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*Making ZEV Policy Despite
Uncertainty: An Annotated Briefing
for the California Air Resources Board*

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DRU-1266-2-ICJ

January 1996

Institute for Civil Justice

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PREFACE

The federal Clean Air Act Amendments of 1990 established national ambient air quality standards, and each state not in attainment must develop a plan for meeting them. California's strategy includes strict emission standards for mobile and stationary sources and for area sources such as solvents, paints, and consumer products.

The cost and efficacy of California's plan have generated substantial debate. Studies by different interest groups and by government agencies have produced widely ranging estimates of the cost and emission reductions associated with various elements of the plan, and there is little commonly accepted empirical information on which to base policy decisions.

Because of the importance of this policy issue for all Californians, the Institute for Civil Justice undertook an analysis of the existing estimates of the cost and effectiveness of California's plan. This interim briefing focuses on one element of the plan--the zero emission vehicle (ZEV) mandate. It is an updated version of a briefing by the same name presented to the California Air Resources Board in December 1995 (DRU-1266-1-ICJ). This revision (1) excludes gasoline taxes in the calculation of ZEV narrow cost effectiveness ratios, (2) refines the assumptions used to calculate long-run narrow cost effectiveness ratios, and (3) includes an appendix with the resulting narrow cost effectiveness ratios. The technical analysis on which this briefing is based is currently in the final stages of RAND's review process. We do not expect the final version of the analysis to differ substantially from the findings presented here. The results reported in this annotated briefing may be cited as preliminary findings, subject to revision. The project is funded by a grant from the California Manufacturers' Association and by the Institute's general research funds.

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This annotated briefing discusses some of the key issues involved in making policy regarding Zero Emission Vehicles (ZEVs) in what we have found to be an extremely uncertain environment.

ZEV Analysis Is Part of Larger Study

- **Project analyzes economics of California's ozone reduction strategy**
 - Mobile and stationary sources
 - Costs, emission reductions, and cost effectiveness
 - Distribution of costs and benefits
- **Initial focus is light duty vehicle (LDV) component of the strategy**
 - Large source of emissions
 - Currently under policy review

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The ZEV analysis is part of a year-long project that analyzes the economics of California's ozone control strategy. Over the course of the study, we are examining both mobile and stationary emission sources; analyzing the costs, emission reductions, and cost effectiveness of the various elements of California's ozone reduction plan; and considering how costs and benefits are distributed both among Californians and across the rest of the nation.

We have focused initially on the light duty vehicle component of California's strategy because these vehicles contribute a significant percentage of overall emissions and because this component of the strategy is currently under review.

The study is being conducted by the Institute for Civil Justice, a research program within RAND. RAND is a nonprofit nonpartisan research institution that helps improve public policy through research and analysis.

Study Approach

- Review, critique, and extend existing studies
- Interview stakeholders to locate and interpret information
- Apply standard economic principles
- Develop models to predict costs, emission reductions, cost effectiveness, and market effects

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In conducting this analysis of California's ozone reduction strategy, we are reviewing, critiquing, and extending the most informative or influential existing studies of various elements of the strategy and talking to many key stakeholders to help us locate additional information and interpret data. In our analysis we apply standard economic principles to interpret data and estimate effects. We have also developed models to predict the costs, emission reductions, cost effectiveness, and market effects of various components of the California strategy.

**Focus of this Discussion:
Study Findings on the ZEV Mandate**

- Estimates of EV costs
- Estimates of EV emission reductions
- Cost effectiveness calculations
- Implications for ZEV policy

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This discussion focuses on one element of the LDV component of California's strategy--the ZEV mandate. We provide estimates of the costs and emission reductions of the battery-powered electric vehicles (EVs) that will be used to meet the mandate, at least initially.¹ Fly-wheels and fuel cells may also power vehicles in the future, but they both appear to be many years away from commercialization. We also discuss what the estimates imply about the cost effectiveness of EVs and draw implications for ZEV policy.

Our full report analyzes potential market effects of the mandate and the distribution of EV costs and benefits, but these issues are not addressed in this discussion.

¹The ZEV mandate does not require a particular technology. However, the only way to currently meet the mandate is with battery-powered electric vehicles. To maintain the distinction between the ZEV mandate and the current means to comply with it, we use *ZEV* when referring to the mandate and policies related to it and *EV* when referring to the vehicles that will be used to satisfy the mandate for the foreseeable future.

The Bottom Line

- **The first five years of the ZEV mandate will be costly**
- **Based on what we know now, the long-term cost effectiveness of the ZEV mandate could be just about anything**
- **California faces very unattractive outcomes with or without the ZEV mandate**
- **Enormous uncertainty and risk suggest a search for near-term policies that**
 - **Enable learning**
 - **Are not susceptible to disaster**
 - **Can be tailored as new information is obtained**

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We summarize the bottom line of our ZEV analysis as follows. First, it appears likely that during the first five years (1998-2002) the costs of the ZEV mandate will be substantial. Second, the studies we have reviewed lead to dramatically different estimates of the long-term cost effectiveness of EVs. Based on current knowledge, it seems possible that the cost effectiveness of EVs could turn out to be low, very high, or somewhere in between (see Appendix for listing of studies reviewed). The current ZEV mandate could be a great success. Or it could be a great failure.

Third, even though the benefits and costs of the ZEV mandate are highly uncertain, because of uncertainties surrounding the effectiveness of the other elements of California's ozone reduction plan, California could also face very unattractive outcomes without the ZEV mandate.

Finally, these uncertainties and risks suggest that we should be searching for near-term policies with certain characteristics. Policies should be

- designed with learning as an interim objective. Things that we want to learn about include EV technology, consumer acceptance and use of EVs, initial EV costs, how quickly costs will decline, and how well other emission control policies perform.
- robust--that is, formulated with specific attention to worst-case scenarios and policy paths that avoid the worst of the worst.
- adaptive--that is, allow us to adjust as new information becomes available.

At the conclusion of this discussion, we suggest four principles that could help to shape such policies.

Components of EV Costs

- **Fixed and variable production costs excluding first battery**
 - EVs of similar size, styling, and performance (except range) as ICEVs on road today
 - EVs converted from ICEVs
 - Small non-traditional vehicles
- **Lifetime operating costs (including first battery)**

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We divide cost into two parts--production costs and operating costs.

We examined the fixed and variable production costs, excluding the first battery, of producing EVs that are similar in size, body style, and performance (except for range) to internal combustion engine vehicles (ICEVs) on the road today. The Big 7 manufacturers subject to the mandate between 1998 and 2002 apparently intend to produce such vehicles to meet the mandate. Most of our analysis focuses on the costs of producing this type of vehicle.

The Big 7 may also meet the mandate by purchasing ZEV credits from companies that convert ICEVs to EVs. These vehicles may be of lesser quality than those EVs produced by the Big 7--for example, less durable, less safe, or harder to handle.

We also examined the production costs of small, nontraditional EVs. These vehicles may have relatively poor acceleration or limited top speed and might be demanded in market niches where freeway capability is not required.

The second cost component is lifetime operating costs. For an EV, these are the costs of electricity, batteries, and repair and maintenance. (For an ICEV, these costs include gasoline and repair and maintenance.)

Strong Disagreement About Initial Costs of EVs Similar to Current ICEVs		
	Incremental Costs Over Comparable ICEV	
	Lower Bound	Upper Bound
<u>1998-2002</u>		
Variable production cost (\$/vehicle)	3,320	15,000
Lifetime operating cost (\$/vehicle)	3,000	13,000
Industry-wide fixed cost (\$billion)	1.1	4.2
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We have considered the costs of EVs in terms of the incremental costs over an ICEV of comparable size, body style, options, and performance, excluding range. This is in keeping with how EV cost studies are typically done, with one important exception. We exclude gasoline taxes from our calculation of ICEV fuel costs. This is because these taxes represent transfers from gasoline producers and consumers to the government, rather than resource costs.

The estimates of EV costs during the first 5 years of the mandate vary dramatically in the studies we reviewed. We used these studies to develop lower and upper bounds for incremental costs--extremes within which the actual average incremental costs for EVs produced to meet the mandate seem very likely to fall. This chart illustrates the large difference between the lower and upper bound estimates and details the values used in the analysis that follows.

Lower Bounds Seem Too Optimistic, Upper Bounds Seem Too Pessimistic

For example, for variable production costs

- **Low cost estimates**
 - **Ignore some ZEV components included by manufacturers**
 - **Appear to reflect vehicles of lower quality**
 - **Ignore warranty costs**
- **High cost estimates**
 - **Assume all EVs will be similar to current ICEVs-- but Big 7 may buy credits from converters and niche vehicle producers**
 - **Cost reductions may be found**

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We consider the lower bound cost estimates too low and the upper bound estimates too high for the vehicles that will actually be produced to meet the mandate between 1998 and 2002.

The lower bound for variable production costs is likely too optimistic. First, it is based on studies that appear to overlook the costs of important EV components--the battery tray or heavy duty wiring, for example. Second, these lower costs appear to be for vehicles of lesser quality than those that the Big 7 plan to produce to meet the mandate. For example, less attention appears to be paid to durability, safety, and handling than will likely be the case for the Big 7. Finally, the lower bound estimates appear to ignore warranty costs.

The upper bound for variable production costs is likely too pessimistic for the average incremental cost of vehicles that will be produced to meet the mandate. First, it is based on studies that assume that the Big 7 will produce vehicles that are comparable to ICEVs currently on the road (except for range). Such costs would be appropriate if we assume that the Big 7 will satisfy the entire mandate with such vehicles. The Big 7, however, may choose to fill some part of their mandated quota by buying credits from converters or from firms producing niche vehicles. Because these EVs are not full-size, fully loaded vehicles, they will be less costly to produce. Second, even if the Big 7 meet their mandate entirely with EVs that they produce themselves, they may find less costly ways to produce them than they have discovered to date.

The lower and upper bounds for incremental lifetime operating costs are likely too low and too high, respectively, because they compound several optimistic or pessimistic assumptions about factors (such as electricity and gasoline costs,

the costs of batteries, vehicle efficiency, and repair and maintenance costs) that are unlikely to occur jointly.

The information available on fixed costs is very sketchy. Our upper and lower bounds should therefore be interpreted as tentative.

Although these cost estimates reflect extreme values, we use them in our subsequent analyses. The uncertainty about costs is so great that choosing any point between the extremes would be arbitrary. Therefore, using upper and lower bounds for costs appears to be the most useful (and most candid) approach.

**Costs of the ZEV Mandate in the
First 5 Years Are Substantial**

	(\$Billions)	
	<u>Lower Bound</u>	<u>Upper Bound</u>
Mandate in California only	1.9	7.9
Mandate in California, Massachusetts, and New York	2.9	12.3

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The ZEV mandate will generate substantial costs between 1998 and 2002. At the volumes required by the California mandate, the studies we reviewed suggest that industry-wide costs will run between \$1.9 and \$7.9 billion dollars.

Currently two other states, New York and Massachusetts, have adopted ZEV mandates identical to California's. The mandates in these states approximately double the number of EVs that the industry must produce nationwide between 1998 and 2002. Assuming the New York and Massachusetts mandates would not exist in the absence of the California mandate increases the cost of the California mandate.

The desirability of the ZEV mandate, of course, depends not just on the costs during the first 5 years but also on the costs in subsequent years and the emissions reduced. We address each of these issues in turn.

Scenarios for EV Variable Cost Reductions After 2002		
	<u>Optimistic</u>	<u>Pessimistic</u>
Percent decline when cumulative output doubles	25	10
Variable production cost (\$/vehicle)		
Initial incremental cost	3,320	15,000
Ultimate incremental cost	0	0
Lifetime operating cost (\$/vehicle)		
Initial incremental cost	3,000	13,000
Ultimate incremental cost	1,000	6,500
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It is very hard to predict how EV costs will change after 2002. Based on values commonly found in the literature about how production costs vary with cumulative output, we create two scenarios for the change of EV costs over time. In the first scenario, variable production costs and lifetime operating costs decline quickly--25 percent each time cumulative output doubles. In the pessimistic case, variable production cost and lifetime operating cost fall by 10 percent when output doubles.

We think it reasonable to believe that the variable production costs of EVs excluding the first battery will approach those of ICEVs. Thus we assume that variable EV production costs decline until they are the same as those for an ICEV. In contrast, our analysis suggests that when gasoline taxes are excluded, EV lifetime operating costs will remain above those of ICEVs even in the long-run. Based on a simulation of future EV lifetime operating costs, we assume that EV operating costs decline until they are \$1,000 above those of an ICEV in the optimistic scenario and \$6,500 above those of an ICEV in the pessimistic scenario.

Scenarios for EV Fixed Cost Reductions After 2002		
	<u>Optimistic</u>	<u>Pessimistic</u>
Percent decline each 5-year product cycle	50	50
Number of product cycles with incremental fixed costs	3	unlimited
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It is very hard to predict how EV costs will change after 2002. Based on values commonly found in the literature about how production costs vary with cumulative output, we create two scenarios for the change of EV costs over time. In the first scenario, variable costs decline quickly--25 percent each time cumulative output doubles. In the slow decline case, variable costs fall by 10 percent when output doubles.

For fixed costs, we adopt the assumption used in one of the studies reviewed that fixed costs decline 50 percent with each 5-year product cycle. We use this rate of decline in both the fast and slow cases, but assume in the fast decline case that incremental fixed costs disappear after three 5 year product cycles whereas they continue on, although in ever smaller quantities, in the slow decline scenario.

Emission Reductions Due to EVs Depend on Effectiveness of ICEV Control Program			
(Pounds avoided over a single EV's lifetime)			
	Effective		Ineffective
	No-NOx	Full-NOx	
ROG			
Exhaust	0	0	152
Evaporative	51	51	210
NOx	0	107	217
ROG + NOx	51	158	579

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The emission reductions due to EVs depend on the effectiveness of the ICEV emission control program. If the emission control program is very effective, the ICEV that an EV displaces will produce far fewer emissions than if the ICEV program turns out to be ineffective.

There is a great deal of uncertainty about how effective the ICEV elements of California's ozone control strategy will be. As detailed in our full report, lifetime in-use emissions of today's ICEV are uncertain, as are how new vehicle certification, warranty, and recall requirements will change those emissions. The future effectiveness of Smog-Check II, accelerated vehicle retirement programs, and on-board diagnostics (OBD) requirements are also very hard to predict. OBD II, for example, is an investment that may pay enormous dividends, but it is still too early to tell.

Given this uncertainty, we develop three estimates spanning a wide range of the emissions avoided over an EV's lifetime. In the lower estimates, the ICEV control program is effective and manufacturers will just meet the non-methane organic gas (NMOG) standard.² The NMOG standard requires that the average tailpipe certification levels for NMOG of each manufacturer's fleet of new vehicles, including EVs, not exceed a series of levels that fall over time. Because we assume that manufacturers just meet the NMOG standard, each additional EV sold allows the manufacturer to slightly increase the emissions of its remaining ICEVs. Thus, as indicated in the chart, EVs produce no

²NMOG emissions are very similar to ROG emissions, and we ignore the difference here.

net exhaust emission benefits for NMOG . EVs do reduce evaporative and marketing ROG emissions, and the reductions are equal the emissions of the low-emission vehicles that will be sold to meet the NMOG standard. The reduction in NOx will depend on how manufactures rebalance their fleets in response to ZEVs across the different types of vehicles they can use to meet the NMOG requirement (these vehicles have different NOx emissions). At one extreme, manufacturers could rebalance their fleets in such as way that EVs generate no NOx reductions. At the other, they could rebalance their fleets in a way that would remove the NOx emissions of one low-emission vehicle (LEV) or ultra low emission vehicle (ULEV). This possibility is labelled the Full-NOx case in the chart.

In the ineffective ICEV control scenario, we assume ICEVs will emit at the same rate estimated for vehicles that meet California's 1993 standards. This might be the case if the new elements of the ICEV control strategy have no effect, which seems overly pessimistic. It might also be the case if the new elements of the ICEV control strategy are partially effective, and, as many believe, the actual in-use emission of 1993 vehicles are substantially higher than current estimates

Both scenarios for emissions avoided assume that EVs are driven the same numbers of miles over their lifetime as the vehicles they displace. However, EVs may be driven more or less than the ICEVs they replace. If range limitations discourage use, emissions avoided would be less than estimated here. On the other hand, it is possible that EVs could be driven more. Advantages such as quiet ride and home recharging might make EVs the vehicle of choice in a two-car household, for example.

Definition of Cost Effectiveness

- **Following principles of economics, we**
 - **Consider costs and benefits, even after 2010**
 - **Discount costs and emission reductions to present value**
- **Cost effectiveness is the ratio of discounted costs to discounted emission reductions**
 - **\$/ (tons ROG + NOx)**

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In the studies we reviewed, cost effectiveness is used to evaluate the various elements of California's ozone reduction strategy. In our analysis, we used an extended definition of cost effectiveness based on accepted principles in the branch of economics called cost-benefit analysis. We consider costs and benefits into the indefinite future discounting both back to the present using a 5 percent annual real discount rate.³

We define cost effectiveness as the ratio of discounted costs to discounted emission reductions, measured in dollars per ton of ROG plus NOx emissions reduced. Note that the higher the cost-effectiveness ratio of a strategy element, the less attractive it appears to be.

To provide a sense of how costs and emission reductions compare during the period covered by the State Implementation Plan for Ozone (SIP), we also calculate cost-effectiveness ratios for vehicles sold between 1998 and 2010. This measure aids understanding of what to expect from EVs in the early years.

³Studies typically consider costs and benefits of electric vehicles sold between 1998 and 2010.

Cost Effectiveness Calculated for Various Combinations of Parameter Values

- Projected incremental costs of EVs depend on
 - Costs between 1998-2002
 - Rate of cost decline after 2002
- Projected emission benefits depend on
 - Emission benefits per vehicle
 - Fleet penetration of EVs over time

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We have calculated the cost effectiveness of EVs for various combinations of parameter values. For example, we have included a range of assumptions about EV costs in the first five years of the mandate as well as assumptions about how rapidly these costs will decline in subsequent years. In terms of benefits, we have included various values for emission benefits per vehicle and different assumptions about how widely EVs are accepted.

Even Long-Term Cost Effectiveness Calculations Ignore Important Policy Considerations

- Tons reduced may not be closely related to health and other benefits
- Reductions in other pollutants are beneficial (e.g., CO, CO₂ and air toxics)
- EV infrastructure costs not included
- Ignores effects of market reactions
 - Effects on vehicle prices
 - Distribution of costs between consumers and producers
 - Effects of price increases on fleet age composition and emissions

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Cost effectiveness is the common currency of the ZEV debate, and as we noted earlier, we have improved this measure by extending it beyond 2010 and by discounting costs and emission benefits to present value.

However, even long-term cost effectiveness ignores some important policy considerations, some of which are listed on this chart.

Cost effectiveness is expressed in dollars per ton of ROG plus NO_x emissions avoided, but we really should judge the economic desirability of an element of the ozone control strategy in terms of its health and other benefits--measures to which tons of emissions may not be closely related. In addition, we have considered only reductions in ROG and NO_x, but reductions in other pollutants such as CO and CO₂ are also beneficial.

Perhaps most important, even long-term cost effectiveness ignores effects of the ZEV mandate mediated through the market, including the sales prices of both EVs and ICEVs, how costs are distributed between consumers and producers, and how prices can affect the age of the fleet and, consequently, emissions. We analyze all of these issues in our full report.

Cost Effectiveness When Initial Costs Are Low and Cost Decline Is Fast					
<i>(calculated using 5% discount rate)</i>					
<u>Costs 1998-2002</u>	<u>Cost Decline</u>	<u>Fleet Penetration in 2020</u>	<u>Emissions Avoided (pounds)</u>	<u>Cost per Ton</u>	
				<u>Through 2010</u>	<u>Long- Term</u>
Low	Fast	10	579	Low	Very low
Low	Fast	10	158	Intrmed	Intermed
Low	Fast	10	51	Very high	High
Low	Fast	10	368	Low	Low
Low	Fast	20	368	Low	Very low
Low	Fast	40	368	Low	Very low
Very low = \$0 - \$10,000/ton;			High = \$50 - \$100,000/ton;		
Low = \$10,000 - \$25,000/ton;			Very high = >\$100,000/ton		
Intermediate = \$25,000 - \$50,000/ton;					
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On the next four slides we present four sets of cost-effectiveness calculations. These cases are not intended to be exhaustive. Rather they illustrate the nature of our analysis and the relative influence of some of the factors we considered.

We first consider cases in which initial costs are low and decline quickly. In the top panel of this chart, we hold the eventual penetration of EVs into the fleet at 10 percent, and we examine the three different levels of emissions avoided discussed previously. The lower panel of the chart considers various scenarios of how EV fleet penetration increases over time, holding other factors constant (emissions avoided is set at the average of the higher two estimates in the first panel). We assume that fleet penetration increases linearly from 10 percent in 2003 to the level indicated in 2020 and remains constant from then on.

We report cost effectiveness in categories of very low, low, intermediate, high, and very high (the numerical values are reported in Appendix A). Measures with cost effectiveness less than \$10,000 per ton (very low category) are very attractive on cost-effectiveness grounds: various estimates of the damage caused by ROG and NOx in the South Coast air basin are at the upper end of this range. Cost effectiveness in the low range (\$10,000 to \$25,000 per ton) characterizes some measures currently in place in the South Coast basin so it is likely that the ZEV mandate would be acceptable if its cost effectiveness were in this range. To achieve federal and state air quality standards we may have to adopt measures in the intermediate range (\$25,000 to \$50,000 per ton), but such measures might be justified only if there are

substantial benefits not captured by these ratios. Policymakers should be very leery of measures with cost-effectiveness ratios above \$50,000 per ton (high and very high categories) because ratios in this range are several times larger than estimates of damages caused by emissions.

When initial costs are low and decline quickly, long-term cost effectiveness ratios vary widely depending on the effectiveness of the ICEV control program. When the program is ineffective (emission avoided equals 579 pounds), the long-term cost effectiveness ratio is very low. This is true even when fleet penetration remains at 10 percent. When the ICEV control program is effective, the long-term cost effectiveness ratio is intermediate or high, depending on what is assumed about NO_x reductions. Cost-effectiveness ratios through 2010 are approximately twice as high as the corresponding long-term ratios.

Cost Effectiveness When Initial Costs Are Low and Cost Decline Is Slow					
<small>(calculated using 5% discount rate)</small>					
<u>Costs 1998-2002</u>	<u>Cost Decline</u>	<u>Fleet Penetration in 2020</u>	<u>Emissions Avoided (pounds)</u>	<u>Cost per Ton</u>	
				<u>Through 2010</u>	<u>Long- Term</u>
Low	Slow	10	579	Low	Very low
Low	Slow	10	158	High	Intrmed
Low	Slow	10	51	Very high	Very high
Low	Slow	10	368	Intrmed	Low
Low	Slow	20	368	Low	Low
Low	Slow	40	368	Low	Very low
Very low = \$0 - \$10,000/ton;			High = \$50 - \$100,000/ton;		
Low = \$10,000 - \$25,000/ton;			Very high = >\$100,000/ton		
Intermediate = \$25,000 - \$50,000/ton;					
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How fast EV costs decline makes some, but not a great deal of difference when initial costs are low. When fleet penetration remains at 10 percent, cost effectiveness through 2010 is now high when emissions avoided are 158 pounds rather than the intermediate value observed when costs declined more quickly.

Fleet penetration above 10 percent decreases the long-term cost-effectiveness ratio from low to very low, illustrating the importance of the long-term marketability of electric vehicles to the success of the mandate.

In several of these scenarios, electric vehicles appear attractive on cost-effectiveness grounds in the long run but not through 2010. This illustrates that if the ZEV mandate pays off, it may do so only over an extended period.

Cost Effectiveness When Initial Costs Are High and Cost Decline Is Fast					
<i>(calculated using 5% discount rate)</i>					
<u>Costs 1998-2002</u>	<u>Cost Decline</u>	<u>Fleet Penetration in 2020</u>	<u>Emissions Avoided (pounds)</u>	<u>Cost per Ton</u>	
				<u>Through 2010</u>	<u>Long- Term</u>
High	Fast	10	579	High	Intrmed
High	Fast	10	158	Very high	Very high
High	Fast	10	51	Very high	Very high
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Low = \$10,000 - \$25,000/ton;			Very high = >\$100,000/ton		
Intermediate = \$25,000 - \$50,000/ton;					
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This third set of cases suggests that even with a fast rate of decline, high initial costs can result in high cost-effectiveness ratios. When emissions avoided are 158 pounds or less and EV sales remain at 10 percent after 2003, cost per ton is more than \$100,000.

In none of these scenarios do electric vehicles look appealing on the basis of cost effectiveness through 2010.

Cost Effectiveness When Initial Costs Are High and Cost Decline Is Slow

(calculated using 5% discount rate)

<u>Costs 1998-2002</u>	<u>Cost Decline</u>	<u>Fleet Penetration in 2020</u>	<u>Emissions Avoided (pounds)</u>	<u>Cost per Ton</u>	
				<u>Through 2010</u>	<u>Long- Term</u>
High	Slow	10	579	Very high	High
High	Slow	10	158	Very high	Very high
High	Slow	10	51	Very high	Very high
High	Slow	10	368	Very high	Very high
High	Slow	20	368	Very high	Very high
High	Slow	40	368	Very high	High

Very low = \$0 - \$10,000/ton; High = \$50 - \$100,000/ton;
 Low = \$10,000 - \$25,000/ton; Very high = >\$100,000/ton
 Intermediate = \$25,000 - \$50,000/ton;

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The worst cases occur when initial costs are high and they decline slowly. Here long-term cost per ton is very high in most of the cases examined. In fact, in one case it was over \$500,000 per ton reduced (see Appendix A). As shown in the lower panel, even fleet penetration up to 40 percent does not reduce cost per ton below \$100,000.

On Cost-Effectiveness Grounds, ZEV Mandate Could Be a Great Success or a Great Failure					
<small>(calculated using 5% discount rate)</small>					
<u>Costs 1998-2002</u>	<u>Cost Decline</u>	<u>Fleet Penetration in 2020</u>	<u>Emissions Avoided (pounds)</u>	<u>Cost per Ton</u>	
				<u>Through 2010</u>	<u>Long- Term</u>
Low	Fast	10	579	Low	Very Low
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High	Slow	10	579	Very high	High
High	Slow	10	158	Very high	Very high
Very low = \$0 - \$10,000/ton; Low = \$10,000 - \$25,000/ton; Intermediate = \$25,000 - \$50,000/ton;			High = \$50 - \$100,000/ton; Very high = >\$100,000/ton		
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We distill several conclusions from the cost-effectiveness estimates summarized on the previous four charts:

Most fundamentally, on cost-effectiveness grounds, the ZEV mandate could be a great success or a great failure. Long-term EV cost effectiveness depends on production costs in the first five years, how quickly costs decline, the eventual level of fleet penetration of EVs, and how effectively other policies reduce emissions from ICEVs. Different scenarios involving various combinations of assumptions about these factors lead to radically different implications about the long-term cost effectiveness of the ZEV mandate.

Some scenarios lead to the conclusion that cost effectiveness of the ZEV mandate will be very low (less than \$10,000/ton of ROG plus NOx emissions avoided). Examples are those constructed assuming that EV production costs are low during the first five years and decline quickly and the ICEV program is ineffective, even if fleet penetration never exceeds 10% of new LDV sales.

In contrast, cost per ton of ROG plus NOx avoided could turn out to be much more than \$100,000 per ton if costs start out high and fall slowly, fleet penetration remains at 10%, and the ICEV program turns out to be effective (in which case EVs will be displacing clean ICEVs).

Comparisons of cost effectiveness through 2010 and long-term cost effectiveness illustrates that electric vehicles should be viewed as an investment that may pay off only after 2010 if at all.

Various participants in the debate confidently predict that the ZEV mandate will be cost effective, and others--just as confidently--predict that on cost-effectiveness grounds it will be a disaster. Based on current knowledge, however, we believe that no one can be sure about the cost effectiveness of the present ZEV mandate.

But Even Without ZEVs, Very Undesirable Outcomes Are Possible

- **ZEV technology stagnates**
- **Results of ICEV control strategy disappointing**
- **Promising, new emission control measures are not discovered**
- **California far short of compliance in 2010**
- **Ozone health effects are worse than currently thought**
- **Available control measures are extremely costly**

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We've analyzed what could happen under the existing mandate and concluded that the results could be very disappointing. Such a possibility does not imply, however, that California policymakers should forget about ZEVs. This is because without ZEVs California might also face very undesirable policy choices. To highlight this possibility consider the following pessimistic--but not inconceivable--scenario as 2010 approaches.

Suppose California were to repeal the mandate and, as a--plausible, yet not inevitable--consequence, ZEV technology stagnates. Suppose further that the ICEV components of the current ozone-reduction strategy don't work very well, new cost-effective emission control options have not been discovered and that (a few years before 2010) California finds itself far short of meeting the current federal ozone standards. To make matters worse, suppose in addition that the health effects of ozone are found to be much worse than currently thought and as a result relaxing air quality standards appears reasonable to almost no one. Under these circumstances, and even some less extreme ones perhaps, California would find itself desperately seeking ways to reduce emissions of ozone precursors and finding only additional measures that are very expensive, such as very aggressive transportation control measures (TCMs) or even restrictions on industrial activity.

Clearly we would like not to leave ourselves open to such a situation. The policy challenge is daunting, and we have no easy answers. We are also skeptical of easy answers proposed by others. Good policy should acknowledge and accommodate the uncertainties we face, rather than denying them.

The Bottom Line

- The first five years of the ZEV mandate will be costly
- Based on what we know now, the long-term cost effectiveness of the ZEV mandate could be just about anything
- California faces very unattractive scenarios with or without the ZEV mandate
- ⇒ • Enormous uncertainty and risk suggest a search for near-term policies that
 - Enable learning
 - Are not susceptible to disaster
 - Can be tailored as new information is obtained

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Available information leads us to conclude that the promise of ZEVs is highly uncertain. How might policymakers best respond to such a dilemma? As we understand the purpose of today's hearing, CARB is considering how best to promote ZEV development and commercialization for the purpose of furthering our air-quality goals. The following suggestions are offered within this context.

We think it crucial to recognize that what needs to be done now is to decide how to proceed over the near term, until a few years into the next century, say. We need not decide now whether or how California policy will address ZEVs beyond such a time horizon. We also think it crucial to proceed in ways that accommodate the facts that the stakes for Californians are high, that the future is very uncertain, and that we will learn more as time passes.

The uncertainties and risks involving ZEVs suggest that we should be searching for near-term ZEV policies with three key characteristics.

First, new knowledge can be very valuable and policy should be designed with learning as an interim objective. Our simulations highlight the importance of learning about key factors such as magnitude of costs during the first 5 years of the mandate, how quickly they decline, consumer acceptance of EVs, and how well other emission control policies perform. As new information becomes available, the most promising set of policies should become better defined.

Second, near-term policy should be formulated while being mindful that very undesirable outcomes--economic, environmental, or both--are possible. This suggests that policy be formulated with specific attention to worst-case scenarios and policy paths that avoid the worst of the worst. Such policies are often referred to as “robust” policies.

Third, as we learn about various factors--such as the promise and cost of ZEV technology, the performance of existing ICEV control measures and the availability of measures that have yet to be identified, we want to be in a position to use this information to improve policy. Policies that can be tailored as new information arrives are often referred to as “adaptive” policies. In thinking about adaption, however, it is important to strike a balance between the value of flexibility and the costs of uncertainty to those who must anticipate future policy when they plan and invest.

We conclude by suggesting four principles that could help to shape ZEV policies along the lines suggested here.

Principles for Reevaluating ZEV Policy

- **Learn whether EVs are an appropriate cornerstone of California's long-term ozone control strategy**
- **Protect long-run prospects for EVs**
- **Accommodate a broad range of vehicles and innovators**
- **Look for ways to lower the costs of accomplishing these aims**

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First, EVs may or may not be an appropriate cornerstone of California's long-term ozone control strategy. Determining this requires learning about many different things. Here are some of the things we need to learn more about:

- The performance, cost, and availability of EV technology
- Consumer valuation of EV performance
- Effectiveness of current ICEV control measures
- Cost and effectiveness of alternative LDV emission control measures such as new transportation control measures or taxes aimed at vehicle-specific emission levels
- The cost and effectiveness of policies aimed at sources of emissions other than LDVs, such as heavy-duty vehicles and stationary sources.

Second, while we are agnostic about whether EVs should be a cornerstone of California's LDV strategy, we think it very important to protect the long-run prospects for EVs. EVs may turn out to be attractive on cost and performance grounds, and for this reason it is critical to avoid near-term developments that would constrain our ability to rely on them in the long term. Both marketing and political factors are relevant here.

On the market side, we need to be concerned about how the mandate or its modification could affect behavior of both consumers and innovators over the long term. Regarding consumers, ZEV policy should consider the potential for consumer disappointment with EVs in the early years, for example, due to

limited range, reliability, or infrastructure. Such disappointment could give EVs a bad name and create long-term difficulties in marketing even EVs that would not disappoint consumers. As our simulations indicate, high future fleet penetration rates for EVs could be essential to their eventual cost effectiveness. Moreover--and more important--if EVs are cost effective relative to other policies available in the future, higher market penetration rates for EVs could be the key to getting large quantities of emission reductions from them. This underscores the importance of preserving the long-run marketability of EVs, and making sure they don't become the Edsel of the 1990s.

ZEV policy should also consider the impact of possible revisions in the mandate on the future willingness of innovators to invest. This calls for striking a careful balance between flexibility and predictability in policy formulation. For example, whatever the outcome of the current deliberations, it would be helpful if CARB would announce future times at which the policy will be reviewed and indicate the major factors that will be considered.

On the political front, it is also important to consider the impact of the mandate on the ability of CARB to adopt innovative policies in the future. If CARB promotes a policy that turns out to be wasteful, then it may not be able, for example, to promote EVs in the future even if technological developments make EVs a good bet.

Third, ZEV policy should also accommodate a broad range of vehicles and innovators because the most promising path to widespread EV use is far from clear. We should beware of policies that put undue emphasis on one type of vehicle or on one type of innovator. For example, some believe that the most promising path to major emission reductions from EVs involves important roles for small EVs (e.g., neighborhood electric vehicles). These are not the type of vehicles that will apparently be produced by the Big 7 in the early years of the mandate, however. The current mandate may thus give us little insight into what electric-drive transportation alternatives are most viable. Similarly, if the mandate is met primarily by EVs produced by established firms, the demand for the products of small, innovative firms may be dampened.

Finally, ZEV policy should look for ways to lower the cost of achieving these aims. For example, how can we learn more about the potential of advanced batteries while avoiding costs associated with commercialization of lead-acid batteries? What can we learn about consumer use of EVs and requirements for range without fielding a large fleet of EVs before the turn of the century? If the mandate is scaled back or delayed, are there cost-effective ways to make up any lost emission reductions?

Of course, such principles--if accepted--must be translated into policy actions. Doing so will require wisdom, energy, creativity, and cooperation.

Appendix A

Table A-1 contains the narrow cost effectiveness ratios calculated for the various scenarios. The four panels in the table correspond to the four sets of cost-effectiveness calculations in the briefing.

Narrow cost effectiveness through 2010 considers the costs and lifetime emission reductions of all electric vehicles produced from 1998 through 2010. Narrow cost effectiveness through 2020 similarly considers costs and emission reductions through 2020 (not presented in the briefing). Long-term narrow cost effectiveness calculates costs and emission reductions assuming that electric vehicles continue to be sold into the indefinite future.

Table A-1 also also presents narrow cost-effectiveness ratios calculated using two different discount rates (3 and 5 percent). This provides some information on the sensitivity of the ratios to this parameter.

Table A-1

Narrow Cost-Effectiveness Ratios for Electric Vehicles
Under Various Assumptions

Fleet Penetration in 2020 (percent)	Emissions Avoided per Vehicle (lbs ROG+ NOx)	Narrow Cost Effectiveness at 3		Narrow Cost Effectiveness at 5	
		Through 2010	Through 2020	Through 2010	Through 2020
		Percent Discount Rate (\$1000/ton ROG+NOx)		Percent Discount Rate (\$1000/ton ROG+NOx)	
		Long-term		Long-term	
A. Low Initial Cost, Fast Cost Decline					
(Initial incremental variable costs=\$3,320 per vehicle; initial fixed cost=\$1.050 billion; initial incremental operating costs=\$3,000 per vehicle; 75 percent learning rate; ultimate incremental operating costs = \$1,000 per vehicle)					
10	579	10	8	5	7
10	158	38	28	20	26
10	51	119	87	62	81
10	368	16	12	9	11
20	368	15	10	7	9
40	368	13	9	7	8
B. Low Initial Cost, Slow Cost Decline					
(Initial incremental variable costs=\$3,320 per vehicle; initial fixed cost=\$1.050 billion; initial incremental operating costs=\$3,000 per vehicle; 90 percent learning rate; ultimate incremental operating costs = \$1,000 per vehicle)					
10	579	15	10	7	9
10	158	54	37	24	33
10	51	168	116	75	102
10	368	23	16	10	14
20	368	21	13	8	11
40	368	17	11	7	9

Table A-1
(continued)

Fleet Penetration in 2020 (percent)	Emissions Avoided per Vehicle (lbs ROG+ NOx)	Narrow Cost Effectiveness at 3		Narrow Cost Effectiveness at 5	
		Through 2010	Through 2020	Through 2010	Through 2020
		Percent Discount Rate (\$1000/ton ROG+NOx)		Percent Discount Rate (\$1000/ton ROG+NOx)	
		2010	2020	2010	2020
		Long-term	Long-term	Long-term	Long-term
C. High Initial Cost, Fast Cost Decline					
10	579	54	42	32	48
10	158	199	153	117	147
10	51	615	475	364	456
10	368	85	66	50	63
20	368	79	58	45	56
40	368	70	52	42	59
<p>D. High Initial Cost, Slow Cost Decline (Initial incremental variable costs=\$15,000 per vehicle; initial fixed cost=\$4.200 billion; initial incremental operating cost=\$13,000 per vehicle; 75 percent learning rate; ultimate incremental operating costs = \$6,500 per vehicle)</p>					
10	579	96	80	59	74
10	158	351	293	217	273
10	51	1,088	909	673	845
10	368	151	126	93	117
20	368	143	112	79	100
40	368	132	98	67	84

Appendix

Studies Reviewed For EV Analysis

We reviewed the following studies in the course of our analysis of the ZEV mandate.

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