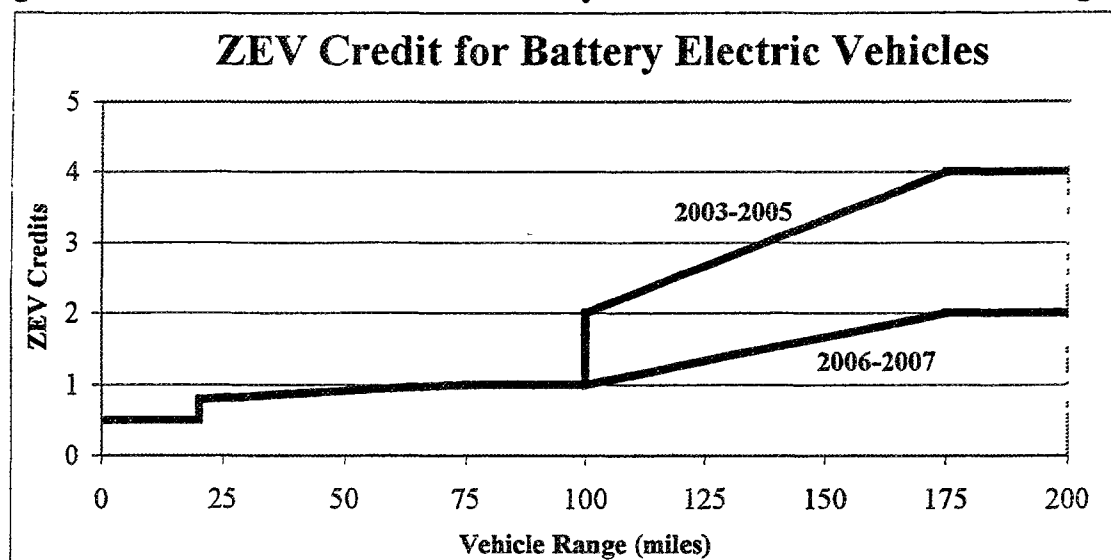
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<sup>6</sup> The criteria they meet are actually slightly different and it may be that a charge-depleting hybrid will have lower emissions per mile than a charge-sustaining hybrid. This is because of the specific emissions test for hybrid vehicles. The regulation is written such that if it is possible to manually turn the engine on and off, the emissions test procedure should be performed with the engine on. At this point, it seems more likely that a charge-depleting hybrid vehicle would be built such that the driver could manually turn the engine on and off than that such an option would be available in a charge-sustaining hybrid configuration. A vehicle which had this option would have to meet the SULEV emissions requirements when the engine was running the entire time. On the other hand, if the engine could not be manually turned on and off, it might not be running for the entirety of the emissions test and thus even though the vehicle may meet the SULEV requirements, the emissions per mile might not be quite as low if the engine were running for the entire test.

<sup>7</sup> The Department of Energy goal for nickel-metal-hydrate (NiMH) batteries is \$350/kWh. For \$2000, this means that the battery can store 5.7 kWh of electric energy. This is approximately the amount that is expected to be needed for 20 miles of all-electric range.

'Pure' zero-emission vehicles with lower ranges such as the Toyota e-com will not receive a full ZEV credit. According to the new formula, if the vehicle has 100 mile range, it will receive exactly 1.0 ZEV credit. Because vehicles can receive an extra 0.1 ZEV credit for off-vehicle charging capability, 'pure' battery electric vehicles with 74

**Figure 2: ZEV Credit Allocation for Battery Electric Vehicles of Different Ranges**



miles of range will receive a full ZEV credit. Vehicles with all-electric ranges under 100 miles are allowed to earn a maximum of 1.0 ZEV credit. For this reason, Figure 2 shows a flat credit earning line between 74 and 100 miles of range. During the first three years of the partial ZEV mandate, there is a peculiar jump in the number of ZEV credits that a pure battery electric vehicle earns at the range level of 100 miles. Vehicles with ranges greater than 100 miles earn credits based on a linear interpolation between 2.0 ZEV credits at 100 mile range and 4.0 ZEV credits at 175 mile range. There is a discontinuity at the 100 mile range level. In 2006, this discontinuity is removed, but the flat ZEV credit for vehicles with ranges from 74 through 100 miles remains.

From a manufacturer's point of view, this presents a clear incentive to make sure that the battery electric vehicles they produce between 2003 and 2005 achieve at least 100 mile range. This is again due to cost issues. If it costs about \$2000 for the batteries in a vehicle with 20 miles of all-electric range, it will cost \$7500 for the batteries for a vehicle that meets the minimum requirements to be a 'pure' zero-emission vehicle, and that vehicle will receive 1.0 ZEV credit. For just \$2500 more, the manufacturer could add extra batteries to make the range jump above the 100 mile mark and earn another ZEV credit. This is a relatively short-lived start-up phenomenon of the partial ZEV mandate that will be eliminated after 2005. However, it could affect manufacturers' early technology decisions that have the potential to impact production well into the future.

### Fuel Cell Vehicles and ZEV credits

Another example of large differences in ZEV credits between similar vehicles is the discrepancy between fuel cell vehicles operating on pure hydrogen and those operating on hydrogen reformed from another fuel such as methanol or gasoline. The chemical

reaction used in fuel cells is more efficient than the kinetic reaction used in combustion engines and emits only water vapor. In this way, fuel cell vehicles meet the original goal of the ZEV mandate to promote inherently clean propulsion technologies.

But a fuel production and supply infrastructure does not exist for hydrogen. As a result, on-board reformer systems are being developed to extract hydrogen from readily available fuels such as gasoline or methanol. In other words, automakers are planning to use gasoline or methanol indirectly in a fuel cell rather than directly in a conventional internal combustion engine vehicle.

The CARB partial credit program does not encourage indirect use of these chemical fuels. Up to 4.0 ZEV credits are provided for a fuel cell vehicle running on direct hydrogen, but a maximum of only 0.5 credits for a fuel cell vehicle running on gasoline reformat, and a maximum of 0.7 if running on methanol reformat. The justification for this differential treatment is the emissions from the on-board reformers. But again, the issue is whether the goal of accelerating the development and commercialization of zero-emitting technology takes precedence over near term air quality gains.

Consider that a fuel cell system with a reformer will not generate many emissions. Thus, although an emissions control system is needed to meet the SULEV standard, the amount of emissions being controlled is very low and thus the potential for the emissions to rise due to deterioration of the emissions control system is low. In this way, a fuel cell vehicle running on reformat made from gasoline or methanol actually goes a long way toward meeting the goals of the original ZEV mandate.

### *Conclusion*

Knowledge of future technology attributes is not complete, and market responses to different rules and technologies cannot be accurately predicted. The actual in-use emissions level of future internal combustion engine vehicles is not known and the costs and performance of future electric-drive technologies are even less certain. The regulators who created the partial ZEV rulemaking were constrained by these conditions of high uncertainty, as well as by political considerations. Given this uncertainty and the existence of strong political forces, the California Air Resources Board has refrained from prescribing specific technologies. Nonetheless, because CARB must rely on regulatory instruments, they are obliged to design a web of complex rules that may have consequences that are not easy to predict. These rules will lead neither to optimal technology development pathways, nor to optimal pollution reduction strategies. Only hindsight will tell us how close CARB came.

This report describes the details of the complex partial ZEV credit program and suggests some potential unforeseen consequences. More research is needed to cast the overall regulatory approach in a larger context. We leave that for a later time and for others.

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