Comments on the Proposed Adoption of Regulations by the California Air Resources Board (CARB) to Control Greenhouse Gas Emissions from Motor Vehicles

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Summary of Comments

NRDC is pleased to submit the following comments regarding the California Air Resources Board (CARB) staff's proposal to control greenhouse gas emissions from motor vehicles. The Natural Resources Defense Council is a national environmental advocacy organization with over 550,000 members. NRDC has spent years working in California and at the national level to reduce the environmental impact of our motor vehicle fleet and was one of the co-sponsors of AB 1493 (Pavley 2002).

Findings

1. California has the clear legal authority to regulate air pollution from motor vehicles including the air pollutants that cause global warming, under AB 1493 and the federal Clear Air Act. These are not fuel economy standards and are not affected by the federal fuel economy law.
2. The staff's analysis of the technical feasibility and cost-effectiveness is scientifically sound. Its analytical thoroughness is comparable to the analysis performed for the highly successful LEV I (adopted 1990) and LEV II (adopted 1998) programs. The staff's conclusions are consistent with the findings of other independent analyses.
3. As one of the sponsors of AB1493 (Pavley 2002), we believe the staff's proposed regulations are consistent with the legislative intent and requirements of AB1493, including the requirements for: maximum technical feasible and cost-effective standards, maximum flexibility (including allowing for alternative compliance mechanisms), and early action credits.
4. Due to California's vulnerabilities to the impacts of global warming, adoption of these standards is necessary to reduce the risks of global warming, including detrimental impacts on public health, sensitive ecosystems, water resources, and the economy.
5. The history of air pollution control demonstrates that California's leadership actions plays a vital role in leveraging pollution reductions by other states, nationwide, and even globally, as other jurisdictions learn from and follow California's leadership and as technologies pioneered in California are adopted elsewhere.
6. Seven northeastern states (NY, MA, VT, ME, NJ, CT, RI) have adopted the California LEV II program. These states will likely also adopt these new standards and, indeed, several have already stated their intentions to do so. Canada has also expressed interest in adopting California's program.
7. The history of past motor vehicle pollution programs shows that the auto industry has consistently exaggerated the costs of proposed regulations. The history also shows that both California and the federal government have typically overestimated compliance costs, though to a much lesser degree than the industry.

Recommendations

Based on its technical and legal soundness, NRDC strongly urges the Board to adopt the staff's proposal. However, we respectively recommend that the Board consider the following amendments to strengthen the program:

1. Reduce the phase-in time by one year (2015 versus 2016 for full implementation of the mid-term package);
2. Increase the stringency of the mid-term standard by considering higher numbers of hybrid vehicles;
3. Increase the weight break point for T1s from 3750 lbs in order to prevent gaming by manufacturers in classifying car-based "crossover" vehicles as light trucks.
4. Reduce the period from four to two years over which the automakers can accrue GHG debits before being assessed penalties.

COMMENTS

1. Legal Authority: California has the legal authority to regulate CO_2 and other greenhouse gas emissions from motor vehicles.

For more than 35 years, California has enjoyed clear authority under its own state laws and the federal Clean Air Act to set pioneering standards to cut air pollution from motor vehicles. Attacks on the California law rest mainly on two arguments, both of which are flawed. First, some claim California lacks authority to set standards for global warming emissions because those emissions are not "air pollutants" under the federal Clean Air Act. Second, they say the new California rule is fuel economy regulation, and barred by exclusive federal jurisdiction over mileage standards. In each case, the opponents are wrong.

CO_2 and other global warming emissions are "air pollutants"

The Clean Air Act gives California authority to set air pollution standards for motor vehicles. Global warming emissions clearly meet both the legal and commonsense definition of "air pollutant":

- The Clean Air Act says an "air pollutant" is any "physical, chemical, biological, [or] radioactive… substance or matter which is emitted into or otherwise enters the ambient air" -- terms that obviously include heat-trapping emissions covered by the California law: carbon dioxide, methane, and nitrous oxide emitted from vehicle tailpipes and hydrofluorocarbons leaking from air conditioners.
- The Clean Air Act authorizes EPA to regulate any motor vehicle air pollutant determined by the agency to "cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare." "Welfare" specifically includes "effects…on weather…and climate."
- The dangers of global warming pollution were specifically recognized in congressional Clean Air Act debates as far back as 1965. Global climate change was also singled out as a concern under the act during legislative debate over the 1970 and 1977 amendments.

The federal fuel economy law does not pre-empt California's authority to regulate air pollution

Under the Energy Policy and Conservation Act the federal government sets fuel economy standards (known as "CAFE" standards). This law has no effect on the authority of California and EPA to set emission standards for air pollution. This is true regardless of whether the technology used to meet emission standards has an effect on vehicle fuel consumption – either to increase it or decrease it. In fact, federal law gives priority to air pollution standards even if federal and California emission standards *hurt* fuel economy. And there is no conflict at all when, as here, air pollution standards have the effect of producing fuel savings.

- In the early days, air pollution standards tended to increase fuel consumption. Today that effect is gone – in fact the reverse is true. But from its beginning, the CAFE law specifically provided for adjusting fuel efficiency standards if California or federal pollution rules made mileage standards more difficult to meet -- not the other way around.

- If the fuel economy law does not stand in the way of EPA or California air pollution standards when they make better fuel economy *harder* to achieve, it certainly doesn't stand in the way when air pollution standards make better fuel economy *easier* to achieve.

2. Global Warming Will Worsen Ozone Problems in California

NRDC recently completed a study, *Smog in the Forecast*, which illustrates a possible range and order of magnitude of the effects of global warming on ozone levels and public health in California (see attachment A). Despite tremendous efforts to control air quality, California has the most polluted air in the nation, and high ozone levels in particular.

Ground-level ozone pollution, or smog, is a persistent environmental health problem that can aggravate allergies, asthma, and respiratory illness, particularly in children and the elderly. Studies in California have linked high ozone levels to decreased lung function in school children, school absenteeism, higher incidence of asthma in children, and increased hospital admissions.

California already faces a major challenge in controlling ozone levels, and global warming will likely compound that challenge. Ozone formation is more sensitive to temperature and weather than other air pollutants. In scenarios examined in this study, global warming conditions in California would increase already unhealthy levels of smog; this in turn could lead to a rise in respiratory symptoms like shortness of breath, lung inflammation and asthma, as well as increased hospital admissions and even death.

Our new modeling effort demonstrates future increases in ozone pollution brought on by global warming's higher temperatures. In the year 2050, 1-hour peak ozone concentrations could increase by an average of 3.2 parts per billion (ppb) in the Los Angeles region, and 2.0 ppb in the San Diego region. In the year 2090, the daily 1-hour maximum of ozone in the air across Los Angeles could rise by 4.8 ppb, and 3.1 ppb in San Diego (see Table 2-1).

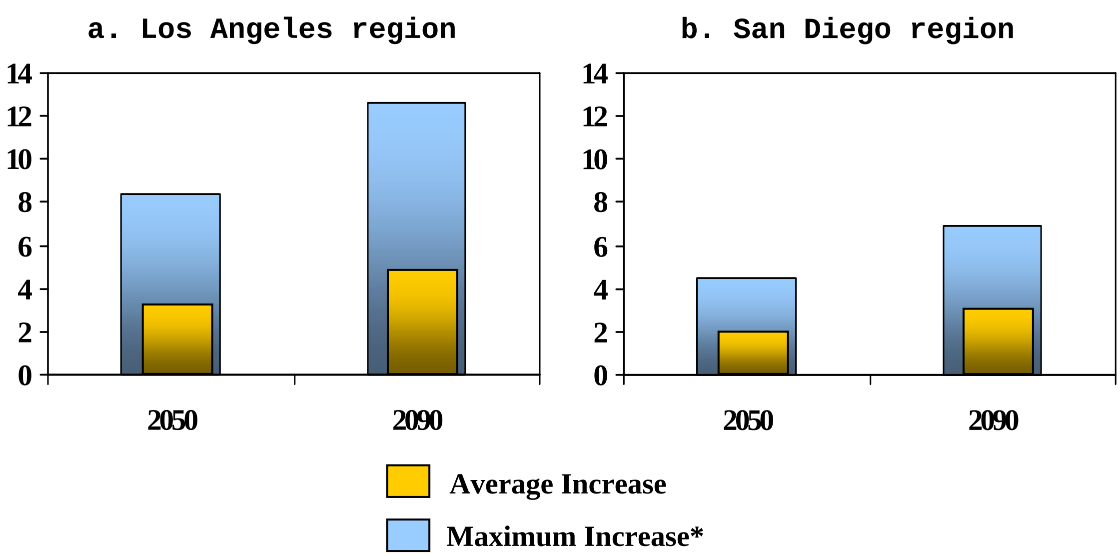
Areas already burdened with high ozone levels could see even greater increases in ozone pollution. In 2050, some Los Angeles residents could see an 8.4 ppb rise in the daily 1-hour maximum for ozone (Figure ES-1a). The regional average increase alone, 3.2 ppb, would be roughly equivalent to the pollution created by an additional 20 million cars and light trucks on the road (about 139 tons of hydrocarbons and nitrogen oxides). Current ozone levels are already hurting Californians' health, and this projected increase in ozone pollution could make matters worse. In both the San Diego and Los Angeles regions, hospital admissions for asthma in people under 65 are predicted to rise, as would the mortality rate.

Table 2-1: Summary of Findings From NRDC's New Study, *Smog in the Forecast*, September 2004

	Los Angeles		San Diego	
	2050	2090	2050	2090
Average temperature increase	2.7C (4.9F)	4.6C (8.1F)	2.1C (3.8F)	5.5C (9.9F)
Average increase in ozone peaks (1-hr), ppb [1]	3.2	4.8	2.0	3.1
Maximum increase in ozone peaks (1-hr), ppb [2]	8.4	12.6	4.5	6.9
Approximate equivalence, tpd of ROG/NOx [3]	85/54	109/70	not estimated	
Approximate equivalence, millions of autos [4]	20	25	not estimated	
Average mortality increase	0.12-0.17%	0.19-0.26%	0.08-0.11%	0.12-0.17%
Average asthma hospital admissions increase	0.93%	1.4%	0.58%	0.90%

[1] Calculated as the average of the changes between the base case and future scenario peaks for each gridcell.
{2] Based on the average of the eight 5 km gridcells with the largest increase.
[3] Based on average increase in ozone peaks from the 1997 LA-basin average peak of 85 ppb.
[4] Based on the average ozone increases. The average 2030 California passenger car and light truck fleet was calculated using EMFAC2002 model runs. 2030 was chosen since it is the latest year available from EMFAC model.

Figure ES-1a, b: Increase from 1997 in the Maximum Hourly Ozone Level in Response to Temperature Increases Predicted by Climate Change Scenarios (ppb)



Note: The maximum increase is the average of the eight 5km by 5km gridcells with the largest increases. This reflects the areas of the largest change within the region.

3. Cost estimates by both industry and regulatory are typically too high

There is a clear historical pattern of automakers exaggerating cost of compliance, and often regulators overestimating the cost, albeit to a much lesser extent. Based on a review of previous analyses, we find that the auto industry and its allies have overestimated the actual costs by a factor of about 2 to 10 times the actual costs. Regulators (CARB and 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. **Hence, based on historical experience it is fair and reasonable to assume that both the automakers and the CARB staff cost estimates will be higher than actual costs.**

The reasons for these overestimates are:[1]

1. Unanticipated innovation
2. Conservative estimates by both regulators and industry.
3. Regulators lacking full access to industry data.
4. Intentional inflation by industry with the purpose to weaken or delay regulations.

According to a study by NESCAUM, "…pre-regulatory estimates, particularly those on the high-end, can usually be considered to reflect worst cast scenarios and do not necessarily form a reliable basis for policy decisions."[2] 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."[3]

3.1 The auto industry has historically overstated the costs and impacts of pollution standards

Automakers and their allies have consistently overestimated the actual cost of compliance. They have consistently claimed that costly and complicated technologies would have to be developed and used in order to meet proposed emission standards (see Figure 3-1). Based on a review of past industry estimates, the auto industry's typical estimates are 2 to 10 times higher then actual costs (see Table 3-1). For example:

- In the 1970s, Chrysler claimed it would cost $1,300 more to comply with the proposed 1975 federal pollution standards.[4] In today's dollars, this is equivalent to $2,770.[5] The actual cost to comply with the standard, which as delayed until 1981, is estimated to have been $875 to $1,350 in today's dollars.[6]

[1] See Harrington et al., "On the Accuracy of Regulatory Cost Estimates, " Resources For the Future, January 1999, NESCAUM, "Environmental Technology and Technology Innovation: Controlling Mercury Emissions from Coal-Fired Boilers," September 2000.
[2] "Environmental Technology and Technology Innovation: Controlling Mercury Emissions from Coal-Fired Boilers," NESCAUM, September 2000.
[3] 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.
[4] Doyle, J., *Taken For a Ride*, 2000, p. 77.
[5] NRDC calculation based on Producer Price Indexes for automobiles from the Bureau of Labor Statistics.
[6] 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.

- In 1994, the automakers claimed the cost of meeting the California TLEV standard to be as high as $862. The actual cost turned out to be about $120.[7] The actual cost to the consumer in some cases was 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.[8]

- In 1994, the automakers claimed the cost of meeting the California LEV standard to be $788, and the actual cost turned out to be ten times less, about $83.[9] The actual cost to the consumer in some cases was even lower. 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.[10]

- In the 1994, automakers claimed that the cost of meeting the California ULEV standards would be as high as $2,799.[11] Honda met the standard for about $336.[12]

- In the 1990's, the automakers claimed that the costs of meeting the 1996 federal standards would be equivalent to $432. The actual costs, according to analysis by the US EPA using data from the US Bureau of Labor Statistics, turned out to be $88.42.[13]

- In 1998, an industry-front group "Californians for Realistic Vehicle Standards" claimed that the cost to meet the LEV II standards would be as high as $7,000 for a light truck and that there would be 33 percent fewer full-size vehicles available to consumers.[14] Today, many cars, pickups and SUVs are certified to these standards, clearly without such enormous price differential as claimed, including the Chevrolet Traiblaizer, Buick Rainer, Ford Explorer/Mercury Mountainer, and the Isuzu Ascender.[15]

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[7] CARB staff estimated the cost to be $35 from a Tier 1 baseline (Cackette, "The Cost of Emission Controls, Motor Vehicles and Fuels: Two Case Studies," 1998). The automaker estimate was from a Tier 0 baseline, so we adjusted the CARB estimate by adding another $85 to account for the cost difference between a Tier 0 and Tier 1 vehicle. The Tier 0 adjustment is NRDC's estimate based on data in Anderson and Sherwood, 2002.

[8] 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.

[9] Cackette, "The Cost of Emission Controls, Motor Vehicles and Fuels: Two Case Studies," 1998.

[10] 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.

[11] NESCAUM 2000.

[12] 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 (see footnote 7).

[13] Anderson and Sherwood 2002.

[14] 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.

[15] See CARB's web site for a list of the MY2005 Certified Vehicles at http://www.arb.ca.gov/msprog/ccvl/2005ccvl.htm.

Figure 3-1 Comparison of Cost Estimates Versus Actual Costs

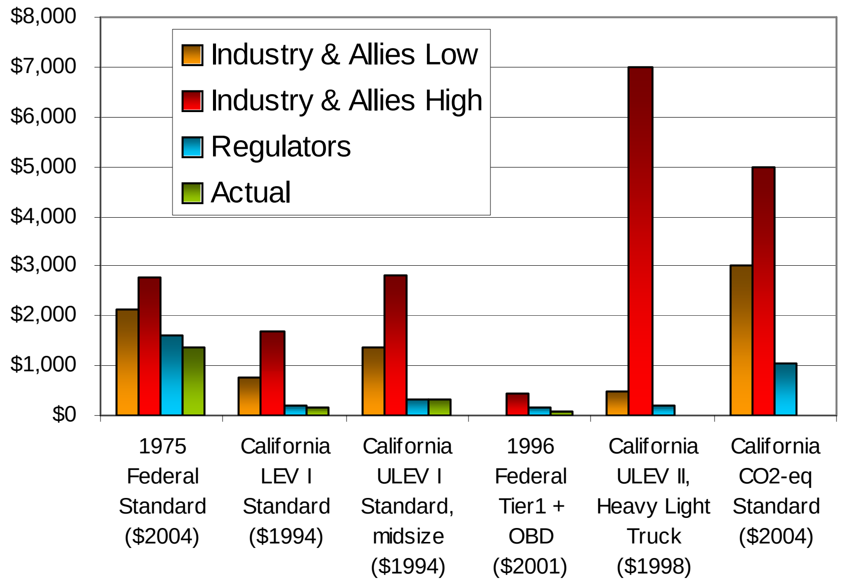

Table 3-1 Comparison of Estimated Costs to Actual Price Changes

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 est'd
California CO_2-eq Standard ($2004)	$3,000-$5,000	$1,048	not est'd

Table 3-2 Factor Actual Costs Overestimated

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

Notes for Tables 3-1 and 3-2:
1975 Federal Standard (estimates are in 2004 dollars unless otherwise noted)

- Industry - Ford estimate of the cost of Pinto might rise $1000, equal to $2130 in 2004 dollars. Chrysler claimed an extra $1,300 to own and operate, equal to $2,770 in 2004 dolllars (Doyle 2000, p. 77). Adjusted using Producer Price Indices from BLS.
- Regulator - 1972 report by the White House Science office estimated $755 (Doyle 2000 p 92), equal to about $1,600 in 2004 dollars.
- Actual - Cited in Sperling 2004, based on a review of the literature (2002 dollars).

California LEV I Program vs Tier 1 Baseline ($1994)

- All estimates from Cackette 1998.

California LEV I Program vs Tier 0 Baseline ($1994)

- Industry - Low is Sierra Research and high is Manufacturers cited in 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..
- Regulator - CARB staff estimates versus a federal Tier 1 baseline, from 1994 bienniel review of LEV program. Adjusted to Tier 0 baseline by adding $85 (NRDC calculation based on Anderson and Sherwood 2002.)
- Actual - CARB staff analysis (Cackette 1998), adjusted to Tier 0 baseline by adding $85.

Federal Tier 1 + OBD (1996) - Includes Tier 1, Cold CO, OBD, Certification Short Test, and Enhanced Evaporative standards

- All values take from Anderson and Sherwood 2002, (analysis by US EPA staff.)

California ULEV II, Heavy Light Truck ($1998)

- Industry - Low by the California Dealers Association (see CARB FSOR 1999). High estimates by "Californians for Realistic Vehicle Standards" (CARB FSOR 1999) which according to the New York Times ("Light Trucks Face Tougher Standards," November 3, 1998) was set up by Detroit automakers with the assistance of the California Chamber of Commerce
- Regulators - CARB staff analysis FSOR, p. 45 (CARB FSOR 1999).

California CO2-eq Standard

- Industry – Low is AAM press release, September 22, 2004. High is Ron Defore of SUVOA, cited in 'Cool gray city' projected to turn murderously hot, Carl T. Hall, "Temperatures likely to rise by mid-century as a result of global warming study warns," San Francisco Chronicle September 14, 2004.
- Regulators - CARB staff analysis addendum to ISOR (CARB 2004).

3.2 Automakers have historically overstated the economic impacts on their industry

Automobile manufacturers have historically overstated the impacts of new pollution standards on their industry. However, California has historically rejected these claims and successfully implemented its requirements without the transpiring of the occasional dire predictions by the automakers. The following is a few examples of the claims that auto industry has made in the past.

1966 California HC and CO standards.

Automakers claimed that pollution-control devices could not possibly be ready until the 1967 model year and used delaying tactics to try to stall the introduction of the regulation.[16]

1975 requirement for catalytic converters (eventually delayed nationally until 1981, but implemented in California in the mid 1970s.)

The introduction of catalytic converters was greeted particularly virulently and provoked automobile executives into making wild proclamations regarding the impact of the regulation.

- During 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." [17]
- 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."[18]

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[16] Motavalli, Jim. *Forward Drive*. Sierra Club Books, 2000: p.41

[17] Ibid. p. 42.

[18] 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

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 catalytics converters in 1977. The catalytic converter alone cut hydrocarbon and carbon monoxide emissions by 96 percent, nitrogen oxides by 75 percent, and reduced the formation of ground-level ozone.

LEV I program (adopted 1990)

In the early 1990's, automakers claimed 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. CARB rejected these arguments and held firm to its program. In fact, by the time Honda introduced the first ULEV vehicle in 1998, it achieved this superior emission rating using technologies that were straight off the shelf. 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. Despite their initial claims, manufacturers have even been able to implement ULEV technology on the 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).

LEV II program (adopted 1998)

Prior to the adoption of the LEV II program in 1998, the industry and their allies made numerous claims about the technical feasibility and economic impacts of the proposed standard. For instance, the group "Californians for Realistic Vehicle Standards" (which was setup by the automakers[19]) 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.[20] AAMA claimed it was unrealistic and infeasible to make large SUVs and full-size trucks meet the proposed standards.[21]

3.3 Regulation stimulates innovation which lowers cost

Aside from currently available and emerging technologies, the history of automotive regulation indicates that manufacturers consistently utilize technologies and implement compliance paths different from initial predictions, resulting in lower then predicted costs. A clear theme emerges from the study of the history of air pollution regulation, that a <u>strong regulation spurs innovation.[22]</u> A strong regulation provides a powerful incentive for industry to comply in the least cost manner.

As shown in Table 1.1, CARB and the US EPA have also typically overestimated the cost of compliance, albeit not to a great of an extent as the industry. <u>Regulator estimates have more typically been about one to two times the actual costs.</u> The reasons, as stated before, are a combination of a bias towards conservatism, lack of full information, and most importantly, the role of unanticipated innovation. In fact, automakers have consistently been able to innovate new solutions to meet the standards at lower cost. The following case studies illustrate how innovation lowers cost.

It is appropriate and reasonable to consider the effects of innovation when setting standards

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[19] According to the New York Times this group was set up by Detroit automakers with the assistance of the California Chamber of Commerce ("Light Trucks Face Tougher Standards," November 3, 1998).
[20] CARB, "'LEV II' and 'CAP 2000' amendments to the California Exhaust and Evaporative Emission Standards," FSOR, September 1999, p. 42.
[21] CARB FSOR, p 26.
[22] NESCAUM 2000.

The concept of innovation improving the performance and lowering the cost of products is a well-observed phenomena across many industries. The concept has been described using a "learning curve" (or experience curve)[23] and there is "overwhelming empirical support" for this relationship.[24]

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 relaying (sp) on catalytic converters."[25] These engineers proceeded by combining existing technologies in a new way to achieve a cleaner burn.[26] 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.[27] 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.[28]

ULEV: Improved catalysts and other refinements eliminate the need for electrically heated catalysts, natural gas and other more expensive technologies

Throughout the early 1990's, automakers consistently expressed doubt as to whether they could meet the Ultra Low Emission Vehicle (ULEV) standard. They claimed that complicated technologies would have to be developed and used, especially for their bigger V-6 and V-8 engine vehicles. By 1994, they claimed that LEVs and ULEVs would have to use close-coupled catalysts, electrically heated catalysts (EHCs), and/or HC traps. Some even predicted that alternative fuels, such as natural gas, would be needed in the larger displacement engines. Estimates ranged as high as $4,005 for the cost of compliance. Actual costs turned out to be much lower, principally by eliminating the need for a costly electrically heated catalyst and dual catalysts. Specifically, the unanticipated innovations were:

- More precise fuel control systems. The development of dual oxygen sensors and adaptive transient fuel control systems reduced engine-out emission levels which allowed

[23] 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.
[24] IEA, *Experience Curves for Energy Technology Policy*, OECD/IEA, 2000.
[25] 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.
[26] Doyle, Jack. *Taken For A Ride*, New York: Four Walls Eight Windows, 2000, p. 326.
[27] Ibid p. 328.
[28] Ibid, p. 328.

the utilization of technologies that were refinements of existing, Tier 1 standard technologies rather than new, sophisticated emission controls.[29]

- Advances in design and materials 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 catalyists and their complementary air injection systems. Table 3-3 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.

Table 3-3: LEV Technologies, Projected versus Actual

1998 LEV Honda Civic Four Cylinder (X) 1998 LEV Toyota Camry Six Cylinder (O) 1998 LEV Ford Crown Victoria Eight Cylinder (V)			
Technology	**1990 ARB Projected**	**1994 ARB Projected**	**1998 Actual**
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
Dual Close-coupled Catalyst	- - -	- - -	- - V
Close-coupled Catalyst	- - -	X 80% -	X O -
Under-floor Catalyst	X O V	X 80% V	- O -
Electrically Heated Catalyst	X O V	- 20% V	- - -
Air Injection	- O V	- 20% V	- - -

(Source: Cackette, 1998)

[29] California Air Resources Board. *Staff Report, Low Emission Vehicle and Zero Emission Vehicle Program Review,* November 1996.

ZEV: "Gold Standard" Stimulates Invention of Super Clean Gasoline Engines and Hybrid Electric Vehicles

In 1997, Honda demonstrated a super clean gasoline engine (dubbed a "Zero Level Emission Vehicle", or "ZLEV"), in order to show the ARB that gasoline engines could be produced at almost the ZEV level without resorting to alternative motors or fuels.

The ZEV program also contributed to the development and sale of hybrid-electric vehicles, which began making their first appearances around the same time. Hybrids, which combine electric motors with super-efficient gasoline engines, gained attention in the 1990s as a way to meet the demands of California's clean air goals without compromising the needs of motorists. Currently, every major automaker either offers a hybrid for sale or plans to within the next few years.

PZEV: "Partial ZEV" Standards Cost Estimates Rapidly Fall

In order to move from 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.[30] 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[31] 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 meets the rigorous SULEV emission standard not because of any single or even multiple new technologies, but, as Ford's vice president of Powertrain Operations Dave Szczupak explains, because of "attention to every little detail."[32] Among these details is the new 2.3-liter engine's computer-designed, friction-welded plastic intake manifold. Within each of the manifold's four runners is a butterfly

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[30] California Air Resources Board, *Staff report,* August 7, 2000.
[31] California Air Resources Board, *Revised Discussion of PZEV Incremental Cost*, 2003.
[32] *Ford's Focus Bringing Thousands of PZEVs to Worldwide Markets,* Green Car Journal, Volume 12, Number 3, March 2003, p. 29.

valve that restricts airflow at low speeds and increases flow at higher speeds, an innovation that enhances more complete fuel combustion. Other details include 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 is of larger displacement than the one it replaces, 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 3-4.

Table 3.4 PZEV Technology Innovations

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.[33] This fills the cylinder better at low speeds, improves the mixing of gasoline and air, and thus improves combustion.[34]
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.

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.[35] The engine is already used in the Mazda6 and Ford Ranger pickup trucks and the company plans to use it in all Ford Focus Models, the Futura, and the hybrid-electric Escape in the near future.[36] Eventually, the engine could replace nearly all of the other inline four-cylinder engines used by Ford and its subsidiaries worldwide.[37]

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[33] ibid
[34] ibid
[35] *ibid*
[36] Carney, Dan. *Global I4 goes PZEV*, Automotive Engineering International, Volume 111, Number 7, July 2003, p. 76-78.
[37] ibid

3.4 Cost overestimates are seen across many other regulatory programs

Cost overestimates by both industry and regulators are seen across many other programs, including reformulated fuels and powerplant emission controls.

California Phase 2 Reformulated Gasoline

In 1991, the ARB estimated that 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 3-5). 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 3-5: 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, 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 percent-132 percent. Other estimations were often less accurate. The DOE overestimated the increase in cost by 55 percent-86 percent for Phase 1 RFG and 49 percent-100 percent for Phase 2 RFG while the API overestimated Phase 2 RVP by 260 percent, Phase 1 RFG by 273 percent-536 percent, and Phase 2 RFG by 118 percent-280 percent. The industry representatives CRA and the NPRA overestimated Phase 1 RFG by 236 percent, Phase 2 RFG by 135 percent, and 500ppm highway diesel by 50 percent.

SO2 Controls for Powerplants

In a study by NESCAUM, researchers found that for Title IV SO2 control costs for powerplants found that EPA's pre-regulatory estimates consistent with actual costs, whereas industry estimated actual control costs by more than 80 percent. A similar tendency for industry to exaggerate costs was also found for NOx control technologies.[38]

[38] NESCAUM 2000.

Another study of powerplant controls found SO_2 scrubbers found that cost decreased by 11 percent for each doubling in installed capacity. The same study found for a NOx control technology (SCR) that cost decreased by 12 percent for doubling in capacity.[39]

Table 3-6: Comparison of Inflation Adjusted Estimated Costs and Actual Price Changes for EPA Fuel Control Rules

Comparison of Inflation Adjusted Estimated Costs and Actual Price Changes for EPA Fuel Control Rules					
	Inflation Adjusted Cost Estimates (c/gal)				Actual Price Changes
	EPA	DOE	API	Other	
Gasoline					
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)

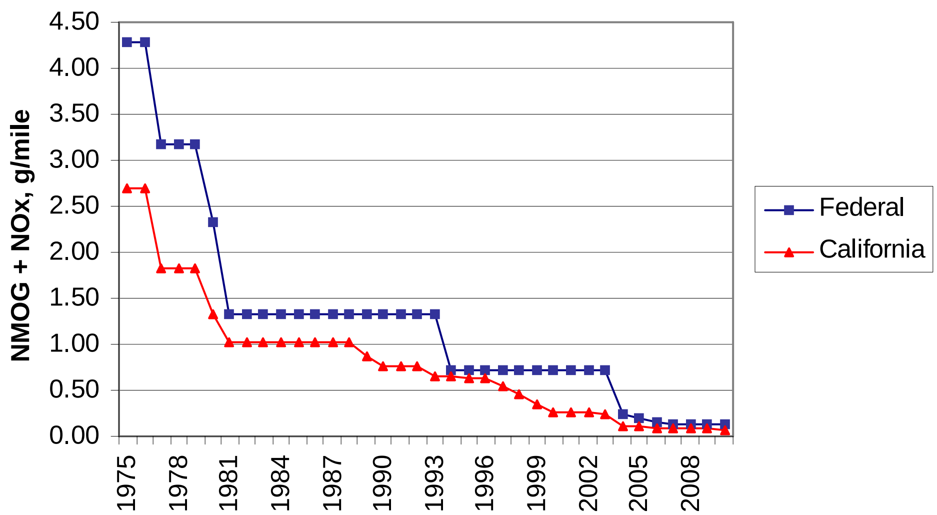
[39] Rubin, E et al. "Learning curves for environmental technology and their importance for climate change policy analysis," Energy 29 (2004) 1551-1559.

4. California CO_2 Standards Will Have National and Global Impacts

California has consistently led the nation in setting tough new air pollution standards (see Figure 4.1), and California standards and approaches have consistently been adopted by other states and at the national level. 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:

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.

Figure 4-1: California Has Historically Led the Nation on Automotive Air Pollution Standards



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. To date seven states have adopted the current California LEV II program and thirteen states have adopted California heavy-duty standards (so-called "Not-to-Exceed" limits). At least one state, New York, has publicly stated its intention to adopt the California CO_2-eq standards, as has Canada. <u>Consequently over 25 percent of the nation's new vehicles sales fleet are subject to the more stringent California LEV II program standards.</u>

It also should be noted that the "threat" of state adoption under Section 177 of more stringent California standards serves to put pressure on the industry and federal EPA to develop standards more stringent then the existing federal standards or to maintain strong federal standards (e.g., the National LEV program, and the 2007 diesel truck standards).

Table 4-1: 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)

Table 4-2: 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 1965/1968	California adopts **the first-ever tailpipe emission standards for hydrocarbons and carbon monoxide** which go into effect 1966. Congress passes Motor Vehicle Control Act of 1965 that adopts California's 1966 standards nationally as of 1968. (NESCAUM 2000, II-4)
--/1971 --/1973	The first automobile **nitrogen oxides (NOx) standards** in the nation go into effect in California First federal standards for NOx.
1973/1975	California adopts stringent new standards, prompting **first catalytic converters** to come into use in California.
1975/1977 1977/1981	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) 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 19941995	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. EPA adopts its federal reformulated gasoline program modeled on California's program, including the phase out of leaded gasoline.
1998/2004 1999/2004	California adopts **the Low Emission Vehicle II (LEV II**) Program for the strictest new emission standards on vehicles. US EPA adopts Tier 2 Program, largely modeled on California's LEV II.

4. 1 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[40]

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[41]

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.

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[40] 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.

[41] 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.

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.

5. Technical Feasibility and Emission Benefits

5.1 Emission and Operating Cost Benefits of Air Conditioning Controls Are Likely Underestimated

As stated by NRDC at previous workshops, we believe the staff's estimate of the direct leakage of HFC-134a is likely undercounted by about 50 percent. We base this estimate on a review of previous leakage rate estimates, applied to the California fleet (see Attachment B). One reason for why CARB staff's estimate being too low is that it could represent "best practices" versus "real-world" maintenance and operation practices. We also believe that there could be significant operating cost savings to a significant portion of the fleet due to reduce AC servicing. Each servicing avoided will save the owner or operator about $100. It is reasonable and logical to assume that some significant portion of the fleet will see reduced maintenance cost due to lower leakage AC systems.

5.2 Phase-in Period is Consistent With Past Programs

We note that a three year phase-in period is consistent with past automotive tailpipe standards, which as typically ranged from three to four years. For example, EPA's Tier 1 rule, Cold CO, and ORVR (onboard refueling vapor recovery) where all implemented on a three year phase in schedule.[42] Therefore, we believe it is consistent with past pollution standards to require a 3 year phase in for the mid-term package.

5.3 Improved Tires and Rolling Resistance

The staff's ISOR (page 56) states that the "rolling resistance force due to friction between the tires and the road can be improved via shoulder design improvements or with design and material modifications to the tread pattern, tire belts, or the traction surface." Rolling resistance is actually not primarily due to friction with the road (less then 5 percent), but rather through the energy lost as heat during the constant deformation of the sidewalls, called "hysteresis"[43] (80-95 percent of the losses). Furthermore, reducing rolling resistance is one way to use improved tire technology to reduce CO2 emissions. Lighter weight materials and smaller diameter tires can reduce the rotational inertia (thus reducing the load on the vehicle during acceleration), and improved sidewall design can reduce aerodynamic resistance. Neither of which is part of the formal definition of "rolling resistance."

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[42] Anderson and Sherwood, 2002.

[43] See for instance,

Attachment A:
NRDC Global Warming and Ozone Study

Attachment B:
NRDC MAC Leakage Estimate

An Estimate of Greenhouse Gas Emissions From Passenger Vehicle Air Conditioners

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Vehicle air conditioners are responsible for a significant amount of greenhouse gas emissions through refrigerant leakage and fuel consumption. The current refrigerant, HFC-134a, has been used in vehicles since 1993 and is potent greenhouse gas, considered to be 1300 times more powerful on a mass basis than carbon dioxide.[44] Refrigerants escape into the atmosphere not only through leakage during the vehicle life, but also are emitted during production, servicing, and at end of life. Air conditioning operation releases additional greenhouse gases due to increased fuel consumption. In addition, carbon dioxide is released during the energy during manufacture of the systems and due to the energy needed to carry the extra weight of the system.

In this paper, we develop estimates of the greenhouse gas emissions associated with an average California car, both direct HFC-134a leakage and indirect CO_2 emissions due to fuel consumption. For direct leakage, this paper reviews past studies of leakage during each stage of the air conditioners life cycle, including manufacturing, vehicle use, servicing, and end of life. Based on the review, we develop a range of estimates (low, mid, and high) for each stage.

Estimate of Current Direct HFC-134a Emissions

Refrigerants are released at all stages of the life of air-conditioning (AC) systems, including manufacturing, vehicle use, servicing, and end of life. We develop a range of estimates (low, mid, and high) at each stage of the AC system’s lifecycle based on previous studies. The mid scenario represents what we believe to be the best estimate of actual emissions.

Manufacturing emissions. A small amount of refrigerant, between 1 to 5 percent, is lost during manufacturing of the AC system (Barrault et al. 2003), including production and equipment charge (known as “capacity heels”). A “realistic” case of may be about 2 percent.[45] The Intergovernmental Panel on Climate Change (IPCC) “best practices” for GHG inventory development recommends using 0.5 percent of the initial charges is lost during the filling of the system (reference?). We adopt the range of estimates from Barrault et al. 2003 **of 1, 2, and 6 percent** are lost at connection.[46]

Leakage or fugitive emissions from vehicles. Over the vehicle life, refrigerant leaks out during normal vehicle operation (“normal” or “regular” emissions) and accidental ruptures (“irregular” emissions). Normal emissions are due to leakage from the compressor shaft seals, hoses, and other connecting seals. Since the refrigerant is always under pressure, leakage occurs throughout the life of the vehicle, even when not operating, but increases when the AC is running due to

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[44] IPCC, Third Assessment Report.
[45] Barrault et al. 2003. p 17-18, Tables 1.4-6.
[46] Ibid.

higher pressures. Manufacturers typically overcharge the system and design for acceptable operation even when the refrigerant is roughly half discharged. Irregular emissions normally lead to total or near complete refrigerant loss and are typically due to vehicle accidents, puncturing of the system during vehicle operation (e.g, stone impact on the condenser), or poor servicing.

IPCC/TEAP "Best Practices" for Inventory Development

For international inventory development, the IPCC has developed recommendations for a "bottom up" method based on a previous study (Baker 1999). For vehicle leakage, Baker 1999 provides a sample calculation for a U.S vehicle with 910 grams of initial charge, two refills at 40 percent level of charge at refill, 6 percent of initial charge lost at servicing and a 12-year average life. These estimates imply a leakage rate of **70 g/year**.

Benchtop or Component Specification Estimates

Car manufacturers specify leak rates for what is required from suppliers of seals, hoses, and compressors. Based on a survey of European suppliers, one study estimated the specifications to be 10 to 30 g for compressor shaft seals, 10 to 20 grams for flexible hose lines, and 2 to 3 g for each O-ring (Schwarz 2001). With a total of 7 to 11 O-rings per design, this yields an allowable leak rate of **34 to 83 g** for a relatively new, well functioning system.

A recent study for the European Commission estimated normal leakage emissions using a combination of past studies of component specifications and benchtop testing (Barrault et al. 2003.) This "bottom up" engineering estimate that found a standard, well-functioning, and relatively new AC system should leak **5.8 to 40.3 g/year.** [47] This was based on a component specification methodology for hoses and fittings of 2.3 to 18.3 g/year (Clodic and Yahia. 1997),[48] a benchtop test methodology for compressor shaft seal emissions of 3 to 20 g/year (Claudic and Fayolle 2001), and a 2 g/yr emission rate from service valves. Finally, according to one expert, General Motors currently specifies a system leak rate equivalent to 25 g/yr (Baker 2003).

Repair Records

Based on repair records from garages in Germany, one study estimated a normal leakage rate of between 34 and 83 g/year, with an average of **52 grams or 6.3 percent** of the initial charge (Schwarz 2001) for vehicles up to seven years old. A total of 678 repair records of three German brands were examined. The study divided the vehicles into two categories: those with less than 40 percent refrigerant loss were assumed to be "regularly" emitting, and those with higher losses were assumed to be "irregular" emitters. The study found irregular emissions to be **1.9 percent of the initial charge (856 g) or about 16 g/year**. The total fugitive emissions, normal plus irregular, was estimated as **70 g/year**. Adjusting for the higher US initial charge of 910 g yields **17 g/year.** Unlike in Europe, the U.S. does not ban the use of small cans of recharge refrigeration so "do it yourself" mechanics can "top off" a system. As a consequence, irregular loses may be greater in the U.S.

Leak Measurements

A recent study done for the European Commission estimated the normal emission rate to be **52.4 ±4.6 g/year, or about 6.9 percent** of the initial refrigerant charge (Schwarz and Harnisch 2003.)[49] This study estimated the leakage rates based on measurements of 276 vehicles up to seven years of age. Most of vehicles were from European manufacturers. The researchers extracted and weighed the charge, and then compared it to the initial charge. The difference was

[47] Barrault et al. 2003, p. 11, Table 1.3.

[49] This is the EU wide average (un-weighted). If leakage rates are weighted to reflect vehicle composition, the leakage rate is 53.0 g/year. Weighting by age of vehicle leads to an estimate of 53.9 g/yr.

distributed over the car's age to derive an annual leakage rate. The study also found that larger-sized ACs (mean initial charge of 883 g versus the mean of all vehicles tested of 756 g) had higher average leak rates of **7.7 percent.** Slight increases were found between vehicles that operate in areas prone to corrosion (winter conditions such as Sweden), and in areas that have higher usage rates (Portugal). But the differences were relatively minor. Large variations among manufacturers were found (three times difference between the best and the worst), indicating that the design and quality of components are a key factor. Assuming a leak rate of 7.7 percent and that the average U.S. charge is about 910 g, implies an average normal leak rate of about **70 g/year** for a U.S. vehicle**.**

Shed tests on a small number of relatively new U.S. vehicles (28 total), shows a somewhat lower normal leakage rate (Siegl et al. 2001). This study estimated an average diurnal emission rate of 0.07 g/day when AC is not operating, and 25.5 g/year assuming one hour/day of system operation and a linear increase in emissions with pressure. However, assuming that the leakage rate increases with the square of the pressure, rather than linearly, and AC operation averaging one hour per day (as assumed in Siegl et al. 2001) yields 0.12 g/day (versus 0.07 g/day estimated by Siegl et al. 2001.) or 45 g/year. Researchers from the National Renewable Energy Laboratory (Rugh and Hovland 2003) estimates AC operation is about 30 percent of the time the vehicle is driving for cooling and demist, or about 116 hours (assuming 400 hours of operation per year). Using this estimate of AC operation yields **31 g/year**. The study by Siegl et al. also concluded that the results "suggest that vehicle mileage is a significant factor associated with HFC-134a leakage rate" since four out of five vehicles with the highest emission rate had mileages greater than 115,000 miles. The testing fleet appears to have a high proportion of low mileage vehicles (over half being under 10,000 miles, less than the average mileage for a one year old vehicle), suggesting that the test fleet average probably underestimates the on-road fleet average normal leakage rate.

Table 1. Summary of Vehicle Leak Rate Estimates

(grams per year)

	Normal	Irregular	Total
IPCC Inventory Method			
Baker 1999	na	na	70
Component specs and/or benchtop testing			
Schwarz 2001	34 to 83	na	
Barrault et al. 2003	5.8 to 40.3	na	
Baker 2003	25	na	
Repair Records			
Schwarz 2001	52	16	70
In-use Vehicle Testing			
Schwarz and Harnisch 2003	52.4	na	
Siegl et al. 2001	25.5	na	
Meta Analysis			
Barrault et al. 2003	57.5	na	75 to 107.3

Meta Analysis of Leak Rates

Based on a review of previous studies, a recent report for the European Commission estimated total lifetime leakage, including normal and irregular leakage emissions, using three different scenarios, "optimistic", "realistic" and pessimistic"(Barrault et al. 2003.). Based on a review of tests of actual vehicles in Europe, this study found a normal rate of **57.5 g/year** for the on-road fleet**.** For both normal and irregular losses, this study estimated 75.0 g/yr for an optimistic scenario, implying an irregular loss rate of about 17.5 g/yr (roughly consistent with Schwarz

2001). For its realistic or pessimistic scenario, the author doubled the irregular losses and estimated **107.3 g/yr**.

This Study

The lower estimates of leak rates are derived from either component specifications and benchtop testing, or testing of relatively low mileage vehicles. It is reasonable to expect that vehicles in-use would experience a higher average emission rate than from a benchtop test that does not simulate real-world conditions and as the vehicles ages.

For the low scenario, we estimate a well-controlled system could emit about 40 g/year with irregular losses of 17 g/year for a total of **57 g/year**. A more realistic scenario would be **70 g/year for normal emissions** (based on Schwarz and Harnisch 2003 leakage rate of 7.7 percent) and irregular losses of **17 g/year for a total for 84 g/year**. Finally, for a pessimistic scenario we double irregular losses, yielding 105 g/year.[50]

Servicing. Servicing of the AC system also results in refrigerant release. For the low scenario, we use Baker 1999 estimates the release to be 6 percent of the remaining charge. Barrault et. al's gives a range of 99 to 107.3 g . We use a mid point, 100 g, for our mid and high scenarios. We assume an initial refrigerant charge of 910 grams and that the charge remaining at service is 60 percent of the original charge based on a SAE survey. We then built a simple spreadsheet model to estimate the lifetime servicing emissions based on servicing when the system reaches 60 percent of original charge. For the low scenario, the system is predicted to be refilled once during the vehicle's life versus twice for the mid scenario, and three times for the high scenario.

End of life. Finally, not all of the refrigerants from scrapped vehicles are recovered. Lacking reliable data on recovery rates, we assume 50 percent recovery for the "low" scenario and a 25 percent recovery for the "mid" scenario. For the pessimistic scenario, we assume zero percent recovery because of the HFC-134a.

Table 2. Key Assumptions for Direct Release of HFC-134a

Assumptions	*Low*	*Mid*	*High*
Vehicle lifetime, years	16	16	16
Vehicle lifetime, thousands of miles	200	200	200
original charge, grams	910	910	910
Capacity Heels, percent loss of orig charge	1%	2%	6%
Fugitive regular, g/yr	40	70	70
Accidental (irregular)	17	17	35
charge at refill, percent	60%	60%	60%
charge at refill, g	546	546	546
Servicing emissions, g	55	100	100
end of life recovery	50%t	25%	0%

Results for direct HFC-134a release. Tables 3 and 4 show the results of this analysis. For the mid scenario, we estimate that the lifetime average leakage is equivalent to 119 grams of HFC-134a per year or 12.4 gram per mile of CO2. As shown in Figure 1, vehicle leakage represents the highest portion of refrigerant emissions at almost two thirds of total emissions, followed by end of life and servicing. Manufacturing appears to represent a small (less than 1 percent) of the total refrigerant release.

[50] For comparison, Schwarz et al. 2003 developed a final estimate of 75, 107.3, and 107.3 g/year for their optimistic, realistic, and pessimistic scenarios.

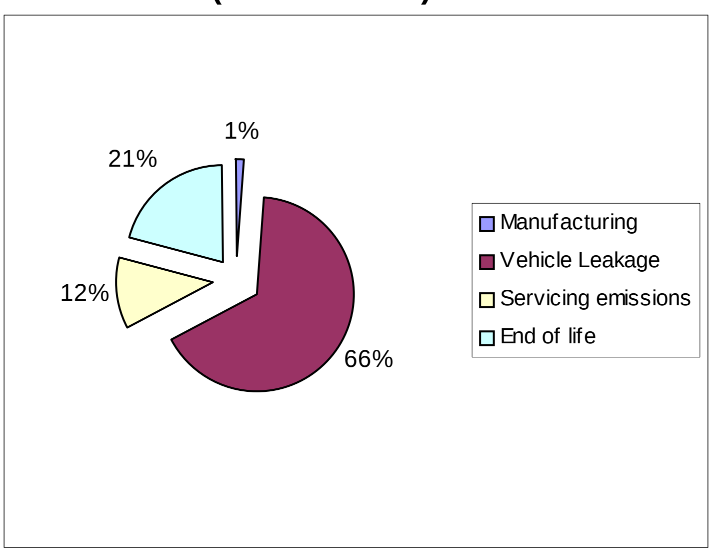
Table 3. Results for Direct Release of HFC-134a, Lifetime Vehicle Emissions

Scenario→	*Low*	*Mid*	*High*	*Low*	**Mid**	*High*
	grams HFC-134a			*kg CO2-eq*		
Manufacturing, production	9.1	18	55	12	24	71
Manufacturing, system charging	5	5	5	6.5	6.5	6.5
Vehicle leakage (including accidents)	1077	1398	1393	1400	1817	1811
Servicing emissions	109	200	200	142	260	260
End of life	320	289	388	417	376	504
TOTAL	1520	1910	2040	1976	2483	2652
TOTAL HFC-134a, per year	95	119	128	124	155	166

Table 4. Summary of Direct HFC-134a Emissions for an Average California Car, CO2 equivalent basis
(gram per mile, CO2-eq)

	Low	*Mid*	*High*
Capacity Heels	0.1	0.1	0.4
Emissions at filling	0.0	0.0	0.0
Fugitive emissions	7.0	9.1	9.1
Servicing emissions	0.7	1.3	1.3
end of life	2.1	1.9	2.5
TOTAL HFC-134a	9.9	12.4	13.3

Figure 1. Results for Direct Release of HFC-134a, Lifetime Vehicle Emissions (Mid Scenario)



References

Barrault, S., J. Benouali, and D. Clodic, *Analysis of the economic and environmental consequences of a phase out or considerable reduction leakage of mobile air conditioners*, final report for the European Commission, February 2003. Service Contract B4-3040/2002/346884/MAR/C1

Baker, James, “Mobile air conditioning: HFC-134a emissions and emissions reduction strategies,” UNEP TEAP HFC/PFC Task Force, Delphi Automotive Systems, Inc., 1999.

Baker, James, “Greenhouse Gas Emissions from Vehicle Air Conditioning Systems,” presentation at the International Vehicle Technology Symposium, Sacramento, CA,. March 11-13, 2003.

Claudic, D.,and F. Fayolle, “Test for Measurement of Leak-Flow Rate of MAC compressors,” Society of Automotive Engineers, 2001. SAE 01PC-183.

Claudic, D. and Yahia, “New Test Bench for Measuring Leak Flow Rate of Mobile Air Conditioning Hoses and Fittings,” International Conference on Ozone Protection Technologies, Baltimore, MA, November 12-13, 1997.

Rugh, J., and V. Hovland, “National and World Fuel Savings and CO2 Emission Reductions by Increasing Vehicle Air Conditioning COP,” National Renewable Energy Laboratory, presentation at the 2003 Automotive Alternate Refrigerant Systems Symposium, July 17 2003.

Schwarz, W. , “Emission of Refrigerant HFC-134a from Mobile Air-Conditioning Systems, Annual Rate of Emission from Passenger-Car Air-Conditioning Systems up to Seven Years Old,” study conducted for the German Federal Environmental Officice, Oko-Recherche, September 2001.

Schwarz, W., and J. Harnisch, “Establishing the Leakage Rates of Mobile Air Conditioners,” prepared for the European Commission, April 17, 2003. B4-3040/2002/337136/MAR/C1.

Siegl, W. O., T. J. Wallington, M. T. Guenther, T. Henney, D. Pawlak, and M. Duffy, “HFC-134a Emissions from Vehicles,” *Environ. Sci, & Technol*., 36: 561-566