Innovation and Regulation in the Automobile Sector
Lessons Learned and Implications for California's CO_2 Standards

Roland Hwang
Natural Resources Defense Council*

Matt Peak
Current affiliation: CALSTART

April, 2006

Introduction

Over four decades of air pollution history control demonstrates that California's leadership actions play a vital role in leveraging pollution reductions by other states, nationwide, and even globally. Other jurisdictions have learned from and followed California's leadership, and air pollution technologies pioneered in California have often been widely adopted.

Based on a review of previous analyses, we find that the auto industry and its allies have historically overestimated the actual costs by a factor of about 2 to 10 times the actual costs. Regulators (California Air Resources Board [CARB] and the U.S. Environmental Protection Agency [EPA]) also tend to overestimate costs, albeit to much less extent. A typical regulator estimate of actual automaker compliance costs are 1 to 2 times the actual costs. A primary reason for regulator cost overestimates is the role of unanticipated technological innovation which has dramatically lowered the actual compliance costs in many instances.

Consequently, it is reasonable to anticipate that the new California CO_2 standards for automobiles will have a nationwide, if not global impact, on greenhouse gas emission control and that the cost of compliance will be consistent with CARB staff estimate. Furthermore, as history has demonstrated, unanticipated innovation could very likely reduce the cost of compliance by an even greater degree in the future.

A Review of Auto Industry's Past Estimates of the Impact of Proposed Emission Standards

There is a clear historical pattern of automakers overestimating the cost of compliance with proposed air pollution emission standards, and often regulators overestimating the cost, albeit to a much lesser extent. According to a study done for Northeast air regulators (NESCAUM,) "…pre-regulatory estimates, particularly those on the high-end, can usually be considered to reflect worst case scenarios and do not necessarily form a reliable basis for policy decisions."[1] Another study by the U.S. EPA of gasoline and passenger vehicle regulations found that the "general pattern that is revealed indicates that all *ex ante* estimates tended to exceed actual price impacts, with the EPA estimates exceeding actual prices by the smallest amount."[2] Researchers have identified the primary reasons for these overestimates:[3]

1. unanticipated innovation;
2. conservative estimates by both regulators and industry;
3. regulators lacking full access to industry data; and
4. intentional inflation by industry with the purpose to weaken or delay regulations.

* 111 Sutter Street, 20th floor, San Francisco CA 94104, (415) 875-6100.

A number of studies have compared pre-regulatory cost estimates (*ex ante*) to the costs that actually occurred once the regulation was implemented (*ex post*) and are summarized below.

1975 Requirement for Catalytic Converters (eventually delayed nationally until 1981, but implemented in California in the mid 1970s.)
The automakers strongly opposed the introduction of catalytic converters. Automobile executives claimed the regulations were not technically feasible and would cause severe economic hardship for their industry. For instance, during a 1972 congressional testimony, General Motors vice president Earnest Starkman declared that if automakers were forced to introduce catalytic converters on 1975 models, "It is conceivable that complete stoppage of the entire production could occur, with the obvious tremendous loss to the company, shareholders, employees, suppliers, and communities."[4] Ford president Lee Iacocca claimed that "If the U.S. Environmental Protection Agency does not suspend the catalytic converter rule, it will cause Ford to shut down and would result in: 1) reduction of gross national product by $17 billion; 2) increased unemployment of 800,000; and 3) decreased tax receipts of $5 billion at all levels of government so that some local governments would become insolvent."[5] Despite these claims, California implemented the regulations and automobile pollution was drastically reduced, requiring the first catalytic converters in 1975 and the first 3-way catalytic converters in 1977.

Chrysler claimed it would cost $1,300 more to comply with the proposed 1975 federal pollution standards.[6] In today's dollars, this is equivalent to $2,770.[7] Ford estimated that the cost of a Pinto might rise to $1,000 (equal to $2,130 in 2004 dollars.) However, a 1972 report by the White House Science Office estimated the cost would be $755 (equal to about $1,600 in 2004 dollars.)[8,9] The actual cost to comply with the standard, which was delayed until 1981, is estimated to have been $875 to $1,350 in 2002 dollars.[10]

California LEV I Program (adopted 1990)
In 1990, the CARB adopted the first Low Emission Vehicle (LEV) program that allowed automakers to choose among four different emission standards (TLEV, LEV, ULEV and ZEV) to meet an increasingly stringent fleetwide average for hydrocarbons. Due to automaker concerns, the Board also required a biennial technology review to ensure that the technology would be ready in time for implementation. Throughout the process, the automakers claimed higher compliance costs than what actually occurred.

For instance during the 1994 biennial review, the automakers estimated the cost of meeting the "transitional low emission vehicle" (TLEV) standard to be $862, the "low emission vehicle" (LEV) standard to be $1,689, and the "ultra low emission vehicle" (ULEV) standard to be $2,799.[11] In 1998, CARB staff analyzed the actual costs and found them to be much lower. [12] As described in the following section when adjusted for the same baseline vehicle (Tier 0), the actual costs were about $120, $168 and $336 for the TLEV, LEV, and ULEV technologies respectively.[13] In some cases, the actual cost to the consumer may have been even lower. In 1993, General Motors submitted to the California Energy Commission a request for approval that indicated a $0 incremental cost for a 1994 model-year TLEV engine.[14] Nissan Motor Company as well as Toyota Motor Corporation indicated $0 incremental costs for two 1994 model-year engine families corresponding to LEV emission standards.[15]

During the first two biennial reviews, automakers focused particularly on the ULEV standard, claiming that costly and complicated technologies would have to be developed and used to meet the ULEV standard, especially in their bigger V-6 and V-8 engine vehicles. In fact, by the time

Honda introduced the first ULEV vehicle in 1998, it achieved this superior emission rating using technologies that were mostly refinements of existing technology and met the standard for about $336.[16] For the 2003 model year, approximately 70 different models of vans, trucks, and SUVs and 67 different models of cars (comprising nearly 40 percent of all cars sold in California) met the ULEV standard, including on their largest vehicles, such as the Chevrolet Suburban (with a 5.3 liter V-8 engine) and the Dodge Durango (with a 5.9 liter V-8).

Federal Tier 1 Program (adopted 1990)
The 1990 federal Clean Air Act required the automakers to meet more stringent emission standards in states outside of California by 1996. The automakers claimed that the costs of meeting the 1996 federal Tier 1 standards (including Cold CO, OBD, Certification Short Test, and Enhanced Evaporative standards) would be equivalent to $432. The EPA staff estimated the cost to be $150. Using actual data submitted by the automakers to the US Bureau of Labor Statistics, EPA staff estimated the actual costs to be $88.42 (all values cited in 2001 dollars).[17]

California LEV II Program (adopted 1998)
In 1998, CARB adopted the LEV II program. The primary automaker lobbying group, the American Automobile Manufacturers Association (AAMA), claimed it was unrealistic and infeasible to make large SUVs and full-size trucks meet the proposed standards.[18] The California Dealers Association estimated the cost for a heavy light truck to meet the ULEV II standards to be $500.[19] The group “Californians for Realistic Vehicle Standards” (which was set up by Detroit automakers with the assistance of the California Chamber of Commerce)[20] claimed that the only way for industry to meet the new standards would require 25 percent of the vehicles sold in California to run on alternative fuels at an increased cost of $7,000 per vehicle.[21] This organization also claimed there would be 33 percent fewer full-size vehicles available to consumers.

CARB’s cost estimate for the ULEV II standard was $206.[22] No studies of actual costs have been completed at this point since the standard is just beginning to be phased in for large pickups, but at least one large pickup is already meeting the standard (2006 Toyota Tacoma), as well as some mid-size SUVs (e.g., 2006 Ford Explorer, Jeep Grand Cherokee.)

California AB 1493 Greenhouse Gas Pollution Program (standards adopted 2004)
Finally in 2004, CARB estimated the fleet average cost of meeting the proposed greenhouse gas emission standards to be $1,018.[23] The auto industry estimates are much higher, $3,000, with at least one industry-funded group claiming even higher, $5,000.[24,25] Implementation of this program begins in model year 2009, so actual cost estimates are not available

Detailed Comparison of Sierra Research and CARB Cost Estimates for LEV I
Cost estimates of the LEV I program have been well studied by CARB and the automakers and so serves as a useful example to examine in greater detail. The auto industry hired a consulting firm, Sierra Research, to provide a more independent assessment of LEV cost then provided by the individual automakers.[26] The study (Austin and Lyons 1994) provided three estimates: a high estimate that was provided by the domestic automakers and two lower, adjusted costs estimates that reflected what Sierra Research believed to be a more plausible estimate for a California only and national implementations.

Table 1 shows the Sierra Research estimate for the LEV program for both “California” and “Nationwide” implementation. Note that costs are lower for nationwide implementation due to the greater economies of scale. Unlike CARB’s analysis which used the federal Tier 1 as a baseline vehicle (see Cackette 1998,) Austin and Lyons 1994 use the previous federal standard, Tier 0, as its baseline. Note that the industry provided estimates were roughly double what Austin and Lyons believed to be plausible for a nationwide implementation.

Table 1. Industry Cost Estimates for California and Nationwide LEV I Implementation ($ 1994, Tier 0 Baseline)

	Manufacturers	California	Nationwide
California TLEV Standard	$862	$463	$ 344
California LEV I Standard	$1,689	$1,019	$ 775
California ULEV I Standard (midsize)	$2,799	$1,475	$ 1,347

Source: Austin and Lyons 1994

In contrast, CARB 1994 Biennial Review of the LEV program estimated $61, $114, and $227 for TLEV, LEV and ULEV incremental costs, respectively, from a Tier 1 baseline (see Table 2.) Cackette 1998 estimated the actual costs of compliance to have been $35, $83, and $251 for TLEV, LEV and ULEV incremental costs, respectively, again from a Tier 1 baseline. When adjusted (see below) to compare to the Tier 0 baseline costs, the actual costs of compliance are about $120, $168, and $336 (all values in 1994 dollars).

We adjust the CARB cost estimates and actual costs estimates to reflect the additional costs of moving from a Tier 1 to a Tier 0 baseline using the following methodology. To account for the additional cost of the Tier 1 vehicle versus a Tier 0 vehicle, we used data from Anderson and Sherwood 2002 for the actual compliance costs for Tier 1 vehicles. According to Table 8 in the paper by Anderson and Sherwood, the actual vehicle price changes for the Clean Air Act requirements reported to the Bureau of Labor Statistics was $39.46 in 1994 when Tier 1 was 40% phased in and $53.51 when Tier 1 was 80% phased in. Subtracting $12 to account for the Cold CO standard (see Table 10 in Anderson and Sherwood) and accounting for the phase-in percentage yields an average cost of Tier 1 in 1994 and 1995 of $85.

Table 2. CARB LEV Program Costs, Estimates and Actual ($ 1994)

	1994 Biennial Review (Tier 1 baseline)	Actual (Tier 1 baseline)	1994 Biennial Review (Tier 0 baseline)	Actual (Tier 0 baseline)
California TLEV Standard	$61	$35	$146	$120
California LEV I Standard	$114	$83	$199	$168
California ULEV I Standard (midsize)	$227	$251	$312	$336

Source: Cackette 1998 and NRDC estimates

Table 3. Ratio of Estimated to Actual Costs (Estimated divided by Actual)

	Manufacturers (cited in Austin and Lyons 1994)	California (Austin and Lyons 1994)	Nationwide (Austin and Lyons 1994)	CARB 1994 Biennial Review
California TLEV Standard	7.2	3.9	2.9	1.2
6alifornia LEV I Standard	10.1	6.1	4.6	1.2
California ULEV I Standard (midsize)	8.3	4.4	4.0	0.9

Source: NRDC

The estimates by Sierra Research for the California LEV program are 4 to 6 times higher than the actual costs (see Table 3 above). We use the California level numbers since the CARB actual cost estimates were presented in 1998, prior to the implementation of the National LEV program and therefore represent California-only implementation costs. The basic conclusion remains the same regardless of which numbers are used for comparison. If Sierra Research's nationwide numbers are used, the cost overestimate is about 2.9 to 4.6 times higher versus 3.9 to 6.1 when California numbers are used. Compared to the manufacturers' cost estimates cited in Austin and Lyon 1994, the automakers' estimates were 7 to 10 times higher than actual costs. In contrast, CARB estimates were 0.9 to 1.2 times higher; with the ULEV cost estimates for a mid-size car slightly underestimated ($312 versus $336).

Summary of Cost Estimates

Table 4 and Figure 1 summarize our review of past cost estimates and actual costs for light duty vehicle pollution control. Our results show that the industry's typical pre-regulatory cost estimates for gasoline vehicle emissions controls have been 2 to 10 times higher then the actual compliance costs (see Table 5). Regulators also have a tendency to overestimate costs, albeit to much lesser extent. A typical regulator estimate of actual automaker compliance costs are 1 to 2 times the actual costs.

Table 4. Comparison of Estimated Costs to Actual Price Changes

Program	Industry & Allies	Regulators	Actual
1975 Federal Standard ($2004)	$2,130-2,770	$1,609	$875-$1,350
California LEV I Program vs Tier 1 Baseline ($1994)	$788	$120	$83
California LEV I Program vs Tier 0 Baseline ($1994)			
California TLEV Standard	$344-862	$146	$120
California LEV I Standard	$775-1,689	$199	$168
California ULEV I Standard (midsize)	$1,347-2,799	$312	$336
1996 Federal Tier1 + OBD ($2001)	$432	$150	$88
California ULEV II, Heavy Light Truck ($1998)	$500-7,000	$206	not estimated
California CO_2-eq Standard ($2004)	$3,000-$5,000	$1,048	not estimated

Sources: Doyle 2000; Sperling et al 2004; Austin and Lyons 1994; Cackette 1998; Anderson and Sherwood 2002; CARB 1999; CARB 2004; AAM 2004; and NRDC

Figure 1. Comparison of Cost Estimates versus Actual Costs

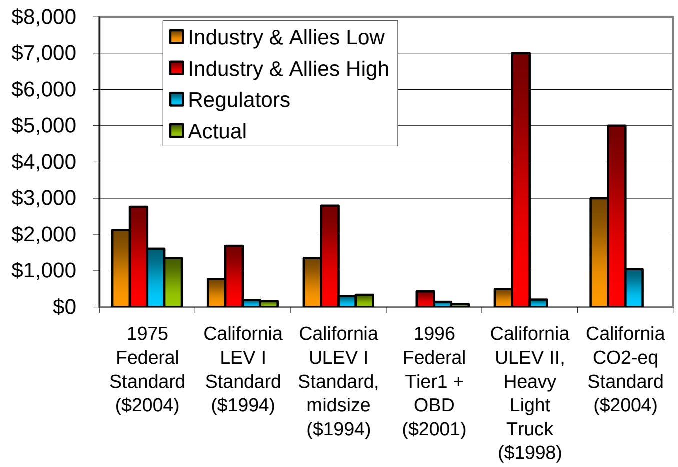


Table 5. Ratio of Estimates to Actual Costs

Program	Industry & Allies	Regulators
1975 Federal Standard ($2004)	1.6-3.2	1.2-1.8
California LEV I Program vs Tier 1 Baseline ($1994)	9.5	1.4
California LEV I Program vs Tier 0 Baseline ($1994)		
California TLEV Standard	2.9-7.2	1.2
California LEV I Standard	4.6-10.1	1.2
California ULEV I Standard (midsize)	4.0-8.3	0.9
1996 Federal Tier1 + OBD ($2001)	4.9	1.7

Source: NRDC

Cost Overestimates in Other Air Pollution Regulatory Programs

Cost overestimates by both industry and regulators are not limited to the automobile sector and are seen across many other programs, including reformulated fuels and power plant emissions controls.

California Phase 2 Reformulated Gasoline

In 1991, the ARB estimated that the cost to meet California's proposed Phase 2 Reformulated Gasoline (RFG) requirements would translate into an estimated increase in cost of 12 to 17 cents per gallon of gasoline (see Table 6). However, a study sponsored by the oil industry, represented by the Western States Petroleum Association (WSPA), placed the increase in the cost of gasoline at 23 cents per gallon. Four California refiners that were cited in the 1991 staff report also estimated an increase in cost of as much as 30 cents per gallon of gasoline when the regulation was implemented statewide in 1996. A price study was performed in 1997 that compared the price differential of California reformulated gas over the average price of five representative cities (Phoenix, Portland, Dallas, Milwaukee, and New York City) from before Phase 2 RFG implementation, in 1995, to after Phase 2 implementation, in 1997. This study concluded that even though gas prices were very volatile due to market forces, the price differential was only 5.4 cents per gallon.

Table 6. ARB Cost Predictions vs. Actual Price Increase of California Phase 2 Reformulated Gas

Year	ARB Increased Cost Estimates (c/gallon)	WSPA Increased Cost Estimates (c/gallon)	Actual Consumer Price Increase
1991	12-17	23	-
1996	10 (5 – 15 range)	-	-
1997	-	-	5.4

Source: Cackette 1998

EPA Fuel Control Programs

In a study of six EPA fuel control programs (see Table 7), EPA staff analyst compared estimates by the EPA, the Department of Energy (DOE), the American Petroleum Institute (API), and, on some occasions, Charles River Associates (CRA) or the American Institute of Automobile Manufacturers (AIAM). The EPA made accurate estimations for the Phase 2 RFG (which was underestimated) and the 500ppm highway diesel sulfur regulations, yet overestimated Phase 2 RVP control by 120 percent and Phase 1 reformulated gas by 41 to 132 percent.

Other estimations were often less accurate. The DOE overestimated the increase in cost by 55 to 86 percent for Phase 1 RFG and 49 to 100 percent for Phase 2 RFG while the API overestimated Phase 2 RVP by 260 percent, Phase 1 RFG by 273 to 536 percent, and Phase 2 RFG by 118 to 280 percent. The industry representatives CRA and the NPRA overestimated Phase 1 RFG by 236 percent, Phase 2 RFG by 135 percent, and 500 ppm highway diesel by 50 percent.

Table 7. Comparison of Inflation Adjusted Estimated Costs and Actual Price Changes for EPA Fuel Control Rules

	Inflation Adjusted Cost Estimates (c/gal)				Actual Price Changes
Gasoline	**EPA**	**DOE**	**API**	**Other**	
Phase 2 RVP Control (7.8 RVP – Summer)	1.1[a]		1.8[a]		0.5
Reformulated Gasoline Phase 1	3.1-5.1[b]	3.4-4.1[b]	8.2-14.0[b]	7.4[b] (CRA)	2.2
Reformulated Gasoline Phase 2 (Summer)	4.6-6.8[c]	7.6-10.2[c]	10.8-19.4[c]	12.0[c] (CRA)	7.2 (5.1)[d]
Diesel					
500ppm sulfur highway diesel fuel	1.9-2.4[b]			3.3[b] (NPRA)	2.2

Notes: [a] 1995 dollars. [b] 1997 dollars. [c] 2000 dollars. [d] Corrected to 5yr average MTBE price
(Source: Anderson and Sherwood, 2002)

SO_2 Controls for Powerplants

In a study by NESCAUM, researchers found that for the Title IV SO_2 control costs for powerplants, EPA's pre-regulatory estimates were consistent with actual costs, whereas industry overestimated actual control costs by more than 80 percent. A similar tendency for industry to exaggerate costs was also found for NO_x control technologies.[27]

Another study of powerplant controls found that for SO_2 scrubbers, control costs decreased by 11 percent for each doubling in installed capacity. The same study found a NO_x control technology (SCR) that decreased cost by 12 percent by doubling capacity.[28]

How Regulation Induces Technological Innovation: Engineering Case Studies

As stated above, there are at least four factors that researchers have identified to account for the differences in *ex post* and *ex ante* regulatory cost estimates. As seen from the above review, a significant portion of the industry cost over estimates are due to highly conservative estimates, either intentional or unintentional. However, even regulators often overestimate the cost.

One very powerful factor that can partially explain both the industry and regulator estimates is the role of unanticipated innovation. The history of automotive regulation indicates that manufacturers very often utilize technologies and implement compliance paths different from initial predictions, resulting in lower than predicted costs. A clear theme also emerges from the study of the history of air pollution regulation, that *a strong regulation spurs innovation*.[29] A strong regulation eliminates regulatory uncertainty and provides a powerful competitive incentive for automakers and their suppliers to innovate to sometimes radically reduce costs.

The concept of innovation improving the performance and lowering the cost of products is a well-observed phenomenon across many industries. The concept has been described using a "learning curve" (or experience curve)[30] and there is "overwhelming empirical support" for this relationship.[31] In addition, technological "spillover" effects provide powerful, unanticipated, advances, such as electronic controls, fuel injection, and advanced sensors spurring the ability to provide much more precise control of the air/fuel ratio inside the engine cylinder.

By examining case studies, one can clearly see how the incentive to meet strong emission standards has spurred engineering advances that often eliminate the need for most costly and complex control technologies thereby lowering compliance costs.

1970s: Honda Innovates Lower Cost, Non-Catalyst Solution (CVCC)

Before 1969, it was commonly thought that the only way to reduce automobile pollution was by using end-of-pipe technology such as catalytic converters. Yet, as California emission standards came into effect, influenced national policy, and culminated nationally in the 90 percent reduction in auto emissions as required by the Federal Clean Air Act of 1970, one automobile manufacturer, Honda, pursued alternative methods of pollution reduction. The company's founder, Soichiro Honda, instructed his engineers to "try to clean up the exhaust gases inside the engine itself without relying on catalytic converters."[32] These engineers proceeded by combining existing technologies in a new way to achieve a cleaner burn.[33]

Their efforts resulted in the "Compound Vortex Controlled Combustion" (CVCC) engine that was designed with a small "pre-burn" chamber upstream of the cylinders. Honda discovered that by pre-burning the gasoline/air mixture, more impurities were removed before they reached the tailpipe. This technology allowed Honda to meet the 1970s Clean Air Act standards without the use of catalytic converters. It also proved beneficial to Honda as Detroit manufacturers, who initially scoffed at Honda's accomplishments, each licensed the technology from Honda in 1973.[34] The implementation of CVCC technology on the Honda Civic in the 1970s disproved Detroit's claim that meeting emissions and fuel economy standards simultaneously was impossible, as the EPA ranked the Civic first in fuel economy among all models.[35]

LEV I: Improved Catalysts and Other Refinements Eliminate the Need for Electrically Heated Catalysts and Dual Catalysts

In 1994, automakers claimed that meeting LEV I vehicles would have to use close-coupled catalysts, electrically heated catalysts (EHCs), and/or hydrocarbon traps, especially for their bigger V-6 and V-8 engine vehicles. Actual costs turned out to be much lower, principally by eliminating the need for a costly electrically heated catalyst and dual catalysts through technologies not originally anticipated by CARB in 1990. Table 8 presents a comparison of 1990 and 1994 ARB technological projections with actual 1998 four, six, and eight cylinder LEVs. Highlighting denotes where inaccurate predictions were made.

A critical innovation was in catalyst technology, enabled by advances in design and materials, which allowed faster "light off" of the catalyst. While three-way catalytic converters traditionally utilized rhodium and platinum as the catalytic material, advances in palladium and tri-metal (i.e., palladium-platinum-rhodium) catalyst technology allowed converters to increase high-temperature durability over previous catalysts and lower the temperature at which 50 percent pollution conversion occurs (called "light-off" performance). Heat-optimized exhaust pipes and heat-producing engine calibrations further contributed to quicker catalyst light-off. This improvement in light-off capability allowed catalysts to be placed further from the engine than was previously predicted and virtually eliminated the need for other, more complicated after-treatment devices in light-duty vehicles such as electrically-heated catalysts and their complementary air injection systems.

Important innovations were more precise fuel control systems enabled by fuel injection, sensor and computer controls. The development of dual oxygen sensors and adaptive transient fuel control systems reduced engine-out emission levels which allowed the utilization of technologies that were refinements of existing Tier 1 standard technologies rather than more costly and complex after treatment emission control technologies.[36]

Table 8. LEV Technologies, Projected versus Actual

X = 1998 LEV Honda Civic Four Cylinder
O = 1998 LEV Toyota Camry Six Cylinder
V = 1998 LEV Ford Crown Victoria Eight Cylinder

Technology	1990 ARB Projected	1994 ARB Projected	1998 Actual
Projected and actually employed			
Dual Oxygen Sensors	X O V	X O V	X O V
Adaptive Transient Fuel Control Systems	X O V	X O V	X O V
Sequential Air-Assist Fuel Injectors	X O V	X O V	X O -
Heat Optimized Leak-Free Exhaust	- - -	X O V	X O V
Greater Catalyst Loading	X O V	X O V	X O V
Innovations			
Dual Close-coupled Catalyst	- - -	- - -	- - V
Close-coupled Catalyst	- - -	X 80% of fleet -	X O -
Projected but mostly not needed			
Under-floor Catalyst	X O V	X 80% of fleet V	- O -
Electrically Heated Catalyst	X O V	- 20% of fleet V	- - -
Air Injection	- O V	- 20% of fleet V	- - -

Source: Cackette 1998

PZEV: "Partial ZEV" Standards Cost Estimates Rapidly Fall

Another very good case study has to do with the technologies used to meet the "partial zero emission vehicle" (PZEV) standard. In order to move from the next cleanest standard (SULEV) to PZEV emission levels, the ARB predicted in August 2000 that vehicles would need to be equipped with separate hydrocarbon absorbers and attendant switching valves. It was also assumed that, as was the case for the first PZEV system in California, all PZEVs would be required to increase catalyst volume. Furthermore, the ARB believed that additional carbon trap capability, improved seals, and some reconfiguration of components (necessary to move from near-zero to zero evaporative emission control systems) would be required.[37] The ARB figured that the cost of this additional hardware would be $200. It also estimated that another $300 would be required to cover the expense associated with increasing the warranty to 15 years/150,000 miles. This figure assumed three repairs per vehicle over the extended warranty period, due in part to the more complex technology involved. Altogether, the ARB estimated that the incremental cost of going from a SULEV to a PZEV would be about $500.

Yet, only a year later in the Fall of 2001, the ARB revised their predictions as it became apparent that the use of simpler PZEV technology would be utilized. By 2003, the ARB said that, as in the LEV I program, technology would actually be simpler than predicted[38] due to the appearance of innovative PZEV systems. Instead of separate hydrocarbon absorbers and attendant switching valves, soon to be introduced PZEVs would utilize a combined hydrocarbon absorber and catalyst. Also, increased catalyst volume would not be required to meet PZEV compliance. Thus, incremental cost estimates for necessary hardware were reduced from $200 to between $60 and $85. The ARB also realized that the less complex nature of underlying technology and the increased durability of emission control components used by PZEVs made their $300 warranty estimate too high. This figure was revised to between $125 and $150 per vehicle, making the total incremental cost of PZEVs relative to SULEVs about $200, which is 60 percent less than their original estimate. The ARB now estimates that the incremental cost of PZEVs relative to SULEVs will soon be less than $100. It is unclear yet whether this prediction is accurate.

A look at one example of a PZEV, the 2003 Ford Focus, indicates that the car met the standard not because of any single or even multiple new technologies, but, as Ford's vice president of Powertrain Operations Dave Szczupak explained, because of "attention to every little detail."[39] Among these details was the new 2.3-liter engine's computer-designed, friction-welded plastic intake manifold. Within each of the manifold's four runners was a butterfly valve that restricts airflow at low speeds and increases flow at higher speeds, an innovation that enhances more complete fuel combustion. Other details included a four-hole injector design that also contributes to better combustion and lower emissions and a precise computer-controlled sequential electronic fuel injection. As a result of these modifications and despite its strict emissions qualification, the car's engine was of larger displacement than the one it replaced, weighs less, produces more horsepower, and is more fuel-efficient. A partial list of new technologies implemented on the Ford Focus to reduce emissions by complete combustion and exhaust scrubbing is listed below in Table 9.

Table 9. New Emission-Reduction Technologies Not Predicted by CARB Implemented on the Ford Focus PZEV

Technology	Effect
12-hole fuel injectors	Better atomizes fuel and results in improved combustion.
Charge Motion Control Valves (CMCVs)	Induces tumble in the intake charge below 1800 rpm by partially blocking the intake port. This fills the cylinder better at low speeds, improves the mixing of gasoline and air, and thus improves combustion.
Upgraded catalysts	Cleans exhaust better and are more durable.
Electric air injection into the exhaust manifold	Burns off excess hydrocarbons at startup and heats the catalytic converter to its most efficient operating temperature (called "light off") faster.
"Black Oak" engine management computer	A new engine management computer that runs at a higher speed and contains more memory than the previous computer, thereby allowing a better optimization of the air-fuel ratio.
Coil-on-plug (COP) ignition	Provides a stronger spark that helps stabilize combustion.
Improved seals on the piston rings, valves, and PCV system.	Reduces oil consumption.
Improved engine cylinder bore finish and cylindricity.	Reduces oil consumption.

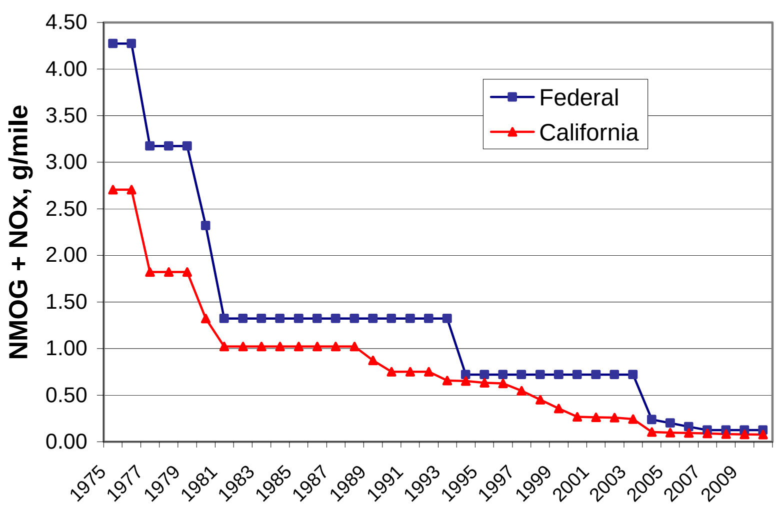
Source: Carney 2003

By the 2003 model year, popular manufacturers such as Honda, Toyota, BMW, and Volvo offered 12 different models of PZEVs while Honda offered their Civic Hybrid as an AT-PZEV. These clean cars benefit not only California, but the rest of the nation as well since several of the manufacturers, such as Ford, Toyota, and Honda offer their vehicles for sale nationwide. The new Ford Focus PZEV has a global effect as its engine replaces a total of eight different engines formerly used by various Ford entities around the world, could ultimately reach an annual production volume of 1.5 million units, and is destined to be produced at four plants and power up to 20 percent of the vehicles Ford produces worldwide.[40] The engine is also used in the Mazda 6, Ford Ranger pickup trucks, the Futura, and the hybrid-electric Escape.[41] Eventually, the engine could replace nearly all of the other inline four-cylinder engines used by Ford and its subsidiaries worldwide.[42]

California Leadership: Examples of How California Standards Have Had National and Global Impacts

California has historically led the nation in setting tough new air pollution standards (see Figure 2.) California standards and approaches have often been adopted by other states and at the national level (see Tables 10 and 11.) Other countries have adopted the clean air technologies and programs pioneered in California, such as the three-way catalytic converter and reformulated gasoline. It appears highly likely that the adoption of new CO_2 standards in California will perform the same function for global warming pollution. Historically and legally, California has served two clear functions that have led to national pollution benefits of its program.

Figure 2. California Has Historically Led the Nation on Automotive Air Pollution Standards



Source: CARB and EPA

First, California serves as a "laboratory" or "pioneer" of new technologies and new approaches. The California "model" then allows the federal government to adopt the same or a similar approach. This role is explicitly recognized in federal law and by Congress which granted California the only state to have the authority to set its own motor vehicle pollution standards. This occurred with the 1966 California tailpipe standards (adopted by the federal government in 1968), the 1990 California LEV program (which became the model for the National LEV program) and finally the 1998 California LEV II program (which served as the model for the federal Tier 2 program.) California also pioneered compliance testing, smog check, and reformulated gasoline and diesel, all of which were adopted nationally.

Table 10. List of Automobile Pollution Standards Pioneered in California and Adopted Nationally

Technology or Standard	California Debut	Federal Debut
First air pollution control requirement (Positive Crankcase Ventilation)	1963	
First HC and CO standards	1966	1968
First NOx standard	1971	1973
First Catalytic Converter (2-way)	1975	
First Catalytic Converter (3-way)	1977	1981
First Ban on Leaded Gasoline	1992	1995
First Reformulated Gasoline	1992	1995
LEV I (NLEV)	1994	1999 Northeast, 2001 National
LEV II (Tier 2)	2004 (adopted 1998)	2004 (adopted 1999)

Source: CARB, Doyle 2000, NRDC

Table 11. Chronology of California Automotive Emission Control Leadership

Year Adoption/Effect	Event
1961/1963	California adopts of the first automotive emissions control technology in the nation, the **Positive Crankcase Ventilation (PCV).** Goes into effect on new passenger vehicles for sale in California for model year 1963.
1964/1966	California adopts **the first-ever tailpipe emission standards for hydrocarbons and carbon monoxide** which go into effect 1966.
1965/1968	Congress passes Motor Vehicle Control Act of 1965 that adopts California's 1966 standards nationally as of 1968. (NESCAUM 2000, II-4)
--/1971	The first automobile **nitrogen oxides (NOx) standards** in the nation go into effect in California
--/1973	First federal standards for NOx.
1973/1975	California adopts stringent new standards, prompting **first catalytic converters** to come into use in California.
1975/1977	California approves adoption of stringent new HC and NOx standards that requires the use of **three-way catalytic converters** for the first time. (Doyle 2000, p108)
1977/1981	New federal law passed with standards for HC and NOx similar to the 1977 standards beginning in 1981, delaying the debut of three-way catalysts nationally until 1981 (Doyle 2000 p 147-8).
1980	California requires compliance testing on automobiles as they age to encourage the manufacturing of more durable emissions control equipment.
1984	California Smog Check Program goes into effect.
1990/1994	California adopts the strictest emission standards, the **Low -Emission Vehicles I (LEV I) Program,** begins in 1994.
	EPA, bowing to northeast state pressure, adopts National LEV (NLEV) program modeled after the California LEV I program.
1990/1992	CARB adopts first-ever **reformulated gasoline program** which takes effect beginning in 1992 (Phase I California Cleaner Burning Gasoline) including the phase out of leaded gasoline.
19941995	EPA adopts its federal reformulated gasoline program modeled on California's program, including the phase out of leaded gasoline.
1998/2004	California adopts **the Low Emission Vehicle II (LEV II**) Program for the strictest new emission standards on vehicles.
1999/2004	US EPA adopts Tier 2 Program, largely modeled on California's LEV II.

Source: CARB, Doyle 2000, NRDC

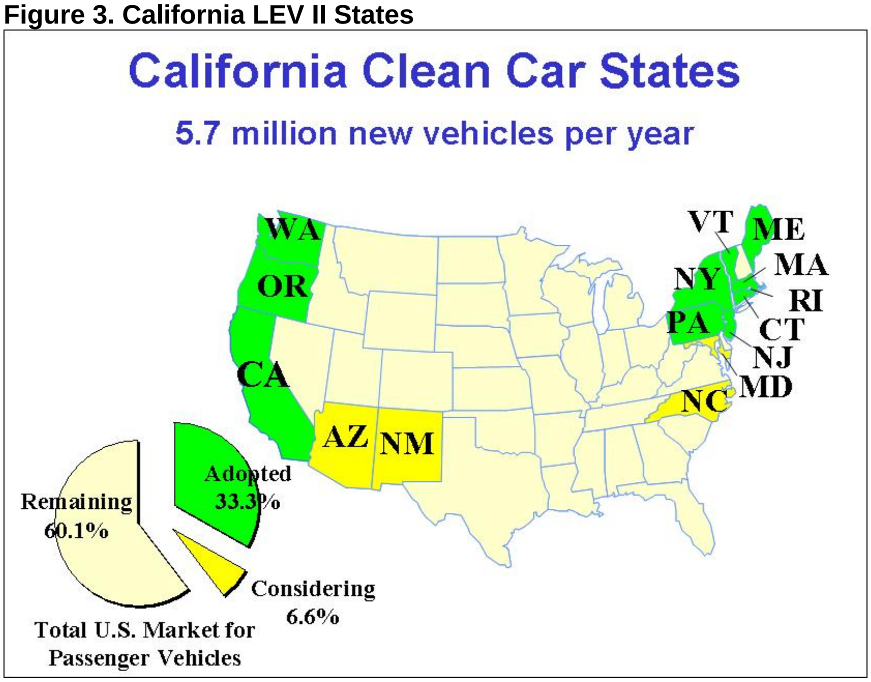
A 2006 National Academy of Sciences (NAS) study confirmed the powerful role that California has played in forcing new technologies. According to this study:

> This history of the LEV and ZEV demonstrates the benefits of using California as a laboratory to experiment with aggressive, high-risk strategies. The technology-forcing requirements that CARB imposes can result in major breakthroughs in emission controls.[43]

Second, under the Clean Air Amendments of 1977, Section 177 allows other states with air quality problems to adopt the California motor vehicle pollution standards. Because of this provision according to the NAS, "the technology-forcing nature of California standards can benefit not California but also the rest of the country."[44] Prior to the adoption of the CO_2 standards in 2004, seven states had adopted the California LEV II program and thirteen states have adopted California heavy-duty standards (so-called "Not-to-Exceed" limits). As of early 2006, ten other states have adopted California's LEV II program with its CO_2 standards. Consequently about 33 percent of the nation's new vehicles sales fleet is subject to the more stringent California LEV II program standard, including its CO_2 standards (see Figure 3).

The "threat" of state adoption under Section 177 of more stringent California standards puts pressure on the industry and federal EPA to develop standards more stringent than the existing federal standards or to maintain strong federal standards (e.g., the National LEV program, and the 2007 diesel truck standards).

Figure 3. California LEV II States



Source: NRDC

Because of the long-standing success of California's role in setting its own mobile source standards, the NAS strongly recommended that California continue its unique authority. Specifically, its recommendation is that:

> California should continue its pioneering role in setting mobile-source emissions standards. The role will aid the state's efforts to achieve air quality goals and will allow it to continue to

be a proving ground for new emissions-control technologies that benefit California and the rest of the nation.[45]

Other Examples of California Programs Serving as a Model for National Standards

Besides motor vehicle pollution control, there are other programs that have been pioneered in California that have been adopted nationally and even internationally (appliance and building codes in Russia and China for example). Again, this further demonstrates that a California CO_2 vehicle standard will likely have impacts that go well beyond California's borders.

Appliance efficiency standards[46]

A major discussion of energy policy options in California in the early 1970s that was undertaken due to environmental concerns regarding new power plant siting prompted California to take the lead on appliance efficiency issues by passing the Warren Alquist Act in 1974. This act established the California Energy Commission with the authority to set appliance efficiency standards. The technical and policy analysis undertaken in California had impacts on the national level, as the federal government's interest in appliance efficiency grew. In 1975, the Ford administration initiated an executive order and later signed the Energy Policy and Conservation Act of 1975 establishing the use of voluntary targets for appliance efficiency to reduce new appliance energy use by 20 percent relative to current levels.

Yet, California and other states were unhappy with the uncertainty of voluntary reductions in energy use and, therefore, began to adopt mandatory energy efficiency standards between 1975 and 1977. This state-level work changed the dynamic at the federal level, prompting newly elected President Carter to propose legislation that would replace the voluntary efficiency targets with mandatory standards. Despite negative reactions by manufacturers, Congress passed and the President signed the National Energy Conservation and Policy Act (NECPA) in 1978. Manufacturers' concerns were placated, in part, by giving these DOE standards preemptive power over state standards.

Upon the change in administration in Washington in 1980, many states became concerned about the government's new hostility towards standards and the lack of progress on appliance efficiency. It was apparent that for progress to be made, it would have to be initiated on the state level. California, with its EPA waiver, adopted stringent two-tiered standards for refrigerators and central air conditioners in 1984. By 1986, Arizona, Florida, Kansas, Massachusetts, and New York had adopted standards on one or more products. In response to the growing desire by manufacturers to preempt these state efforts at setting standards, Congress passed and the President signed the National Appliance Energy Conservation Act (NAECA) in 1987.

Building efficiency standards[47]

Before the DOE established energy efficiency standards for new buildings, the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) promulgated an energy standard, "Standard 90", that was the predominant influence on standards adopted by states. This standard, which was comprised of Standard 90.2 (for residential buildings) and 90.1 (for commercial buildings), drew heavily from California's pioneering work in the field.

California's standards originated in 1975 when the newly established CEC, under a mandate by the Warren Alquist Act, adopted efficiency standards for residential buildings. California's work continued when, after a comprehensive review of the standards, the state adopted new standards in 1980 that required significantly increased levels of energy efficiency as well as embodied several regulatory innovations. Then, in 1987, the state made modifications that resulted in great improvements in the energy efficiency and political acceptability of the standards. Much of the research and regulatory structure developed in California was adopted directly or in modified form by the ASHRAE committees and thereby adopted by most states.

Conclusion

The past four decades of California leadership and pioneering efforts in automobile pollution control also strongly suggests that the California CO_2 standards will have a national and probably even global impact. In this paper, we have also demonstrated that there is a clear historical pattern of automakers overestimating the cost of compliance with proposed air pollution emission standards for gasoline automobiles. Our review of previous estimates from as far back as 1975 finds that the auto industry and its allies have historically overestimated the actual costs by a factor of about 2 to 10 times the actual costs. Regulators have also tended to overestimate costs, albeit to a much lesser extent. A typical regulator estimate of actual automaker compliance costs are 1 to 2 times the actual costs. Hence, based on this past three decades of historical evidence, it is fair and reasonable to assume that both the automakers and the regulator air pollution control cost estimates, including for the proposed California CO_2 standards, will be higher than actual costs. A primary reason for regulator cost overestimates is the role of unanticipated technological innovation which has dramatically lowered the actual compliance costs in many instances. Furthermore, as history has demonstrated, unanticipated innovation could very likely reduce the cost of compliance by an even greater degree in the future.

---

[1] NESAUM, "Environmental Technology and Technology Innovation: Controlling Mercury Emissions from Coal-Fired Boilers," Northeast States for Coordinated Air Use Management, September 2000.
[2] Anderson and Sherwood, "Comparison of EPA and Other Estimates of Mobile Source Rule Costs to Actual Price Changes," presented at the SAE Government Industry Meeting, DC, May 14, 2002, SAE 2002-01-1980.
[3] See Harrington et al., "On the Accuracy of Regulatory Cost Estimates," Resources For the Future, January 1999, and NESCAUM 2000.
[4] Doyle, Jack. *Taken For A Ride,* New York: Four Walls Eight Windows, 2000, p. 42.
[5] Sierra Club of Canada. "Will the Kyoto Protocol shutdown Canada? No it won't. Our economy will continue to grow and grow." October 11, 2002. [online] http://www.sierraclub.ca/national/media/kyoto-economy-02-10-11.html
[6] Doyle 2000, p. 77.
[7] NRDC calculation based on Producer Price Indexes for automobiles from the Bureau of Labor Statistics.
[8] Doyle 2000, p. 77 and p. 92.
[9] NRDC calculation based on Producer Price Indexes for automobiles from the Bureau of Labor Statistics.
[10] Sperling, et al., "Analysis of Auto Industry and Consumer Responses to Regulations and Technological Change, and Customization of Consumer Response Models in Support of AB 1493 Rulemaking," June 1, 2004.
[11] Austin and Lyons, "Cost Effectiveness of the California Low Emission Vehicle," SAE Technical Paper Series 940471, presented at the International Congress & Exposition, Detroit MI, February 28-March 3, 1994.
[12] Cackette, "The Cost of Emission Controls, Motor Vehicles and Fuels: Two Case Studies," presentation at MIT, 1998.
[13] CARB staff estimated the cost to be $35 from a Tier 1 baseline (Cackette 1998). We adjusted the CARB estimate by adding another $85 to account for the cost difference between a Tier 0 and Tier 1 vehicle based on data in Anderson and Sherwood 2002.
[14] Kourt, J.M., Letter to Charles Mizutani of the CEC, *Request for Approval of $0.00 Incremental Cost for General Motors 1994 Model Year TLEV 2.2L Engine Equipped J and L Models (Engine Family RIG2.2V7G2EA),* April 22, 1993.

[15] Patterson, Susan. Letters to Motoko Katoh (Nissan Motor Company) regarding $0.00 incremental cost for Nissan engine family RNS2.4VJG2EA, and David Hermance (Toyota Motor Corporation) regarding $0.00 incremental cost for engine family number RTY2.2VJG2GA.

[16] CARB staff estimated the cost to be $251 from a Tier 1 baseline (Cackette 1998). We adjusted the CARB estimate by adding another $85 to account for the cost difference between a Tier 0 and Tier 1 vehicle based on data in Anderson and Sherwood 2002.

[17] Anderson and Sherwood 2002.

[18] CARB, "'LEV II' and 'CAP 2000' amendments to the California Exhaust and Evaporative Emission Standards," Final Statement of Reasons (FSOR), September 1999, p 26.

[19] CARB 1999.

[20] According to the New York Times ("Light Trucks Face Tougher Standards," November 3, 1998), the so-called "Californians for Realistic Vehicle Standards" was set up by Detroit automakers with the assistance of the California Chamber of Commerce:

> The address of the month-old lobbying group is the Sacramento headquarters of the California Chamber of Commerce, while the group's telephone number is that of the Sacramento office of Burson-Marsteller, an international public relations firm often used by the auto industry.

[21] CARB 1999, p. 42.

[22] ibid, p. 45.

[23] CARB, "Addendum Presenting and Describing Revisions to: Initial Statement of Reasons and Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions fomr Motor Vehicles," September 10, 2004.

[24] AAM press release, September 22, 2004.

[25] High is Ron Defore of SUVOA, cited in article "'Cool gray city' projected to turn murderously hot, temperatures likely to rise by mid-century as a result of global warming study warns," Carl T. Hall San Francisco Chronicle September 14, 2004.

[26] Austin and Lyons 1994.

[27] NESCAUM 2000.

[28] Rubin, E et al. "Learning curves for environmental technology and their importance for climate change policy analysis," Energy 29 (2004) 1551-1559.

[29] NESCAUM 2000.

[30] For example, see Arrow K, "The Economic Implications of Learning by Doing", *Review of Economic Studies*, p. 155, 1962, and Argote, L. and Epple, D. "Learning Curves in Manufacturing", *Science*, Vol. 247, p. 920, 1990.

[31] IEA, *Experience Curves for Energy Technology Policy*, OECD/IEA, 2000.

[32] Sakiya, Tetsuo. *Honda Motor: The Men, The Management, The Machines*, Tokyo and New York: Kodansha International, 1982, p. 181, in Doyle, Jack. *Taken For A Ride*, New York: Four Walls Eight Windows, 2000, p. 326.

[33] ibid, p. 326.

[34] ibid, p. 328.

[35] ibid, p. 328.

[36] California Air Resources Board. *Low Emission Vehicle and Zero Emission Vehicle Program Review*, staff report, November 1996.

[37] California Air Resources Board, *2000 Zero Emission Vehicle Biennial Review*, staff report, August 7, 2000.

[38] California Air Resources Board, *Revised Discussion of PZEV Incremental Cost*, 2003.

[39] *Ford's Focus Bringing Thousands of PZEVs to Worldwide Markets*, Green Car Journal, Volume 12, Number 3, March 2003, p. 29.

[40] ibid

[41] Carney, Dan. *Global I4 goes PZEV*, Automotive Engineering International, Volume 111, Number 7, July 2003, p. 76-78.

[42] ibid

[43] National Research Council, *State and Federal Standards for Mobile Source Emissions*, prepublication copy, Committee on State Practices in Setting Mobile Source Emission Standards, National Research Council of the National Academies, the National Academy Presses, 2006, p. 115.

[44] ibid, p. 117.

[45] ibid., p. 3.
[46] All the information for this section was obtained from: Nadel, Steven and Goldstein, David. *Appliance and Equipment Efficiency Standards: History, Impacts, Current Status, and Future Directions,* Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington, DC, 1996.
[47] All the information for this section was obtained from: Goldstein, David. *The American Experience with establishing energy Efficiency Standards for New Buildings: Case studies of California and National Energy Standards,* Presented at the third Soviet American Symposium on Energy Conservation, Yalta Crimea, U.S.S.R. National Resources Defense Council, San Francisco, 1988.