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Learning from California's Zero-Emission Vehicle Program

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SUMMARY

The California Air Resources Board (CARB) created the Zero-Emission Vehicle (ZEV) program in 1990 hoping to achieve significant new emission reductions from the state's passenger vehicle fleet. In contrast to CARB's past approach of securing emission reductions from automakers through incremental improvements in conventional internal combustion engine vehicles, the ZEV program linked a performance standard—zero emissions—with a sales mandate. Given the limited zero-emissions options available at the time, ZEV created a de facto mandate for a specific technology: battery-electric vehicles.

By setting a sales mandate, thus creating an assured market for a particular technology, the ZEV program was intended to help overcome obstacles to the deployment of advanced-technology vehicles and infrastructure and the development of vehicle components. But when it became clear after several years that battery-electric vehicles were not meeting necessary cost and performance goals, the ZEV program was modified to provide credit for new types of clean conventional vehicles and for vehicles that employed advanced technology but which did not have zero emissions.

This outcome reflects the uncertainty in the potential for furthering advanced technology. Patenting data, for example, show an initial innovative push by industry in response to the ZEV program, but as it was amended over time, this relationship weakened. There has been little improvement in the cost or performance of battery-electric vehicles since CARB's 1990 mandate, although there have been some important technology spillovers, particularly battery technology for use in hybrid-electric vehicles. The environmental outcomes of the ZEV program also reflect uncertainty in the potential for advancing conventional technology. Although the ZEV program has resulted in environmental benefits at least as large as those associated with the original structure of the program, these benefits have been achieved primarily through continued but unanticipated improvements in conventional vehicles. The lower emissions from these vehicles will result in a roughly 10 percent reduction in evaporative and upstream non-methane organic gas (NMOG) emissions relative to a similarly sized fleet of the cleanest non-ZEV eligible conventional vehicles.

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The ZEV program's history also illustrates the challenge of using technology mandates as environmental policy tools. CARB's overestimation of the potential of advanced technology led to significant changes in the program when the potential went unfilled. These changes resulted in an extremely complex program and a weakened demand signal for zero-emissions vehicles. Meanwhile, CARB also underestimated the potential for conventional technology improvements.

Together, these findings suggest that CARB would be better served by a technology-neutral program, such as an updated version of the original Low-Emission Vehicle program, which capitalizes on the significant advances in conventional technology that have been made under the ZEV program and includes upstream emissions.

Acronyms

AB	Assembly Bill
ACP	alternative compliance path
AT-PZEV	Advanced-technology partial-zero-emission vehicle
BEV	battery-electric vehicle
BTAP	Battery Technology Advisory Panel
CARB	California Air Resources Board
FCV	fuel cell vehicle
GHG	greenhouse gas
GM	General Motors
HEV	hybrid-electric vehicle
LEV I	Low-Emission Vehicle program I
LEV II	Low-Emission Vehicle program II
NiMH	nickel metal hydride
NLEV	National Low Emission Vehicle program
NMOG	non-methane organic gas
PEM	polymer electrolyte membrane
PNGV	Partnership for a New Generation of Vehicles
PZEV	partial-zero-emission vehicle
SULEV	Super-ultra low-emission vehicle
SUV	sport utility vehicle
ULEV	Ultra low-emission vehicle
USABC	U.S. Advanced Battery Consortium
ZEV	zero-emission vehicle

Introduction

California is known as an international leader in environmental policy, particularly in the realm of air pollution. The state is home to the worst air quality in the nation and has developed aggressive programs to reduce emissions, especially from passenger vehicles. Achieving further reductions as the state's population of both people and cars continues to grow will require major technological advances. It is therefore useful to consider one of the state's previous efforts to spur major innovation in clean technology to learn lessons for future efforts.

The Zero-Emission Vehicle program is unique, targeting the introduction of advanced technology vehicles through the coupling of a performance standard—zero emissions—with a sales mandate to automakers. When the program was initiated in 1990, mandating a zero-emission vehicle was considered a radical step forward but one that was necessary given the state's projected growth and the need to meet federal air quality standards. This radical innovation is in contrast to the previous regulatory framework that targeted incremental improvements in vehicle emissions by improving on the existing internal combustion engine and by using add-on pollution control technologies.

Although the ZEV program has since been modified, to provide more time for the introduction of "pure" ZEVs, and the production and sale of such vehicles remain the program's ultimate goals, these goals have yet to be realized on a large scale.

We aim to answer three questions:

1. What has been the relationship between the ZEV program and technology development?
2. What have been the environmental outcomes of the ZEV program?
3. What lessons can we learn from ZEV?

Answers to these questions should help inform the ongoing review process for the ZEV program itself and give guidance for the state's wider efforts to reduce greenhouse gas emissions (see the text box and Figure 7 on page 12).

The Context of ZEV

Vehicle emissions result from the combustion of fuel (in California passenger vehicles, predominantly gasoline) and from evaporative emissions from the vehicle itself during operation and refueling. In addition, emissions occur in the extraction, refining, and distribution of fuel; together with vehicle refueling emissions, these are defined as "upstream" emissions. Almost all regulatory efforts to reduce emissions from passenger vehicles have focused on reducing emissions from vehicles, rather than upstream emissions, although there have been efforts to reduce refueling emissions as well.

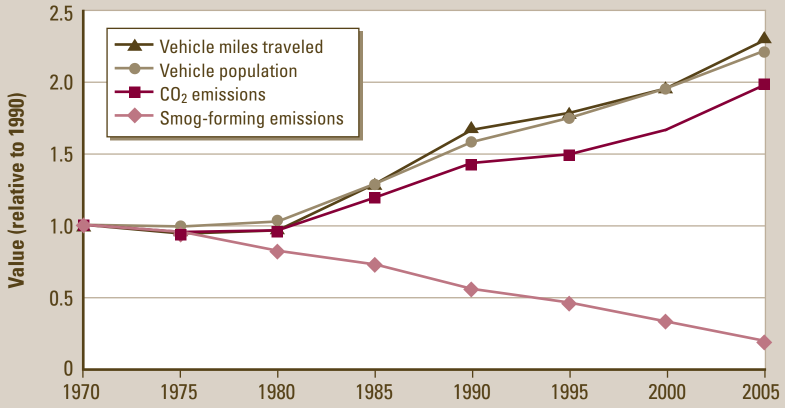
Because of the state's early leadership in the area of environmental policy regarding vehicle emissions, as well as its severe air quality problems, the Federal Air Quality Act of 1967 gave California a waiver to set its own emission standards for mobile sources. It is the only state to have this authority, which is maintained in the current federal Clean Air Act, in section 209.[1] The state's expertise and experience with mobile source pollution is found largely within the California Air Resources Board, which was formed in the late 1960s by combining the California Motor Vehicle Pollution Board and the Bureau of Air Sanitation. CARB, now part of the California Environmental Protection Agency, has the authority to set air quality standards in the state and to mandate programs to improve that air quality.

Pushing Technology: California's Emission Standards for Passenger Vehicles

Since 1970, California has achieved significant success in reducing emissions from new passenger vehicles. As shown in Figure 1, even as the state's vehicle population, vehicle miles traveled, and amount of driving have increased, smog-forming emissions from California's passenger vehicle fleet have decreased. The reductions in smog-forming emissions are projected to continue into the future, despite continued growth in vehicle population and use (California Air Resources Board, 2007a). (Meanwhile, carbon dioxide emissions, which contribute to global warming, have not been targeted by past regulations and have continued to increase.) Moreover, as Figure 2 shows, California has led the nation in setting more stringent standards. One result is that over the past several decades, federal emission standards for passenger vehicles have become progressively more stringent as well.

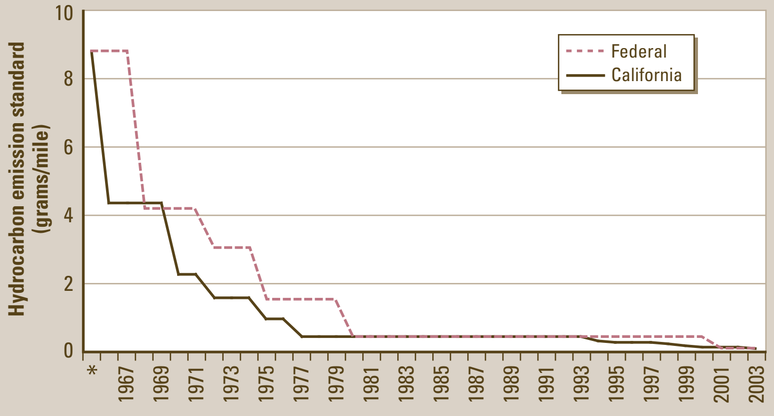
Over time, the form of emission regulations for passenger vehicles in California has evolved, gener-

Figure 1. California Average Daily Vehicle Miles Traveled, Vehicle Population, and Emissions from Passenger Vehicles, 1970–2005



Source: California Air Resources Board (2006).

Figure 2. Federal and California Hydrocarbon Emission Standards for Passenger Vehicles, 1967–2003



Source: National Research Council (2006).
* Uncontrolled.

ally increasing in flexibility. CARB's first regulation, in 1966, took the form of a technology mandate that required positive crankcase ventilation (PCV). In the late 1960s and early 1970s, CARB established single performance standards for four vehicle types, one each for new gasoline and diesel passenger cars and new gasoline and diesel trucks, which were subsequently updated and revised. In 1990, CARB established the LEV program, which took effect with the 1994 model year. The LEV rules were a notable change. Rather than creating a single performance standard, the LEV program established a number of emission categories for both cars and light-duty trucks (i.e., sport utility vehicles (SUVs), minivans, and pickup trucks) with varying levels of stringency to which manufacturers could certify new vehicles, but with no requirements placed on the number of vehicles in any one emission category that had to be sold. Vehicle sales mix is constrained by a sales-weighted fleet average emissions rate.

This structure is maintained in the current incarnation of the LEV program, LEV II, which was passed in 1998 and took effect with the 2004 model year.

Technology Mandates

A major challenge in establishing any program to induce innovation for improving environmental performance is uncertainty, in particular uncertainty in technology development. If regulators underestimate technology development, they run the risk of setting a performance standard that is not stringent enough, leaving potential environmental benefits on the table. On the other hand, regulators can overestimate technological potential and create a performance standard that is too stringent, resulting in unacceptably high control costs relative to the environmental benefits.

Most previous studies of environmental innovation in the automotive sector link higher levels of innovative activity directly to regulatory efforts, predominantly performance standards (see, for example, Brown, 1995; Lee, 2005; van den Hoed, 2005). The level of the performance standards is generally set to be "technology forcing"—in the sense that the standards are to be met through unspecified technology that is not yet available for widespread commercial use (National Research Council, 2006, p. 115). As the standards have been strengthened, emission-control technologies have been developed and improved to meet the more stringent limits (National Research Council, 2006). Automakers have typically met regulations more quickly and at lower cost than anticipated when the regulations were created (Harrington, Morgenstern, and Nelson, 1999; Anderson and Sherwood, 2002).

The LEV I and LEV II programs followed this model but added flexibility. They focus on reducing emissions of oxides of nitrogen, NMOG, and carbon monoxide.[2] NMOG and carbon monoxide are the precursors of ozone, the primary component of smog. Although regulators anticipated that complying with the most stringent LEV emission categories could require clean-burning fuels, the regulations did not mandate a particular technology or the mix of vehicles to be sold (California Air Resources Board, 1990). Instead, the constraint on the manufacturers under LEV I and LEV II was that the sales-weighted average emissions of the vehicles sold in California (including zero-emission vehicles) had to remain below a set NMOG emissions level, known as the NMOG average, which declines over time.

The ZEV Mandate

When CARB established the ZEV mandate as part of the LEV regulation in 1990, it departed from the trend toward more flexibility. At the time, CARB believed that ZEVs—defined as vehicles that have "no exhaust or evaporative emissions of any regulated pollutant" (California Air Resources Board, 1990, p. 32)[3]—were necessary to meet federal air quality standards in the most polluted regions of the state. Two characteristics of ZEVs made them attractive from an air quality perspective. First, they emit no criteria air pollutants or toxic emissions either from the vehicle or in refueling. Second, they do not require an emission-control system that can deteriorate over time; deterioration is a major issue that leads to high emissions from old and high-mileage vehicles in the fleet. In addition to specifying a performance standard—zero emissions—the ZEV mandate included a sales requirement. By imposing this, CARB created a de facto technology mandate for battery-electric vehicles (BEVs)—at that time, such vehicles were the only types able to meet the zero-emission standard.[4] The sales mandate required that sales of ZEVs constitute a specified share of sales by each large-volume automobile manufacturer: 2 percent of new vehicles sold annually in 1998 through 2000, 5 percent of new vehicles in both 2001 and 2002, and 10 percent of new vehicles sold in 2003 and after.[5]

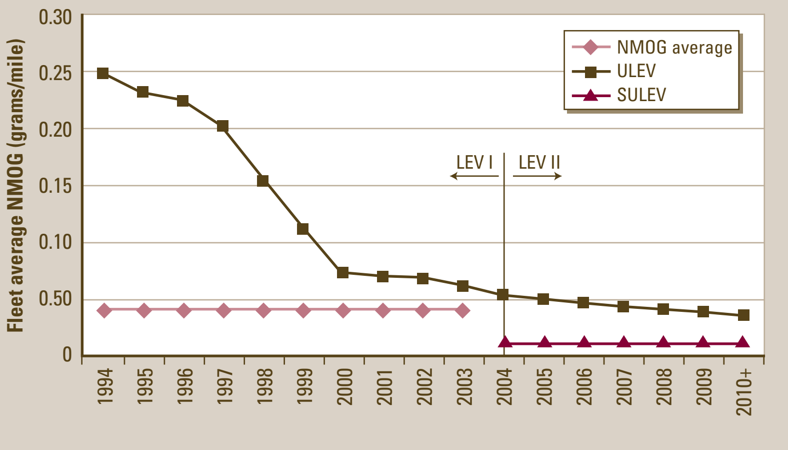
Such mandates are designed to overcome impediments to the widespread diffusion of new inventions. By creating a market for new technology, they can help overcome cost barriers by encouraging larger production volumes that can take advantage of economies of scale and learning, and they can encourage the development of necessary infrastructure that might not otherwise be a target of investment.

However, a sales mandate for a specific technology comes with risks as well. If the policy is too specific or too stringent, regulators run the risk of choosing the wrong technology and getting locked into a "suboptimal" technology pathway (Kemp, 1997). In the case of vehicles, a suboptimal path would be one that relied on technologies that do not meet consumer demands or are not cost-effective. This could result in high costs being passed on to consumers and the diversion of resources from the development of other promising technologies. For these reasons, a sales mandate can be riskier than a more general performance standard, which can also help create a market for new technology while providing industry with greater flexibility.[6]

Although the ZEV program maintained a long-term environmental goal (widespread use of zero-emission vehicles), the near-term goal had a primarily technological focus. This is evident when comparing the most stringent non-ZEV LEV I and LEV II emission categories, known as Ultra LEV (ULEV) and Super-Ultra LEV (SULEV), with the declining NMOG average required in the regulation, as shown in Figure 3. In both cases, the most stringent non-ZEV emission categories are lower emitting than the NMOG average (the calculation of which includes ZEVs). This shows that the NMOG average could be met without any ZEV sales. Thus, ZEV sales were not required to provide the near-term environmental benefits established in the LEV standards; instead, ZEV sales were part of a longer-term vision that encompassed a need for radical innovation in vehicle technologies to achieve future environmental goals. It is important to note, however, that ZEVs provide an environmental benefit beyond the reduction in tailpipe emissions reflected in the NMOG average, because ZEVs have no evaporative emissions and result in lower upstream emissions.

Several factors supported the 1990 proportional sales requirement for large-volume automobile manufacturers. ZEVs appeared to be technologically and economically feasible within the 8–13-year time frames originally envisioned. Manufacturers appeared to be headed in that technological direction, as reflected by the debut of General

Figure 3. Fleet Average NMOG Requirement and Most Stringent Emission Categories Under LEV I and LEV II



Source: LEV II regulations.

Motors' (GM's) BEV, the Impact (later sold as the EV1), at the 1990 Los Angeles Auto Show (Shnayerson, 1996). In April 1990, GM's chairman, Roger Smith, said he intended to institute a "major development program" for the Impact, which he envisioned capturing synergies between the expertise of GM subsidiaries: Hughes for electronic engineering and Rockwell for lightweight materials (Wallace, 1995).[7] GM's commitment to the vehicle was in turn informed, in part, by knowledge that "CARB was considering some type of mandate for zero-emission vehicles" (Wallace, 1995). At the same time, GM's public commitment to the Impact played a large role in making that consideration by CARB a reality. CARB also anticipated that BEVs would be cost-competitive with conventional internal combustion engine vehicles, except for the batteries, which they estimated would cost $1,350 by the time the program got into full swing (California Air Resources Board, 1990, p. 64). Moreover, the 1990 LEV I and ZEV regulations hedged CARB's bet by including a requirement that CARB staff prepare biennial reviews to assess the status of the technology needed to meet the standards. Because they were part of the much broader and higher-profile LEV regulations, which also included a clean fuel component, the ZEV mandate received very little attention at the time that it was passed (see Collantes, 2006, for a more detailed discussion).

Ultimately, battery-electric vehicles failed to meet cost and performance goals.

In addition, several other programs that complemented ZEV emerged in the 1990s, providing funds for research, development, and the means for cooperation in the development of advanced vehicle technology. The U.S. Advanced Battery Consortium (USABC) formed in 1990 to support the ZEV mandate and created a partnership among domestic automakers and the federal government to research and develop electric vehicle batteries. In 1993, the federal government initiated the Partnership for a New Generation of Vehicles (PNGV) with domestic automakers, which included a focus on several ZEV-relevant technologies, including hybrid-electric vehicles. Still later, in 2000, foreign and domestic automakers, fuel cell manufacturers, hydrogen refueling partners, and several California state and local agencies formed the California Fuel Cell Partnership to promote fuel cell vehicle development and deployment.

ZEV Reviews and Amendments

Ultimately, battery-electric vehicles failed to meet cost and performance goals. Battery costs were too high and prevented BEVs from competing with internal combustion engine vehicles. Nor could BEVs compete successfully with conventional vehicles on vehicle range.[8] GM dropped the Impact program in 1993 and replaced it with a much more modest electric vehicle program (Wallace, 1995, p. 169), although the program's demise was hastened by the tremendous losses posted by GM in 1991 and 1992 that led to important internal leadership changes and cost-cutting. As established in the original LEV I regulatory language, the LEV and ZEV programs jointly were to undergo biennial reviews, and these reviews became a critical element in the ZEV process.

During the reviews, the ZEV program was changed in response to the state of the technology—changes that altered the time frame in which the ZEV mandate was to be met and broadened the scope of the vehicle types that were allowed credit under the program (see Table 1). In the 1992 and 1994 reviews, CARB confirmed that the ZEV technology was progressing on schedule and reaffirmed its commitment to both the LEV and ZEV regulations. Subsequent reviews focused solely on the ZEV regulations and the development status of ZEV-enabling technology, and for these, CARB convened a panel of independent experts, the Battery Technology Advisory Panel (BTAP), to assess the state of battery technology development.

This panel's first review in 1995 concluded that batteries that would meet consumer performance and cost expectations would probably not be available until the 2000–2001 time frame, three years later than originally planned. Figure 4 shows battery performance by composition (nickel metal

Table 1. Vehicle Categories Established in the ZEV Program Through October 2006

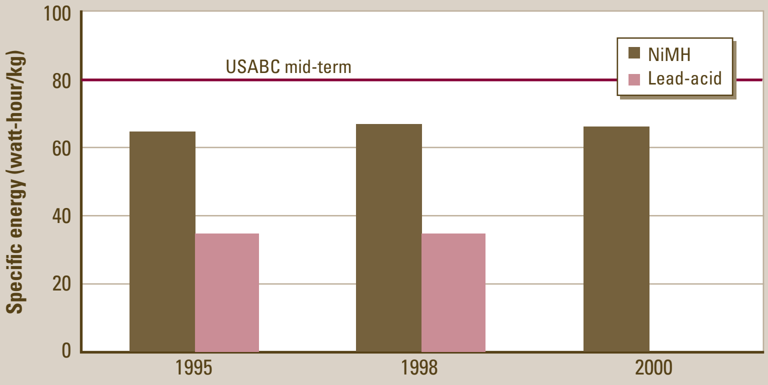
Vehicle Category	Date Introduced in ZEV	Vehicle Sales 2001–2005	Example Models
Zero-emission vehicle	1990	4,400[a]	Toyota RAV4 electric vehicle
Partial-zero-emission vehicle (PZEV): Vehicle that meets the most stringent tailpipe standards, meets the zero-evaporative-emission standard, and has a 150,000-mile emission warranty	1998	430,000	Some models of Ford Focus, Toyota Camry
Advanced technology partial-zero-emission vehicle (AT-PZEV): Vehicle that meets the PZEV requirements and incorporates such advanced technology as energy storage or electric motors	2001	70,000	Toyota Prius, Honda Civic Hybrid, Honda Civic GX (CNG)
Fuel cell vehicle (FCV)	2003	None to date, although some demonstration vehicles are in use	

Source: Vehicle sales figures were obtained through personal communication with K. Eley, Air Pollution Specialist, ZEV Implementation Section, California Air Resources Board, 2006.
[a] These are BEVs that were either sold or placed into use between 1996 and 2003.

hydride (NiMH) versus lead-acid) and specific energy relative to the "mid-term" specific energy goal set by the USABC. Even 10 years after the ZEV program began, batteries were still not close to achieving even the USABC mid-term goal.

In response to the 1995 BTAP report and subsequent staff recommendations, CARB members voted in 1996 to eliminate the ZEV vehicle-fleet requirements for 1998 and 2001 but to maintain the 10 percent fleet requirement for 2003. To ensure that the state did not lose the actual emission reductions ascribable to the ZEV program (i.e., upstream emission benefits) because of this modification, CARB and each major automaker signed a memorandum of agreement,[9] in which the automakers committed to introducing low-emission vehicles nationwide[10] and to participating in a technology development partnership with CARB to deploy electric vehicles with advanced batteries.[11] A little more than 4,400 BEVs were eventually deployed in California between 1996 and 2003, primarily as a result of these agreements.[12] Some of the vehicles were placed in use with large organizations rather than being sold to consumers. Those that made it into the marketplace were either leased or sold at subsidized prices.

Figure 4. Battery Performance Relative to USABC Mid-Term Goals



Sources: Battery Technology Advisory Panel (1995, 2000); Kalhammer (1999).
Note: Lead-acid batteries were not evaluated in the 2000 report.

In 1998, to provide additional flexibility, CARB introduced a new vehicle technology category, the partial-zero-emission vehicle (California Air Resources Board, 1999). To qualify for credit under the ZEV program, a PZEV must meet the most stringent non-ZEV emission standard category under LEV II, SULEV; meet a zero-evaporative-emission standard; have an extended emission warranty (150,000 miles) to prevent significant emission-control deterioration; and meet second-generation onboard diagnostic requirements. Automakers could use PZEV to fulfill their ZEV requirement, at the rate of five PZEVs for every ZEV, but they still were required to meet at least 40 percent of their ZEV requirement with pure ZEVs. The PZEV credit could be augmented if the vehicles were capable of at least some zero-emission travel, were equipped with advanced components, or used a fuel that had low fuel cycle emissions (California Air Resources Board, 1998, 1999).[13]

Despite its focus on conventional technology, the PZEV requirement was nevertheless a strong technology-forcing component. The automakers did not receive it well. They stated that the PZEV requirement was "unachievable" and that it would be impossible to reach the sales volumes specified in the time frame allotted (California Air Resources Board, 1999, p. 56).

The 2000 review assessed progress in battery development as not much better than the previous reviews did. At the review hearing, CARB staff and automobile manufacturers agreed that the cost of a BEV battery, originally estimated to be $1,350, was likely to be closer to $20,000. Several automakers testified that this translated into $1.8 million per ton of smog-forming pollution reduction, compared to a typical cost-effectiveness of $10,000 per ton for other CARB programs (California Air Resources Board, 2000a).

However, BTAP also reported a different development: that automakers were beginning to pursue different kinds of advanced technology vehicles, including HEVs and mini electric vehicles.[14] In turn, battery manufacturers such as Panasonic EV Energy, which had supplied NiMH batteries for Honda, Toyota, and Ford's BEVs, had begun to shift toward increased production of HEV batteries and to reduce or even eliminate production of BEV batteries. BTAP viewed these efforts as leading to improvements in batteries that could ultimately make BEVs more widely accepted (Battery Technology Advisory Panel, 2000).

The 2000 biennial review also resulted in the creation of another new technology category, the AT-PZEV. AT-PZEVs are vehicles that meet the PZEV requirement but also incorporate advanced technology such as electric drive systems or high-pressure gas storage.[15] Like PZEVs, AT-PZEVs are not credited on a one-to-one basis with ZEVs, although the amount of the credit varies over time and with the vehicle's level of technology. The regulatory changes prompted by the review provided credit for AT-PZEVs, both with and without the capability of zero-emission travel, to count toward the 40 percent "pure ZEV" requirement established in 1998. This requirement is primarily being met through the sale of hybrid-electric vehicles. Honda introduced the first hybrid passenger vehicle to the U.S. market in 1999. The 10 percent ZEV mandate for 2003 was maintained and additional requirements were added for later years.[16]

However, manufacturers and dealers challenged the 2001 regulations in court. The settlement of that dispute brought about the 2003 ZEV amendments and created an alternative compliance path (ACP). Under the conventional compliance pathway, known as the base path, manufacturers could choose to meet the ZEV requirement through pure ZEVs, PZEVs, and AT-PZEVs. The ACP let them meet the ZEV requirement through sales of PZEVs and AT-PZEVs and through the production of an initially small number of FCVs at a level directly proportional to the manufacturer's market share of new vehicle sales in California. The ACP therefore established FCVs as a new technology category. As with the initial ZEV program targets for battery-electric vehicles, the ACP regulations assumed that the cost of producing fuel cell vehicles would come down considerably by the time large quantities would need to be sold. Current cost estimates from fuel cell manufacturers vary widely, ranging from approximately two to 13 times the targets set by the U.S. Department of Energy FreedomCAR program, for fuel cells to become competitive with conventional vehicles.[17] The wide range represents different assessments of technical maturity and assumptions of fuel cell production levels. In addition to its cost, fuel cell vehicle performance is challenged by fuel cell life limitations and hydrogen storage issues (California Air Resources Board, 2007b). Table 2 shows the compliance options following the passage of the 2003 amendments.

Aftermath of Reviews

CARB estimates that by 2020, as a result of the ZEV program, approximately 60 percent of new vehicle sales in California will be made up of ZEVs, PZEVs, or AT-PZEVs (California Air Resources Board, 2003). Nevertheless, the various ZEV amendments taken together resulted in not only a much more complicated regulatory program but also one that deployed much less advanced technology than was originally envisioned. The divergence of goals and outcomes is seen in Table 3, which compares a hypothetical example of ZEV compliance in 2007 through the ZEV base path and the ACP to the pathway the original ZEV mandate envisioned in its unmodified form. (The example assumes that an automaker sold an average of 100,000 ZEV-eligible vehicles in California in the years used as a baseline for the 2005–2008 time period and accounts for 10 percent of the ZEV-eligible passenger vehicles sold in the state.[18] As a result, the automaker must meet ZEV program obligations between 2005 and 2008 based on a baseline sales volume of 100,000 vehicles.) The table shows that following the base path requires a larger number of ZEV sales but that the ACP requires fewer ZEVs and a larger number of AT-PZEVs. In both cases, because of the credit system, approximately one-third of the manufacturer's ZEV-eligible sales volume is composed of ZEV-qualifying vehicles, although less than 1 percent of these sales are pure ZEVs.

Innovation Outcomes of ZEV

Here, we explore indicators of innovation to see if the shifting focus of the ZEV program is reflected in changes in advanced technology innovation. We also use data from interviews and reviews of public records to provide evidence of technological spillovers and of market and infrastructure development.

In both examinations, there is evidence of positive outcomes from the ZEV mandate but also the suggestion that ZEV changed from a proactive force in technology development to a more reactive stance.

Patent Analysis. The first indicator we examine is patenting activity.[19] Patents are best thought of as an outcome of invention that has commercialization as an eventual goal; studies have shown that patent activity can be linked to events that occur outside the firm such as investment in research and development (R&D) or regulation (see

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Table 2. ZEV Compliance Options Following the 2003 Amendments

	ZEV—"Base Path" (% Total Sales as ZEV)	Alternative Compliance Path (Total FCV Sales—Manufacturer Responsible for Its Market Share of the Total)
2005–2008	10	250
2009–2011	11	2,500
2012–2014	12	25,000
2015–2018	14	50,000
2019+	16	

Notes: The fuel requirements are not annual but cumulative for each time interval. The baseline for determining the number of vehicles required is the average of a manufacturer's ZEV-eligible vehicles delivered for sale in California in the three years preceding the time interval. The fuel cell requirement is from 2015 to 2017. No fuel cell requirement is stated past 2017.

Table 3. Hypothetical 2007 ZEV Sales Volumes for a Large Automaker

	Base Path	ACP	Original ZEV—Unmodified
ZEV	200	6	10,000
AT-PZEV	2,857	5,371	-
PZEV	30,000	30,000	-

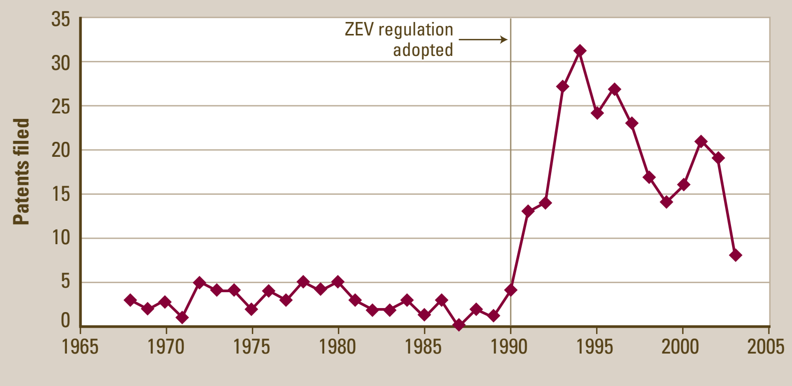
Source: Authors' calculation based on California Air Resources Board (2003).
Notes: The calculations assume that the automaker has a 10 percent market share, meets one-fourth of its ACP fuel cell obligation for the 2005–2008 period in each year, and has an annual ZEV-eligible sales volume of 100,000 passenger vehicles. For the base path and the ACP, the following credits per vehicle were assumed: PZEV, 0.2; AT-PZEV, 0.7; BEV, 10; and FCV, 40.

Griliches, 1990, for a review). Our analysis of patenting data for BEV-related patents shows a spike in activity following the creation of the ZEV program, whereas patenting for later technologies peaks before the changes in the regulation that provide credit for these technologies.

The BEV was the only near-term technology that was expected to meet the ZEV mandate in its early years, but it was not yet market-ready when the program was launched in 1990. Therefore, one might expect to observe an increase in innovative activity in BEV-related technology in subsequent years. Figure 5 shows that there is indeed a dramatic increase in the number of BEV-related patents filed, particularly in the early 1990s. A comparison of BEV patents granted to automakers (roughly 50% of the total) with overall automaker patents confirms that the observed pattern is not due to a general increase in patenting by these firms.[20]

Analysis of the country of origin of the patent filers shows that patenting by Japanese firms grew most rapidly, in turn suggesting that the federal R&D support efforts noted above and which included only domestic automakers, provided no advantage to Detroit. Although innovation by Japanese firms may have benefited from a Japanese government R&D program focusing on development of electric vehicles, it is likely that California's ZEV mandate was also a driving factor for these export-oriented firms, given the importance of the California market to them (Åhman, 2006).

Figure 5. BEV Patents Filed, 1968–2003



Source: U.S. Patent and Trademark Office.
Note: This figure accounts for patenting by all sources, including automakers and component suppliers as well as other firms and individuals.

Information gathered from interviews, public testimony, and documents confirms the importance of the ZEV program's initial technology push, especially for advanced vehicle component specialty firms, which are involved in such things as advanced automotive batteries and fuel cells. The component specialty firms particularly emphasized the importance of the ZEV sales mandate in creating a clear signal for a future market for their technologies. In the 1995 BTAP report, for example, battery manufacturers told the panel that ZEV "has been the main driving force behind their development of advanced batteries, and that the successful recruitment of investment . . . will depend in large part on a continuous and orderly California program" (Battery Technology Advisory Panel, 1995 p. iv).

But patenting data for later technologies included in the ZEV program suggest a somewhat different story. The trends for the later ZEV technologies show marked increases in patenting *before* the regulations that provided alternative credit pathways. Figure 6 shows patenting patterns for hybrid-electric vehicles (HEVs)—the vehicle type most likely to be used to satisfy the AT-PZEV requirements—and polymer electrolyte membrane fuel cells (PEMs), the type of fuel cell most likely to be used in fuel cell vehicles. The available data suggest that in the cases of HEVs and FCVs, CARB was responding to emerging trends in technology development (and, in the case of HEVs, market penetration) when it modified the regulations. (Because our data end in 2003, the year fuel cell vehicles were admitted into the program, we are unable to gauge whether the ZEV program has stimulated new patenting activity for PEMs, although patenting did decline in that year.)

Technology Spillovers. Although program changes effectively displaced battery-electric vehicles as the major component of the ZEV sales mandate, BEV efforts were not all lost. Technology spillovers from BEV development proved beneficial to the rise of hybrid-electric vehicles. The 2000 BTAP report (p. vii) states

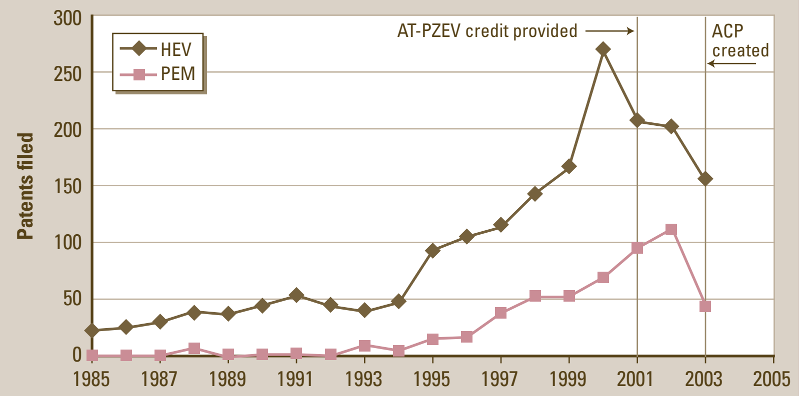
> There is little doubt that the development of nickel metal hydride (NiMH) and lithium ion (Li Ion) battery technologies for HEV and mini-EV applications has benefited directly and substantially from EV-battery development.

Cost, materials, and limitations of battery performance are the same for both hybrid-electrics and BEVs, but because the former require lower battery capacity, they were able to capitalize on these advances at a lower overall cost. BEV development efforts also resulted in improvements in high-voltage controllers and electric motors, which are attributed in turn with facilitating the more rapid commercial production of hybrid-electric vehicles. This spillover also allowed for the preservation of knowledge within companies by incorporating technical and managerial know-how from BEV development into programs for hybrid-electric development (Siroyama and Ueno, 2005).

Market and Infrastructure Development. Automakers such as Nissan chief executive officer Carlos Ghosn have acknowledged that the AT-PZEV provision in the ZEV program means that HEVs make business sense because the mandate has created a larger market demand for the vehicles (Durbin, 2006). In an interview conducted for this study, a supplier indicated that the ZEV program has provided a means for attracting capital and partners to work with and a push to develop necessary infrastructure such as refueling stations or charging facilities. Similar sentiments were expressed by battery developers at the start of the ZEV program.

Other benefits from the ZEV program can be found in vehicle design, such as the broadening of the range of power train options, the exposure to researchers of alternative fuels and sources of energy, and in providing the industry experience with the concept of home refueling—an important consideration in the deployment of new technology.[21] This integration of market and infrastructure development with vehicle technology development is continuing through the California Fuel Cell Partnership.

Figure 6. Patents for Hybrid-Electric Vehicles and Polymer Electrolyte Membrane Fuel Cells, Including Relevant ZEV Modifications, 1985–2003



Source: U.S. Patent and Trademark Office.
Note: Includes patenting by all sources.

Environmental Benefits of ZEV

The ZEV mandate carried with it two goals—one technological and one environmental (see the text box and Figure 7). As shown in Figure 3, the fleet average NMOG emission requirements (tailpipe emissions) of the LEV I and LEV II programs could be met without the sale of any ZEVs. One would not, therefore, expect the loss of environmental benefits from the program changes relative to tailpipe emissions. The benefits attributable to lower evaporative and upstream emissions from BEVs could be lost, however, because they are not reflected in the NMOG average. As CARB changed the ZEV program, it maintained its dual air quality and technology goals. Although the new car categories that could receive credit under ZEV did not have zero emissions, they were significantly cleaner than the conventional vehicle categories authorized under the LEV program. The program also provided additional credit to vehicles that incorporated advanced technology (namely, AT-PZEVs) even if, from an emissions perspective, they were similar.

Figure 8 shows the average lifetime emissions (upstream, evaporative, and tailpipe) for four vehicles: a BEV, a PZEV, a hybrid electric that gets credit as an AT-PZEV, and, for reference, a SULEV, the cleanest

ZEV and California's Climate Goals

California has recently undertaken several legislative and regulatory efforts to reduce greenhouse gas (GHG) emissions. Human activities generating four different gases account for almost all GHG emissions in the state: carbon dioxide from fossil fuel combustion; nitrous oxide, primarily from agriculture and transportation; methane, primarily from agriculture and landfills; and "high global warming potential" gases used in industry. The main piece of legislation addressing the state's climate change effort is Assembly Bill (AB) 32, the California Global Warming Solutions Act (Núñez and Pavley). It requires that the state reduce GHG emissions to 1990 levels by 2020.

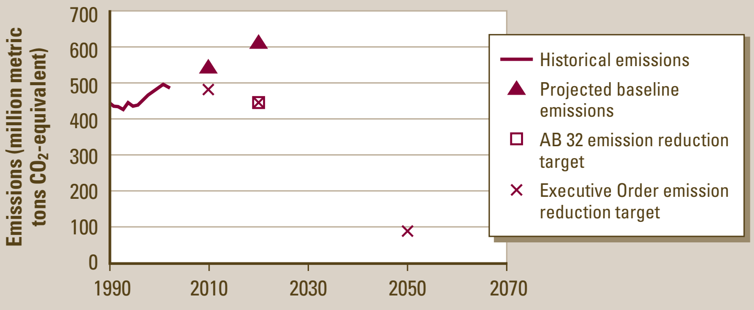
Although that target is ambitious, Executive Order S-3-05, from which AB 32 was derived and which is also applicable, is even more ambitious: It targets an 80 percent reduction in GHG emissions below 1990 levels by 2050. A reduction of this magnitude lies in the range that scientists estimate is needed to achieve climate stabilization (Intergovernmental Panel on Climate Change, 2007).

Whereas the AB 32 goal can be met with aggressive deployment of technologies that are presently in use or on the verge of deployment, meeting the 2050 target will require a profound refashioning of the economy (Climate Action Team, 2006). In both cases, government policy will play an important role in charting the way. Responsibility for meeting the AB 32 target lies with CARB, although other agencies will also take actions to reduce emissions. Potential approaches to meeting the target include new legislation, extending existing regulatory programs and creating new ones, and developing new market-based and incentive programs.

Such government programs can help bring new technology to the market by assisting in overcoming obstacles to its introduction: lack of infrastructure, high initial costs, and lack of awareness or information (Jaffe, Newell, and Stavins, 2005). Four lessons from the ZEV program could be useful for developing climate change programs, especially in relation to the transportation sector:

1. Actions that the state undertakes to reduce GHG emissions can provide strong market demand signals for new technology. In the ZEV program, that action was the sales mandate. Changes in the ZEV program were necessary to avoid passing on unacceptably high costs to consumers or creating vehicles that did not meet expectations, but these changes also created uncertainty for new technology providers. Policies to reduce climate change emissions need to maintain a balance between sending stable market demand signals while also ensuring that emission reductions are feasible and cost-effective.
2. Technology neutrality can help achieve such a balance. Neutrality can prevent a regulation from being tied to the fate of a single technology—vehicle batteries in the case of the ZEV program. Neutrality can also reduce volatility, preserve a stable demand signal, and reduce the risks to consumers by avoiding a commitment to suboptimal technology.
3. Performance standards have been largely responsible for the successful reduction of vehicle emissions to date. These standards have maintained flexibility while maintaining aggressive environmental goals.
4. Climate policies need to consider full life-cycle emissions. The fuel cell vehicle requirements under the current ZEV program could result in increases in GHG emissions if the source of hydrogen is not taken into consideration.

Figure 7. Recent GHG Emissions in California and Emission Reduction Targets from AB 32 and Executive Order S-3-05



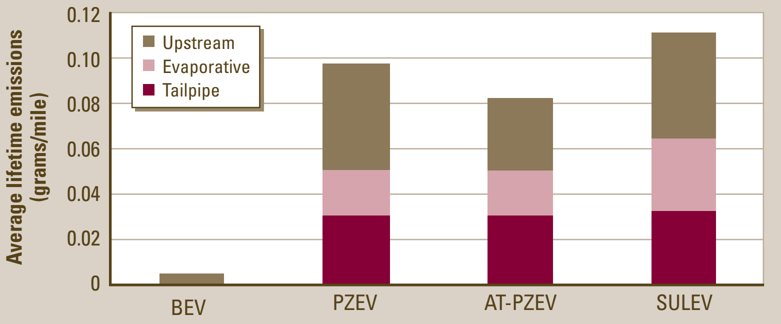
Source: Data from Bemis (2006).

Notes: Values include emissions from imported electricity and international bunker fuels. Total emissions are net of sinks (e.g., forest growth and rangeland improvements).

emission category created under LEV II. In terms of the NMOG average, which is based on tailpipe emissions, a PZEV will appear identical to a SULEV. But for each PZEV that is deployed to comply with the ZEV mandate, there will be almost 95 percent fewer evaporative emissions than from a SULEV, providing an additional environmental benefit. Table 4 lists the ZEV credit that each vehicle would receive; note that PZEVs receive more credit than SULEVs but less than vehicles that incorporate advanced technology with slightly lower upstream emissions.

The conventional and hybrid vehicles that have resulted from the ZEV program amendments are significantly cleaner than the cleanest vehicles that were required under either the LEV I or LEV II programs. Figure 9 provides a graphical comparison of the relative environmental performance of the ZEV portion of the fleet, assuming a fleet size of one million vehicles, approximately the size of the annual ZEV-eligible fleet for the 2005–2008 time period.[22] The calculation is based only on upstream and evaporative emissions and assumes that the NMOG average for tailpipe emissions will be met. (Details of the calculation are included in the technical appendix at www.ppic.org/content/other/907LBEP_technical_appendix.pdf.) The graph shows four compliance scenarios: a baseline scenario with only SULEVs (the cleanest non-ZEV vehicles under LEV II), the 2003 base path, the 2003 ACP, and the original ZEV mandate. The environmental benefits that would have occurred under the original ZEV program have not been lost as a result of the amendments; compliance under both current pathways provides approximately the same level of emissions reductions. Over the lifetime of this fleet, upstream and evaporative NMOG emissions will be just under 10 percent lower than for a fleet containing only the cleanest non-ZEV cars.[23]

Figure 8. Lifetime Average Smog-Forming Emissions from Four Vehicle Types, from the Tailpipe and Fuel Cycle



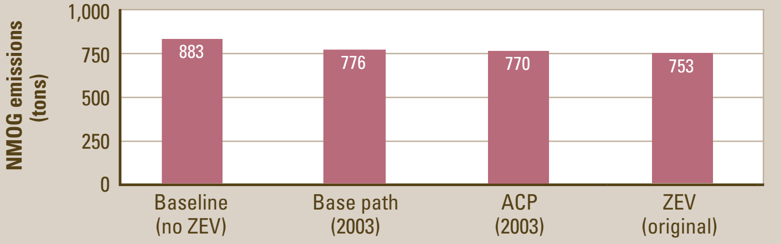
Source: California Air Resources Board (2000b).
Notes: The difference in upstream emissions between a PZEV and an HEV qualifying as an AT-PZEV is based on the assumption that the HEV has higher fuel economy and, therefore, consumes less fuel, resulting in lower upstream emissions. This might not always be the case, for instance when HEV technology is used to increase performance rather than to improve fuel efficiency.

Table 4. ZEV Credit for Vehicle Types Shown in Figure 8

	BEV	PZEV	AT-PZEV	SULEV
ZEV credit	1.0	0.2	0.7	0

Notes: A BEV deployed under the ZEV program in 2007 would actually receive a credit of 10, a reward for early introduction. The amount of the ZEV credit, as well as that for AT-PZEVs, declines over time.

Figure 9. Lifetime Average Annual Evaporative and Upstream NMOG Emissions from One Million Vehicles Sold in 2007, Under Four Compliance Scenarios



Source: Authors' calculation.
Notes: The vehicle proportions for the various ZEV pathways are those shown in Table 3, scaled to the total size of the ZEV-eligible fleet, using the compliance pathways outlined in Table 2 and the 10 percent ZEV requirement adopted in 1990. Emissions are expressed as average lifetime NMOG emissions, as shown in Figure 8 for PZEV, AT-PZEV, and SULEV (California Air Resources Board, 2000b). Upstream emissions for fuel cell vehicles are assumed to be equivalent to upstream BEV emissions. Baseline without ZEV assumes that only SULEVs are sold. It is assumed that 25 percent of the 2005–2008 ACP fuel cell vehicle requirement is met in 2007.

Lessons from the ZEV Program

The ZEV program fell prey to the uncertainty noted above that haunts environmental regulation; this uncertainty caused CARB to underestimate the potential of conventional technology to meet environmental goals and to overestimate the potential for advanced technology to enter the marketplace in a timely way. Technological improvements in conventional vehicles surprised CARB as well as the auto industry, and progress in developing battery-electric vehicles failed to meet CARB's expectations. However, the review process enabled CARB to amend the ZEV program and to avoid being stuck on a suboptimal path.

The result is a complex program that provides credits for a variety of technologies, with reliance predominantly on very clean conventional vehicles rather than on the advanced technology originally envisioned. As the program has evolved, a number of technologies have emerged that could provide comparable benefits to current ZEV-credited vehicles, such as plug-in hybrid-electric and biofuel-powered vehicles, but that are not credited under the current program structure.

The changes to the ZEV program have also undermined the original ZEV goal of creating a strong demand signal for zero-emissions technology and created uncertainty for some advanced technology developers. Certainty of future markets allows suppliers of emerging technologies to attract investment. The changes in the ZEV program were necessary given the poor performance and high cost of battery technology. But for many battery manufacturers, these changes translated into a loss of resources and investment. Luckily, not all of these investments were for naught, thanks to the potential for spillovers. Many of the battery developments that did occur could be capitalized on for hybrid-electric vehicles, as were many of the improvements in other electric vehicle system components.

The alternative compliance path that was created in 2003 resembles a true technology mandate even more so than the original ZEV mandate. Because the ACP requires the production of fuel cell vehicles, it is providing a demand signal for fuel cell manufacturers and others, laying the groundwork for a fuel cell vehicle market. Fuel cell manufacturers have indicated the importance of this signal for sustaining investment levels. However, automakers are already calling for delays in the implementation of and reductions in the required number of fuel cell vehicles, given the high costs of the technology and the fact that fewer vehicles are needed for learning (Hermance, 2006). The most recent biennial review of the ZEV program corroborates this view and recommends delays in the ACP schedule. Yet it also expresses concern about maintaining the momentum to invest and to build partnerships between automakers, fuel cell manufacturers, and fuel providers (California Air Resources Board, 2007b).

A corollary to this risk to fuel cell providers and related industry is the risk that the ZEV mandate places on consumers. By focusing on a single advanced technology, there is a risk of getting locked into a path that will result in high costs for society while preventing or slowing the development of other, promising clean vehicle technology. In the earlier phases of ZEV, CARB avoided passing unacceptably high costs on to consumers and the auto industry by providing credits for non-zero-emission technologies. CARB staff's recent recommendations to delay increases in the fuel cell requirements continue this tradition (California Air Resources Board, 2007b).

In contrast to earlier ZEV technologies, the technology mandate for fuel cell vehicles also raises the potential for conflicts with CARB's goal of limiting greenhouse gas emissions. Greenhouse gas emission reductions were not part of the regulatory calculus when the ZEV program was created but are now a component of CARB's mission as it is defined legally. Fuel cell vehicles use hydrogen fuel, which results in zero emissions from the tailpipe. However, the production of hydrogen fuel can result in an increase in upstream emissions, particularly of greenhouse gases (Wang, 2002). Therefore, this mandate could result in a potential conflict with the state's climate change goals if the program does not expressly consider the production pathways used to generate hydrogen to power fuel cells.

Future Paths for ZEV

The current value of the ZEV program for advanced technology is not clear. Its environmental benefits are being derived primarily from very clean conventional vehicles, and this will continue at least through the middle of the next decade. From an environmental standpoint, CARB would likely be better served by eliminating the ZEV mandate and incorporating the technological gains achieved through the ZEV program into the LEV regulations. A revision of the LEV II regulations (i.e., LEV III) could capitalize on the advances that have been made in conventional vehicle control through an increasingly stringent NMOG average—in particular, one that incorporates upstream and evaporative emissions as well as tailpipe emissions. The stringency should be set to a level that forces development of new technology, as CARB has done in the past. By not relying on a single technology, CARB and manufacturers will have greater flexibility to reach environmental goals.

A focus on advanced technology that provides environmental benefits should be maintained through mechanisms that are less prone to the volatility associated with a changing mandate such as ZEV. This can be accomplished, for example, by providing incentives and credits for advanced technology and evidence of innovation within a revised LEV II regulation. In addition, CARB can develop mechanisms to ensure that appropriate infrastructure investment and development occur as new technologies emerge. Support for emerging technologies can be maintained through alternative means, including research and development funding, tax credits, and manufacturing incentives. Maintaining an adaptable and flexible program is desirable, given the broad range of emerging clean vehicle and fuel technologies and the need to achieve both air quality improvements and greenhouse gas emission reductions. ❖

A focus on advanced technology that provides environmental benefits should be maintained through mechanisms that are less prone to the volatility associated with a changing mandate such as ZEV.

Notes

[1] Any state that has areas that do not meet federal air quality standards can choose to follow California vehicle standards instead of federal standards, which tend to be less stringent than California's (section 177). Several states have elected to follow California's standards over the years; they and California account for almost one-third of the new passenger vehicle market in the United States. Today, these states are Massachusetts, New York, Vermont, Maine, Connecticut, Rhode Island, Washington, Oregon, New Jersey, and Pennsylvania.

[2] These are known as health-based "criteria" air pollutants and result from incomplete combustion, contaminants in fuel, or by-products of the combustion process.

[3] Although emissions from the tailpipe are zero, there are emissions associated with electricity generation. Therefore, on a full fuel cycle basis, CARB assumed that the emissions from ZEVs were equivalent to those associated with electricity generation in the South Coast Air Basin (California Air Resources Board, 1994).

[4] BEVs date back to the beginning of the auto industry but have had consistent difficulties competing with internal combustion engines in terms of range and power.

[5] In its original form, the ZEV mandate applied only to new passenger cars and the lightest light-duty trucks (approximately half of the new passenger vehicles sold in the state), meaning that only these vehicles were used to calculate the number of vehicles required for ZEV compliance. A later amendment, which will be fully phased in by 2012, added heavier light-duty trucks (including most SUVs) to the calculation.

[6] Other examples of policies that can be employed to overcome these obstacles include tax credits on purchases of clean technology and information provision (Jaffe, Newell, and Stavins, 2005).

[7] In part, the Impact was to help GM reemerge as an automotive leader after a decade of declining market share vis-à-vis Japanese automakers.

[8] Vehicle range is the distance that a vehicle can travel on a single charge, which depends on the specific energy of a battery, or the amount of energy per unit weight. Energy requirements could be met from a battery with a low specific energy by using a heavier battery on a vehicle. But vehicle design must be optimized and the battery cannot account for too large a portion of a vehicle's weight.

[9] At the time that ZEV was passed, a large-volume manufacturer was one that sold more than 35,000 vehicles a year in California. In the current regulations, the cutoff is 60,000 vehicles per year. In 1996, there were seven major automakers: Ford, General Motors, Nissan, Honda, Toyota, Chrysler, and Mazda.

[10] This commitment was fulfilled through the National Low Emission Vehicle (NLEV) program, which was an agreement between federal officials and the automakers. Through the NLEV program, the automakers agreed to deploy vehicles that met standards more stringent than the existing federal standards in states that opted into the program.

[11] An advanced battery is defined as having specific power of at least 40 W-hr/kg for 1998 and 50 W-hr/kg in 1999 and subsequent years (California Air Resources Board, 1996).

[12] Personal communication with K. Eley, Air Pollution Specialist, ZEV Implementation Section, California Air Resources Board, 2006.

[13] The full fuel cycle refers to the emissions associated with energy used in a vehicle from the point of extraction to the tailpipe. In the case of an electric vehicle, this includes electricity generation.

[14] Hybrid-electric vehicles use internal combustion engines and electric batteries to power electric motors. Mini electric vehicles have limited range and speed.

[15] The first vehicle to be certified as an AT-PZEV was the Honda Civic GX, a compressed natural gas vehicle. The Civic GX was introduced in 1997 and built to demonstrate that it is possible to achieve near-zero emissions with non-BEV technology (personal communication with B. Knight, Honda Motor Company, 2006). Several hybrid-electric vehicles have also been certified as AT-PZEVs.

[16] Although credits for advanced technologies in PZEVs were possible under the 1998 amendments, the 2001 regulations defined AT-PZEVs and allowed them to count toward the "pure" ZEV requirement.

[17] The FreedomCAR program was created in 2003 to replace the previous PNGV program.

[18] Approximately two million new passenger vehicles are sold in California annually. However, because light-duty trucks (approximately half of new vehicle sales) are just beginning to be phased into the ZEV program, this example is a close approximation of what could be required of a manufacturer.

[19] This analysis uses patent search results for competing vehicle technologies compiled from U.S. Patent and Trademark Office data. Each dataset was created using keyword searches of patent titles, abstracts, and claims. (For details, see the technical appendix at www.ppic.org/content/other/907LBEP_technical_appendix.pdf.)Because of the relatively high cost of the examination process in the U.S. patenting system, companies and inventors tend to patent their most promising technologies in the United States (Pavitt, 1982; Watanabe, Tsuji, and Griffy-Brown, 2001; van den Hoed, 2005). Although many of the companies patenting advanced vehicle technologies are not based in the United States, U.S. patent data are considered a good indicator of innovative activity in this area because the primary markets for these technologies are in California and other states following California vehicle emission regulations (van den Hoed, 2005).

[20] A chi-square test confirms that the pattern observed in the BEV patent data is significantly different from the pattern observed for all automaker patenting over the same time period.

[21] Personal communication with B. Knight, Honda Motor Company, 2006.

[22] The ZEV mandate only applies to the large-volume manufacturers (responsible for approximately 80% of new vehicle sales) and in 2007 includes all passenger cars and the lightest light trucks and 17 percent of heavier light trucks. This implies that the size of the ZEV-eligible fleet is based on approximately 60 percent of new vehicle sales. Slightly fewer than two million new vehicles were sold in the years serving as a baseline for the 2007 requirement, so one million new vehicles is the approximate size of the 2007 ZEV-eligible fleet.

[23] Because the ZEV-eligible fleet is only a portion of total passenger vehicle sales (see footnote 18), the total environmental benefits of the program will be smaller.

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Learning from California's Zero-Emission Vehicle Program

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