No Way Back
Why Air Pollution Will Continue to Decline

Joel Schwartz

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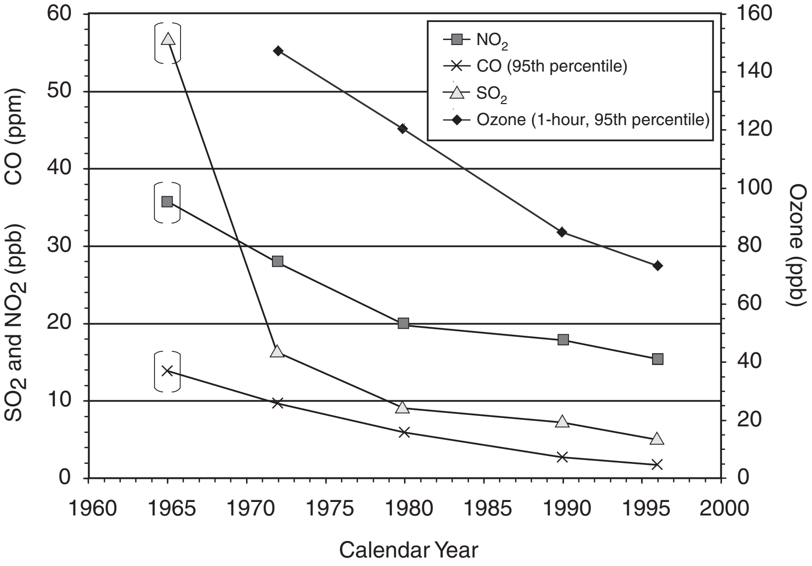
Introduction

The United States has made tremendous progress in reducing air pollution during the last forty years. Air pollution has declined dramatically since the 1960s and 1970s, and virtually the entire nation now meets federal health standards for carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2).[1] Many areas of the country still exceed health standards for ground-level ozone ("smog") and airborne particulate matter (PM), but both of these pollutants continue to decline as well. Half of the nation's ozone monitoring locations exceeded the federal one-hour ozone standard in the early 1980s, but only 13 percent exceeded the standard by the end of 2002.[2] PM measurement methods have changed a number of times during the last forty years, but all trend data show PM levels dropping. Average levels of $PM_{2.5}$—the form of PM now of greatest regulatory concern—have declined by a third during the last twenty years.[3] Figures 1a and 1b summarize pollution trend data.[4]

Will air pollution continue to improve? Many opinion leaders do not think so. After the Bush administration announced plans to modify certain provisions of the Clean Air Act's New Source Review (NSR) program, which requires large industrial plants to install state-of-the-art pollution controls if they make a "major modification" to their facilities, *New York Times* columnist and Princeton University economist Paul Krugman suggested "it might be a good idea to breathe deeply now, while you still can."[5]

Newspaper headlines and editorials likewise declared that the administration was working to roll back years of progress on air pollution at the behest of large utilities and other regulated industries.[6] Environmental activists also turned up the heat, asserting the NSR changes "would allow millions more tons of soot, smog, and toxic pollution to

Figure 1a. Trends in Average Ambient Levels of Gaseous Air Pollutants

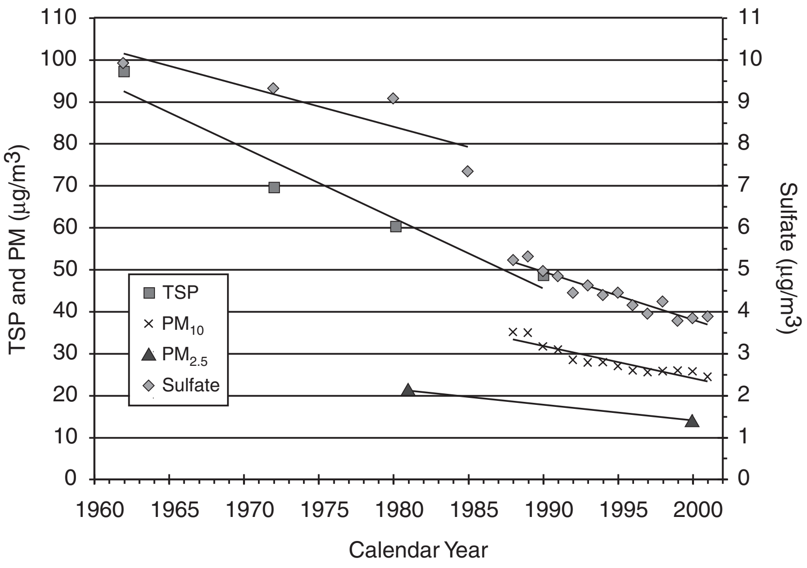


Source: Based on data reported in F. W. Lipfert and S. C. Morris, "Temporal and Spatial Relations between Age Specific Mortality and Ambient Air Quality in the United States: Regression Results for Counties, 1960–97," *Occupational and Environmental Medicine* 59, no. 3 (2002): 156–74.

Note: Averages were calculated for periods of several years. The markers on the graph are placed at the mid-point of each averaging period (e.g., 1972 represents 1970–74). Brackets for 1960s values are included as a reminder that only a few dozen counties were monitored at the time, while later averages are based on monitoring data from hundreds of counties.

SO_2	Sulfur dioxide (average of annual means from all monitoring locations)
NO_2	Nitrogen dioxide (average of annual means from all monitoring locations)
CO	Carbon monoxide (average of the 95th percentile of daily readings for each monitoring location)
Ozone	Average of the 95th percentile of peak daily one-hour-average readings for each monitoring location
ppm	Parts per million
ppb	Parts per billion

Figure 1b. Trends in Average Ambient Levels of Airborne Particulate Matter



Sources: TSP and early sulfate trend, Lipfert and Morris, (2002). Recent sulfate trend is based on 42 EPA CASTNET sites in the eastern United States that had data for each year from 1988 to 2001. CASTNET data were downloaded from www.epa.gov/castnet/data.html. PM$_{10}$ trend is based on 199 monitoring sites around the United States that had data for each year between 1988 and 2001. PM$_{10}$ data were downloaded from EPA's AIRData Web site, www.epa.gov/aqspubl1/select.html. Average PM$_{2.5}$ levels for 1979–1983 and 1999–2000 are reported in C. A. Pope et al., "Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution," *Journal of the American Medical Association* 287, no. 9 (2002): 113–41.

Trend lines were derived from least-squares linear regressions. The early sulfate trend is based on data collected on glass-fiber filters, which are now known to create "artifactual" sulfate from ambient SO$_2$ gas drawn through the filter. Thus, these early sulfate data are biased high in terms of absolute sulfate values; the trend in sulfate levels from these data is less likely to suffer from this bias since all the data were collected with the same technique. Data points for TSP, the earlier sulfate values, and PM$_{2.5}$ represent averages over two to four years. The year given in the chart is the average year for each point.

PM$_{10}$	Particulate matter less than 10 micrometers in diameter
PM$_{2.5}$	Particulate matter less than 2.5 micrometers in diameter
TSP	Total suspended particulates (roughly equivalent to PM$_{30}$)
Sulfate	The sulfate component of airborne particulates
μg/m^3	Micrograms per cubic meter

be spewed into our air each year," and dubbing the Bush Environmental Protection Agency (EPA) the "Environmental Pollution Agency."[7] And nine attorneys general from northeastern states sued EPA over the new NSR rules, asserting that "the Bush administration has taken an action that will bring more acid rain, more smog, more asthma and more respiratory disease to millions of Americans."[8]

The public is also pessimistic on air pollution—presumably at least partly as a result of gloomy and alarming forecasts from activists and the media. Polls consistently show that a large majority of Americans believe air pollution has been increasing and will continue to worsen in the future.[9]

Despite the heated rhetoric on New Source Review and the Bush administration's approach to environmental protection, the concerns raised by the media, environmentalists, and opinion leaders reflect a profound misunderstanding of the processes that have improved air quality in the past and will continue to in the future. Policy choices can indeed affect the rate of future progress, but it would be virtually impossible for anyone, no matter how tenacious and determined, to prevent continued reductions in air pollution. This is because of three simple facts:

- Most air pollution comes from motor vehicles.[10] But the actions necessary to clean up the vast majority of vehicle pollution have already been taken. The car and light-truck (i.e., SUV and pickup) fleet turns over every twenty years or so, which means that progressively tougher vehicle emissions standards implemented during the last decade have yet to fully come to fruition.[11] On-road pollutionmeasurements and emissions test data from vehicle inspection programs show that with each new model-year, motor vehicles start out and stay cleaner than previous models. This means that we will be reaping the benefits of progressively cleaner vehicles for decades to come. These data also show that emissions from SUVs are converging with emissions from cars, muting the effect on air quality of the increasing popularity of larger automobiles. Furthermore, these pollution reductions are unstoppable, because they depend only on older vehicles being retired, rather than on newer vehicles becoming cleaner. Likewise, the heavy-duty diesel truck fleet turns over on an even longer time scale than for cars, yet diesel standards have been tightened three times in the last fifteen years.

- In addition to the future pollution reductions we will see from already implemented standards and existing technologies, EPA has also promulgated additional regulations for both automobiles and heavy-duty trucks that will begin to phase in, respectively, in 2004 and 2007. Depending on pollutant and type of vehicle, these new standards will lower emissions by 70 to 90 percent below the stringent levels already achieved during the last decade. While these upcoming standards could theoretically be repealed, many auto manufacturers are already selling some models that meet the new standards, and there is no significant political support for weakening these standards. Furthermore, California adopts its own stringent vehicle standards independent of federal actions, and other states, including New York and Massachusetts, have adopted California's Low Emission Vehicle (LEV) regulations.[12] The 2004 standards also require big SUVs to achieve the same low emissions as regular cars, so the relative popularity of SUVs will not affect future air quality. Even after accounting for growth, total vehicle emissions are certain to decline more than 80 percent during the next twenty years or so.

- While the Bush administration has tinkered with New Source Review requirements for existing facilities, other laws and regulations require systemwide emission reductions from the same large industrial facilities regardless of NSR requirements. EPA's NO_x "SIP Call" regulation requires a 60 percent reduction in warm-season emissions of nitrogen oxides (NO_x) from Eastern power plants and industrial boilers starting in 2004.[13] EPA is enforcing this regulation. The Clean Air Act's Title IV acid rain program requires a 20 percent reduction in SO_2 emissions from power plants between 2000 and 2010. This program has broad, bipartisan support and has no chance of being repealed. Both of these programs put firm, declining caps on systemwide emissions that cannot be exceeded, regardless of New Source Review requirements.

Together, these sources account for more than three-fourths of ozone- and PM-forming emissions. Since future reductions from these sources are all but guaranteed, air pollution in America will decline dramatically in coming years. Because already adopted requirements will eliminate most remaining air pollution, the challenge of ensuring that every American breathes healthy air has been met—or rather, it will be met when we see the full effect of existing programs. Yet public debate on air pollution policy is being dominated by the false premise that air pollution will rise unless we redouble our efforts to reduce it.

Instead, policymakers should be thinking about remaining air pollution as a near-term problem and seek ways to cost-effectively achieve more rapid near-term pollution reductions in areas that still have substantial air pollution problems. For example, on-road emission studies show that the worst 5 percent of volatile organic compound (VOC) emitters accounts for about half of all automotive VOC emissions, so appropriate policies would probably best be focused on speeding the demise of the remaining stock of high-polluting, older vehicles, and repairing the smaller number of newer high polluters. This approach could achieve rapid, inexpensive pollution reductions, without imposing new long-term costs.

If already adopted regulations will eliminate the vast majority of remaining vehicle pollution, then measures based on the premise that air pollution is a continuing long-term problem are likely to be both expensive and relatively ineffective. For example, the Clean Air Act's transportation conformity requirement and other regional growth management policies are based on the premise that transportation infrastructure decisions should be driven by air quality concerns. But such policies are at best superfluous if air pollution has already been dealt with through technological advancements.

In addition, since the rate of future pollution reductions depends on how fast the vehicle fleet turns over, policymakers should be particularly cautious about imposing regulatory costs that would artificially slow the purchase of new vehicles. For example, the California Air Resources Board estimates that electric vehicles will cost about twice as much as a comparable gasoline-powered car. Mandating such vehicles would slow new-car purchases, slowing down turnover of the fleet and making future air pollution worse than it would otherwise be.

The rest of this report presents the analysis behind these conclusions.

Past and Future Air Pollution Emissions

Gasoline Vehicles

Gasoline vehicles include light-duty vehicles, such as cars, minivans, SUVs, and pickup trucks, as well as some larger medium- and heavy-duty vehicles powered by gasoline. Gasoline vehicles are the major source of VOCs and CO in metropolitan areas, and are also a substantial contributor to NO_x emissions. NO_x and VOCs combine to form ground-level ozone (commonly known as smog) on hot, sunny days, and are therefore known as "ozone precursors." NO_x can also be converted into nitrates, which contribute significantly to PM in the western United States. VOCs can also be chemically converted to organic PM through atmospheric reactions, and are a significant component of PM in most metropolitan areas. NO_x also contributes to acid rain.

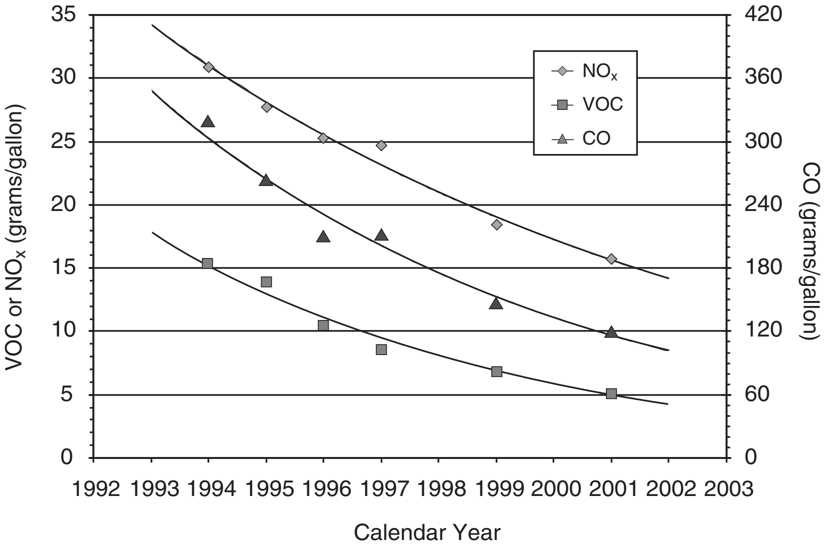
"Source apportionment" studies have found that gasoline exhaust and evaporation accounts for 50 to 80 percent of total anthropogenic VOC emissions in metropolitan regions.[14] On a nationwide basis, gasoline vehicles also account for about 20 percent of NO_x emissions, and probably a greater percentage in metropolitan areas where gasoline vehicles are concentrated.[15] About 85 to 95 percent of CO comes from gasoline-vehicle exhaust as well.[16]

Tunnel studies, on-road remote sensing, and vehicle emissions inspection and maintenance (I/M) programs are the main sources of data on gasoline-vehicle emission trends. Figure 2a displays average vehicle emissions rates, in grams of pollutant emitted per gallon of fuel burned, from 1994 to 2001, as measured in the Caldecott Tunnel in the San Francisco Bay Area.[17] The point markers represent the actual measured values, and the curves were derived from a least-squares regression of the data using an exponential function.

Emission rates declined substantially for all three pollutants during the seven-year measurement period—67 percent for VOCs, 49 percent for NO_x, and 62 percent for CO. Based on the exponential trend fit to the data, these represent annualized reductions in average vehicle emission rates of 15, 9, and 13 percent, respectively.[18] Although not shown in the graph, benzene emissions declined 82 percent.

Figure 2b presents similar data for Chicago, based on remote sensing measurements taken at

Figure 2a. Light-Duty Vehicle Emission Trends Measured in a San Francisco Bay Area Tunnel

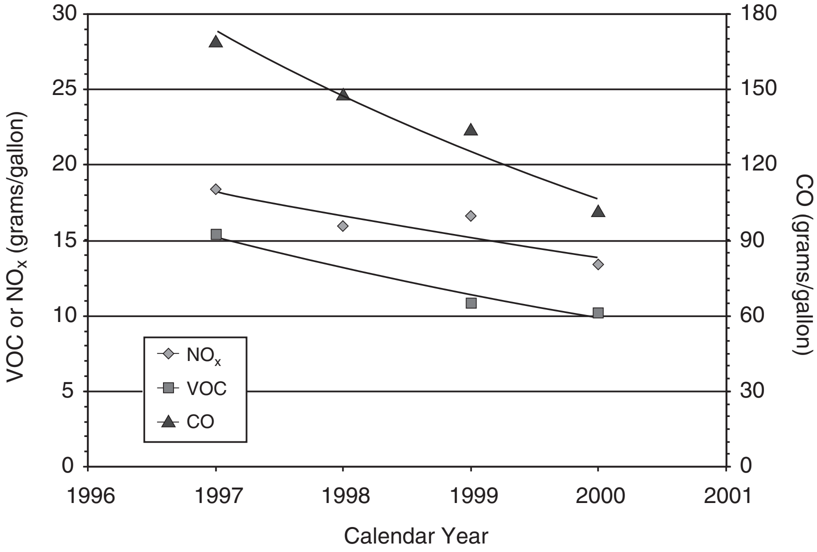


Source: Based on data in A. J. Kean et al., "Trends in Exhaust Emissions from In-Use California Light-Duty Vehicles, 1994–2001" (Warrendale, Penn.: Society of Automotive Engineers, 2002).

the same location each year from 1997 through 2000, while Figure 2c displays trend data for Denver from vehicle emissions inspection tests as well as remote sensing data for CO and NO$_x$.[19] The Chicago and Denver data also show substantial declines in vehicle emission rates. Once again, the lines in each graph represent a least-squares regression using an exponential function.

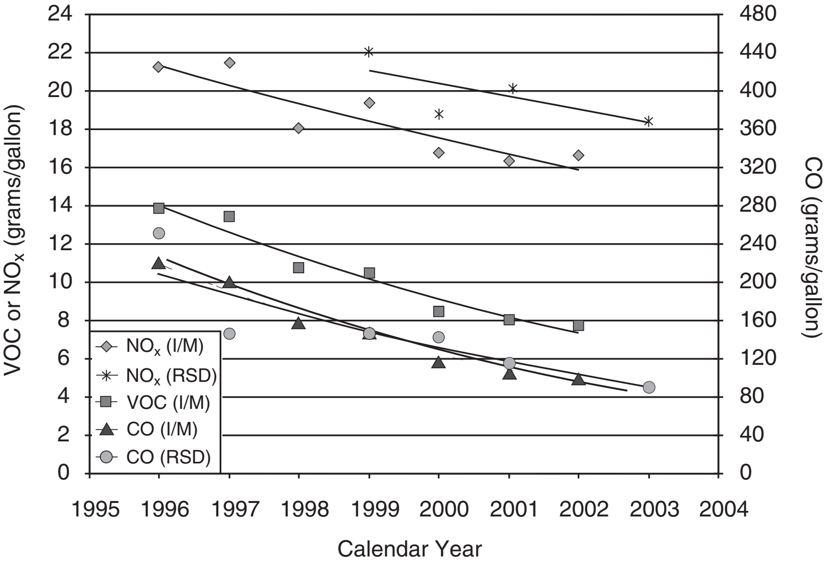
Table 1 summarizes emission trends from these data and also compares them with predictions of EPA's and the California Air Resources Board's (CARB) vehicle emissions models, MOBILE6 and EMFAC-2000, respectively.[20] For each pollutant, the table gives the annualized percent decline in emissions for the given time period, and the number of years during each time period in which measurements were made. Average emission rates declined rapidly for all pollutants, and output from the emission models parallels these declines.[21]

Figure 2b. Light-Duty Vehicle Emission Trends Measured by On-Road Remote Sensing in Chicago



Source: Based on remote sensing data provided by Don Stedman and Gary Bishop, University of Denver, and downloaded from www.feat.biochem.du.edu/.

Figure 2c. Light-Duty Vehicle Emission Trends Measured by I/M Testing and On-Road Remote Sensing in Denver



Source: Based on remote sensing data provided by Don Stedman and Gary Bishop, University of Denver, and I/M data supplied by Tom Wenzel, Lawrence Berkeley National Laboratory.

I/M = inspection and maintenance program data; RSD = on-road remote sensing data. In terms of absolute emissions, I/M and remote sensing data are not directly comparable for two reasons. First, the I/M data span vehicles of age zero to fourteen years, while the remote sensing data include cars of all ages. Second, the I/M data are based on the IM240 test, which does not necessarily include the same distribution of engine loads as observed at the remote sensing sites.

Effect of Growth in Miles Driven and the Popularity of SUVs. The discussion above focused on emission *rates* from vehicles, either in grams per mile driven or grams per gallon of fuel consumed. All other things being equal, declines in *total* emissions would match declines in emission rates. But total emissions are also affected by several other factors, including:

- *Changing composition of the vehicle fleet.* SUVs and pickups—often referred to as "light trucks"—have higher per-mile emissions than cars (although, as will be shown below, light-truck emissions have been approaching those of cars, and all light trucks will be held to the same emissions and durability requirements as cars under EPA standards that begin phasing in for the 2004 model year).

- *Increased per-capita driving.* If people drive longer distances, total emissions will also increase. Suburbanization might increase commuting distances, resulting in more driving per capita.
- *Population growth.* More people in a metropolitan area means more cars on the road, adding additional emissions.

Table 1. Average Annual Percent Reduction in Emissions for Various Time Periods, Locations, and Data Sources

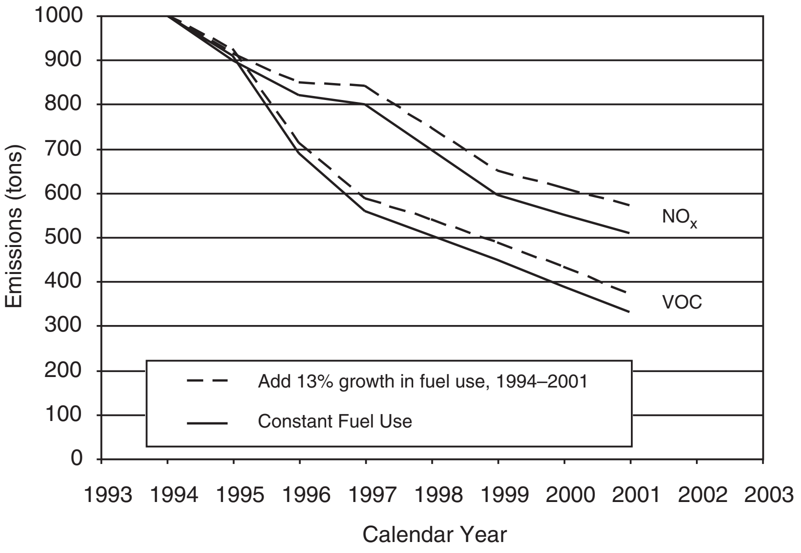
Location	Time Period	VOC	NO_x	CO	Number of Years Measured
Bay Area Tunnel	1994–2001	14.9%	9.4%	12.8%	6
Chicago RSD	1997–2000	13.3%	8.5%	14.9%	4*
Denver RSD	1996–2003	NA	3.4%	8.3%	6**
Denver I/M	1996–2002	13.2%	4.7%	10.1%	7
Phoenix I/M	1995–1999	11.5%	5.3%	10.3%	5
EMFAC2000	1990–2000	9.0%	6.8%	9.0%	NA
MOBILE6	1990–2000	8.2%	8.4%	9.3%	NA

Sources: Based on Bay Area tunnel data in Kean et al. (2002). Chicago and Denver remote sensing data (RSD) provided by Don Stedman and Gary Bishop, University of Denver. Denver and Phoenix I/M data supplied by Tom Wenzel, Lawrence Berkeley National Laboratory. EMFAC2000 and MOBILE6 output were reported in Darlington et al. (2001).

* 3 for VOC, spanning 1997 to 2000

** 4 for NO_x, spanning 1999 to 2003

Figure 3. Effect of Growth in Fuel Consumption on Emissions



Source: Based on Bay Area tunnel data in Kean et al. (2002). Solid line is what the total emissions trend would look like if fuel consumption remained constant from 1994 to 2001. The dashed line gives the actual trend in total emissions from 1994 to 2001, given actual growth in gasoline consumption.

Let us assess the net effect of these factors on total vehicle emissions. The Caldecott Tunnel data discussed earlier provide emission trends in grams per gallon of fuel consumed. Total fleet emissions in a given year are then equal to this emission rate times the total amount of fuel consumed. The effects of SUVs, suburbanization, and population growth would all be reflected in their combined effect on total fuel consumption.

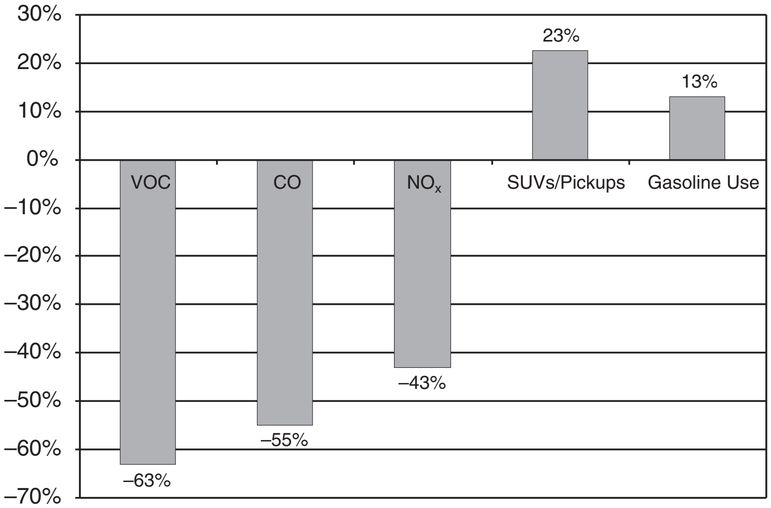
Between 1994 and 2001, fuel consumption in California increased 13 percent, or about 1.7 percent per year.[22] Figure 3 shows the effect of increasing fuel consumption on total emissions for a hypothetical fleet with emissions arbitrarily set at 1,000 tons of VOC and NO_x in 1994. The solid lines show emissions each year at constant annual fuel consumption, but including the observed annual reduction in emissions per gallon of fuel consumed. The dashed line adds in the observed growth in fuel consumption of 13 percent from 1994 to 2001. As the graph shows, rapid declines in vehicle emission rates overwhelmed the effects of more SUVs, more cars on the road, and more per-capita miles of driving. Indeed, as actually measured in the Caldecott Tunnel, SUVs and pickups

Table 2. Effect of Growth in Fuel Consumption on Vehicle Emission Trends from 1994 to 2001 in the San Francisco Bay Area

	Pollutant		
	HC	NO_x	CO
Change in Fleet Emission Rate	– 67%	– 49%	– 62%
Change in Total Fleet Emissions	– 63%	– 43%	– 55%

Source: Based on data in Kean et al. (2002).

Figure 4. Percent Change in Total Vehicle Emissions Compared with Percent Change in Gasoline Use and in SUVs and Pickups as a Fraction of the Vehicle Fleet, 1994–2001



Source: Based on data in Kean et al. (2002).

went from 31 to 38 percent of the vehicle fleet between 1994 and 2001, but this had little effect on overall emission reductions. Table 2 compares changes in emission rates with changes in total emissions after accounting for growth in fuel consumption. Figure 4 compares emission reductions with growth in gasoline consumption and in SUVs and pickups as a fraction of the vehicle fleet.

The increasing popularity of SUVs has done little to slow the declining trend in vehicle emissions, because the absolute difference in emissions of cars and SUVs has also been declining. Figures 5a and 5b demonstrate this using data from the Phoenix and Denver I/M programs, respectively. Each graph displays NO_x and VOC emissions by model year.[23] The Phoenix graph divides the vehicles into three categories—traditional cars, small and medium SUVs and pickups, such as the Toyota RAV-4 or the Ford Explorer, and large SUVs and pickups, such as the Chevrolet Suburban.[24] The Denver data include all light trucks in a single category.[25]

As the graphs show, emissions of SUVs and pickups are getting closer and closer to car emissions with each successive model year, such that there is now little difference between cars and light trucks. This result is not an artifact of the more recent model years' also being younger at the time they were measured, as both the Denver and Phoenix data show that the difference in car and SUV/pickup emissions remained stable with vehicle age for all model years.[26]

In addition, figures 5a and 5b display emissions in grams per mile, so the relative emissions levels inherently account for the lower fuel economy of larger vehicles relative to cars. VOC emissions from cars and trucks are virtually indistinguishable in recent model years.[27] Another factor to keep in mind is that federal and California emission regulations eliminate the distinction between car and SUV/pickup emission standards starting with the 2004 model year.[28] Overall, the data clearly show that the increasing popularity of larger vehicles will have little impact on future pollution emissions from the vehicle fleet.

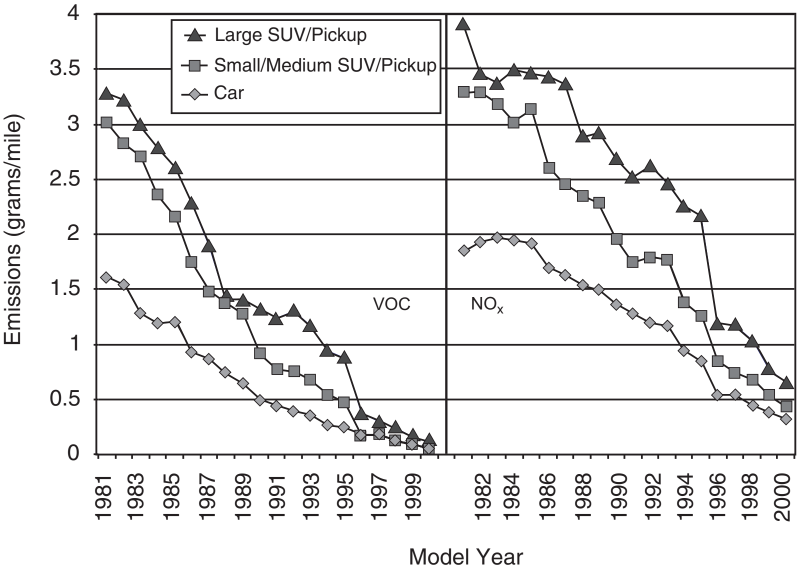
Projecting Future Emissions. Although emissions have declined in the past, can we expect continued declines in the future? The following factors guarantee substantial reductions in future automobile pollution:

- *On average, more recent vehicle models start out and stay cleaner than earlier models.* This means that even if future vehicles have the same emissions performance as vehicles sold in 2003, emissions will continue to decline for the roughly twenty years required for the fleet to turn over to vehicles with current emissions control technology and durability.

- *"Exogenous" improvements in vehicle performance.* Vehicle emissions have been continuously improving for at least two decades, even during multiyear periods during which regulatory standards stayed the same. This suggests that regulatory standards are not the only factors that spur automakers to improve vehicle emissions performance.

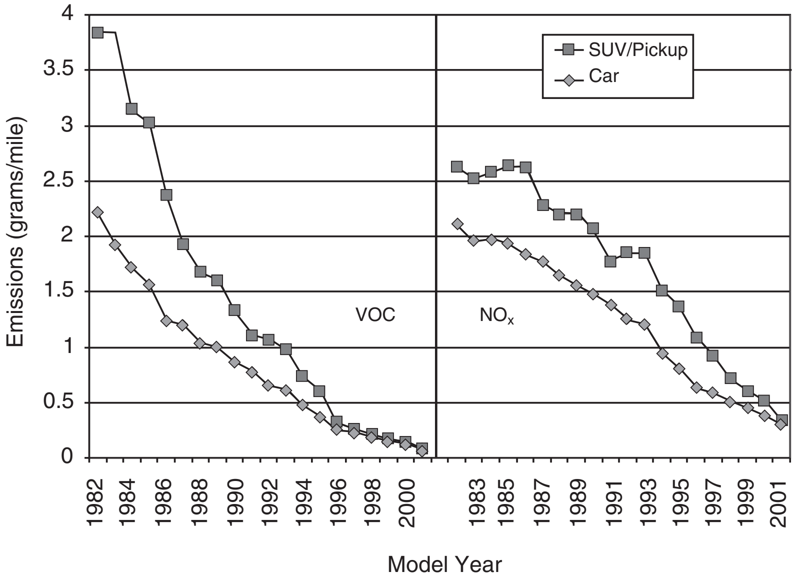
- *Progressively more stringent emission standards.* Both federal and California emission standards and durability requirements continue to become more stringent, culminating with the federal "Tier 2" standards and California "LEV II" standards that begin phasing in for the 2004 model year. Continued improvements in vehicle emissions and durability ensure that fleet turnover will continue to improve air quality for decades to come.

Figure 5a. Comparison of Average Car and SUV/Pickup Emissions, from Phoenix I/M Data



Source: Based on IM147 test data collected in 2001. Data provided by Tom Wenzel, Lawrence Berkeley National Laboratory.

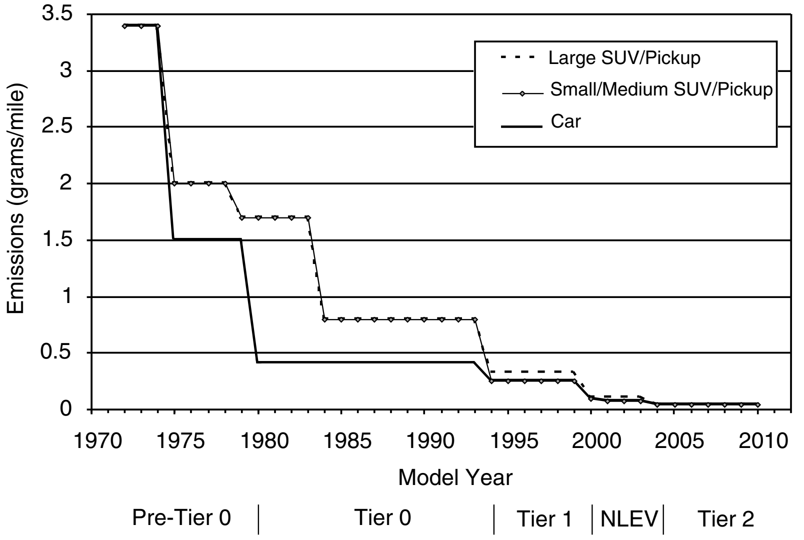
Figure 5b. Comparison of Average Car and SUV/Pickup Emissions, from Denver I/M Data



Source: Based on IM240 test data collected in 2002. Data provided by Tom Wenzel, Lawrence Berkeley National Laboratory.

Figures 6a and 6b display federal VOC and NO_x emission standards by model year for cars and light trucks.[29] The designations along the bottom of each graph give EPA's names for its emission standards categories and the model years covered by each standards category.[30] CO standards have become similarly more stringent with time. California standards followed a similar path but declined more rapidly than the federal standards. Durability requirements have

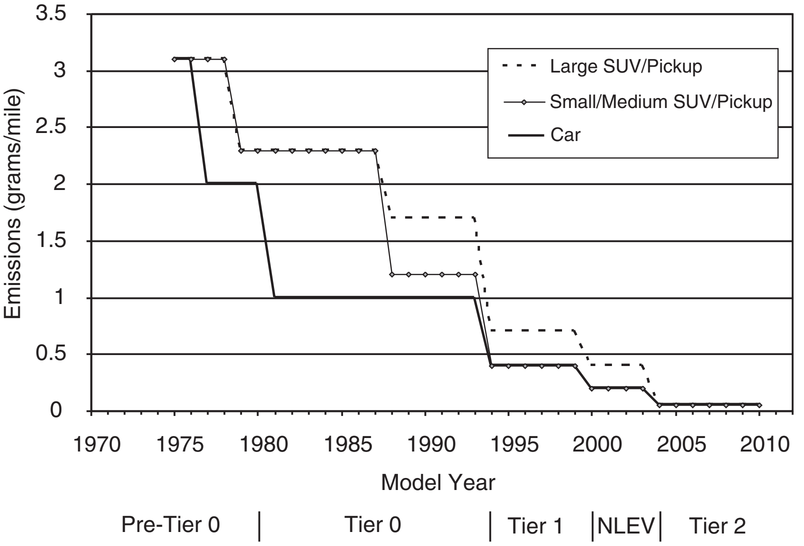
Figure 6a. Federal VOC Emission Standards for Cars and Light Trucks



Sources: S. C. Davis and S. W. Siegel, "Transportation Energy Data Book: Edition 22" (Oak Ridge, Tennessee: Oak Ridge National Laboratory, September 2002); EPA, "Federal and California Exhaust and Evaporative Emission Standards for Light-Duty Vehicles and Light-Duty Trucks" (Washington, DC: February 2000).

NLEV = National Low Emission Vehicle

Figure 6b. Federal NO_x Emission Standards for Cars and Light Trucks



Sources: Davis and Siegel, "Transportation Energy Data Book: Edition 22," (2002); EPA, "Federal and California Exhaust and Evaporative Emission Standards for Light-Duty Vehicles and Light-Duty Trucks," (2000).

NLEV = National Low Emission Vehicle

also become more stringent with time. Through 1993, vehicles had to meet emission standards only up to 50,000 miles. Starting with the 1994 model year, the durability requirements were extended to 100,000 miles. The 2004 standards extend the durability requirement up to 120,000 miles.[31] When compared with the Tier 1 standards, which phased in starting in 1994, the Tier 2 standards represent VOC and NO_x reductions of 80 to 90 percent. The increased durability requirements make the true percentage reduction requirements even greater.

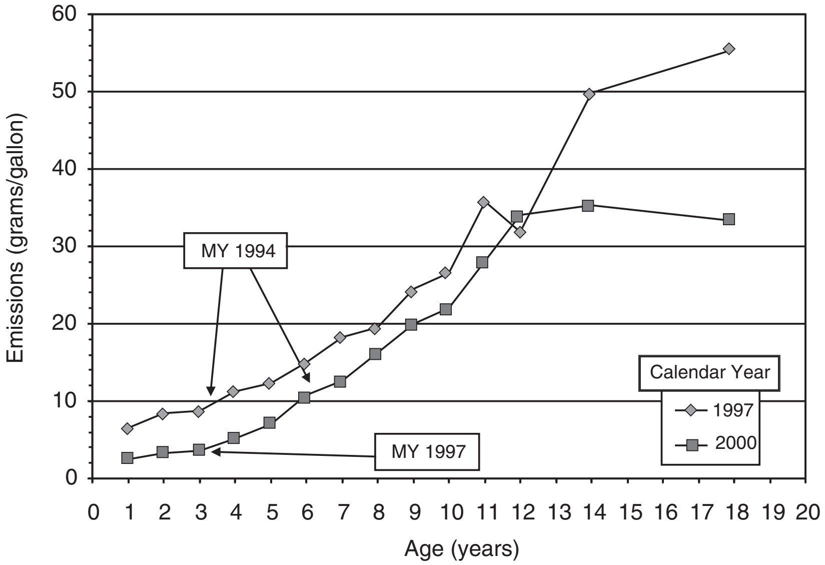
Remote sensing and I/M emissions data can show us how vehicle emissions change with age, and how emissions vs. age changes with calendar year. In the following charts, the abbreviation CY refers to a calendar year in which emissions were measured, and MY refers to a given model year of vehicles—for example, "MY1994" refers to the cohort of vehicles built in the 1994 model year.

Figure 7a displays VOC emissions vs. vehicle age for CY1997 and CY2000, based on Chicago remote sensing data. MY1994 and MY1997 are marked on the graph to show the relationship between age, calendar year, and model year in these data. MY1994 was three years old in CY1997 and six years old in CY2000, so this graph shows emissions of each model year at two different ages. This graph also shows emissions of *different model years at the same age*. For example, when compared at three years of age, MY2000 emits much less VOC than MY1997. Note that at any given age, vehicles were usually much cleaner in CY2000 than in CY1997. Figure 7b displays similar data for NO_x.[32]

Figure 8a presents the same data but with NO_x emissions plotted by age for each model year.[33] This format shows how a given model year's emissions change with age. More crucially, this graph shows why average vehicle emissions have declined—improved performance and durability—and why we should expect additional pollution reductions in the future. As Figure 8a shows, at any given age, more recent vehicle model years generally have lower emissions than earlier model years.[34] For example, looking at three-year-old vehicles, MY1994 averages 14.7 grams per gallon, but MY1997 averages only 8.3 grams per gallon—about 45 percent lower. In general, more recent MYs start out cleaner and stay cleaner than previous MYs. As a result, future vehicle fleets will have lower emissions than the current fleet. Figure 8b shows the same pattern for VOC emissions.[35] The Chicago remote sensing data are not unique; remote sensing and I/M data show similar patterns in all cities for which such data are available.

At least two factors ensure that emissions performance will continue to improve for future vehicle model years. First, both federal and California emission requirements continue to become progressively more stringent, both in terms of allowable emissions levels and of the length of time and mileage over which automakers must warranty vehicle emission control systems (see discussion above). To the extent that past improvements in emissions performance have been driven by these regulatory standards, we can probably expect substantial pollution reductions to continue in the future.

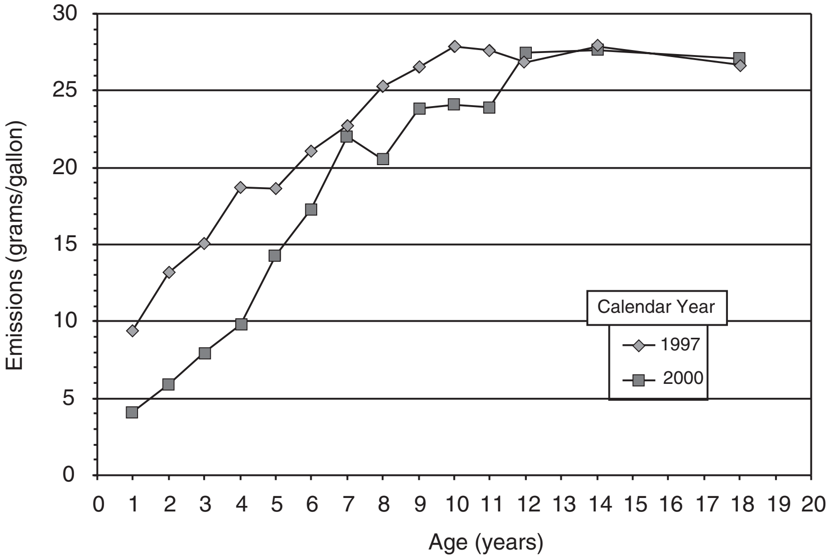
Figure 7a. VOC Emissions vs. Vehicle Age, for Calendar Years 1997 and 2000, from Chicago Remote Sensing Data



Source: Remote sensing data collected by Don Stedman and Gary Bishop of the University of Denver, and downloaded from www.feat.biochem.du.edu/.

Age 14 represents an average of ages 13–15; age 18 represents an average of ages 16–20.

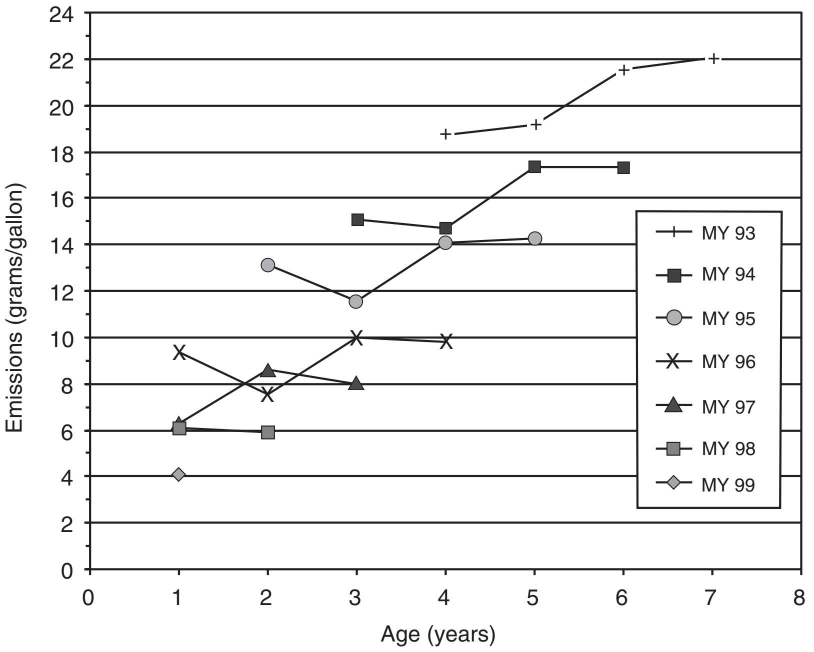
Figure 7b. NO_x Emissions vs. Vehicle Age, for Calendar Years 1997 and 2000, from Chicago Remote Sensing Data



Source: Remote sensing data collected by Don Stedman and Gary Bishop of the University of Denver, and downloaded from www.feat.biochem.du.edu/.

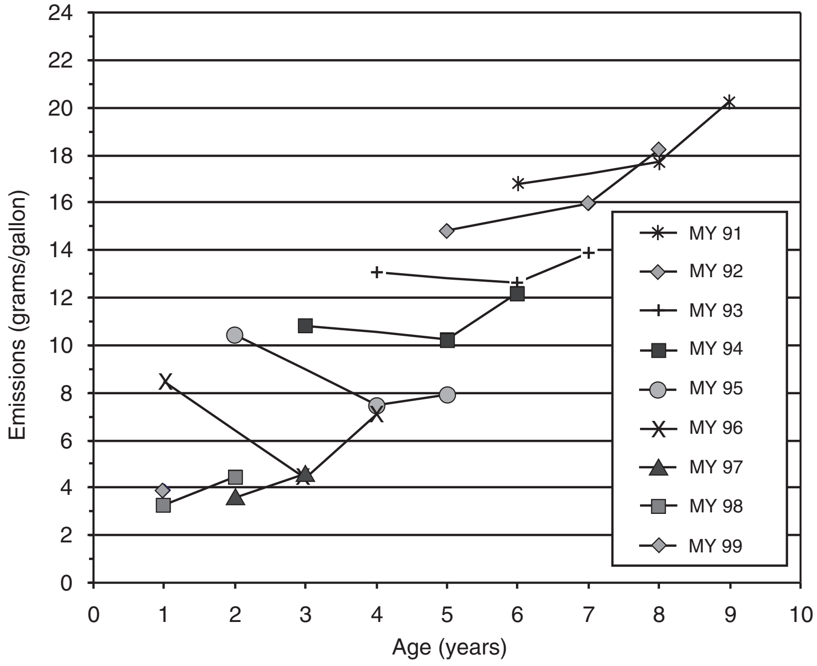
Age 14 represents an average for ages 13–15; age 18 represents an average of ages 16–20.

Figure 8a. NO$_x$ Emissions vs. Vehicle Age for Model Years 1993–1999, from Chicago Remote Sensing Data



Source: Remote sensing data collected by Don Stedman and Gary Bishop of the University of Denver, and downloaded from www.feat.biochem.du.edu/.

Figure 8b. VOC Emissions vs. Vehicle Age for Model Years 1991–1999, from Chicago Remote Sensing Data



Source: Remote sensing data collected by Don Stedman and Gary Bishop of the University of Denver, and downloaded from www.feat.biochem.du.edu/.

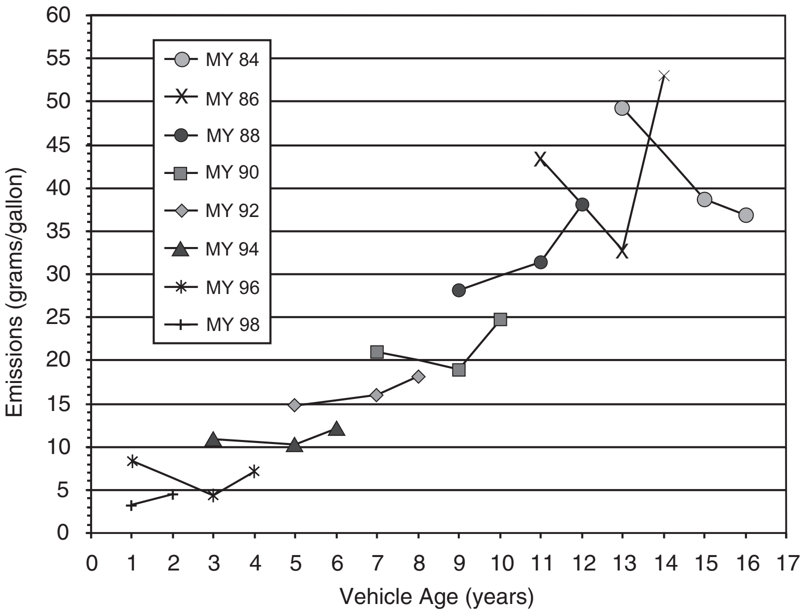
Other regulatory factors might also encourage automakers to improve the durability of emission control systems. For example, MY1996 and newer vehicles are equipped with the second generation of on-board diagnostics (OBDII)—a system of sensors that monitors various aspects of engine performance and illuminates the "check engine" light if a potential problem occurs. EPA and CARB require the OBDII system to be set with very stringent tolerances, and many I/M programs now "test" vehicles' emission control systems by querying the OBDII system. This may encourage manufacturers to over-engineer their cars beyond the nominal emission certification requirements in order to reduce the likelihood that the OBDII system will be triggered.[36]

Second, automakers have improved the emissions performance of their vehicles beyond regulatory requirements. Figures 9a and 9b display VOC emissions data from, respectively, Chicago and Denver in the same format as Figures 8a and 8b. The Denver data show emissions separately for cars and light trucks. For ease of legibility, the graphs include only even model years. Regulatory standards for VOC emissions were constant for model years 1982 through 1992, yet all three graphs show substantial improvement in the emissions performance of vehicles built during this period. A detailed understanding of the reasons for these emission improvements would require a separate analysis. However, one might surmise that the same competitive forces that spurred manufacturers to improve the general reliability, durability, and performance of their vehicles would also benefit emissions performance. For example, the widespread introduction of fuel injection and computerized engine control during the 1980s also permitted finer control of the fuel-air mixture, which benefits emissions performance. The Denver I/M data also amplify the points made earlier on the declining difference in emissions between SUVs and cars and on the ongoing improvement in emissions with each successive model year.

We can use existing information to make reasonable projections of how emissions will evolve in the future. As a start, we can ask what would happen if emissions performance had stopped improving after the 1999 model year. If this happened, emissions would have declined until the current fleet was replaced with vehicles built from CY1999 onwards—say about fifteen to twenty years from now. Predicting emissions from such a fleet requires an estimate of emissions from new vehicles, and a deterioration function to estimate emissions as the fleet ages.

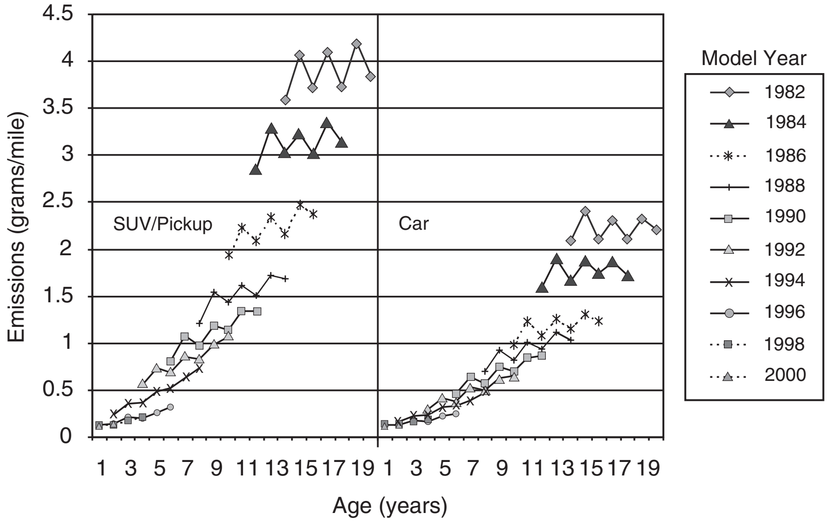
Figure 10a displays projections of future NO_x emissions under four scenarios. The top curve in the graph represents actual emissions in CY2000 from the Chicago remote sensing data.[37] The next four curves represent scenarios described in the following paragraphs. The values at the right of the graph give, for each scenario, the percentage reduction in fleet emissions from the CY2000 base.

Figure 9a. VOC Emissions vs. Vehicle Age from Chicago Remote Sensing Data



Source: Remote sensing data collected by Don Stedman and Gary Bishop of the University of Denver, and downloaded from www.feat.biochem.du.edu/.

Figure 9b. VOC Emissions vs. Vehicle Type and Age from Denver I/M Data



Source: Data provided by Tom Wenzel, Lawrence Berkeley National Laboratory.

The zigzag pattern in the data results from differences in the vehicles between adjacent ages. The Denver program requires testing every two years and at change of ownership. Even-model years receive a biennial test in even years, while odd-model years receive a biennial test in odd years. But vehicles with an even model year can be tested in an odd calendar year if they are sold, and these "change-of-ownership" vehicles have higher emissions, on average, than vehicles that are not sold.

The "High Deterioration" scenario begins with a fleet that has the same emissions as MY1999 at one year of age. This pessimistically assumes MY1999 vehicles will deteriorate at a rate similar to that of much earlier model years.[38] This scenario is intended to be a conservative "worst-case" for how recent model years will deteriorate over time. The scenario is worst-case, because the deterioration rate is based on the deterioration rate of vehicles built years ago, even though newer vehicles deteriorate more slowly. Even so, NO_x emissions still decline 35 percent under this scenario.

Figure 10a. Future NO_x Emissions under Four Scenarios

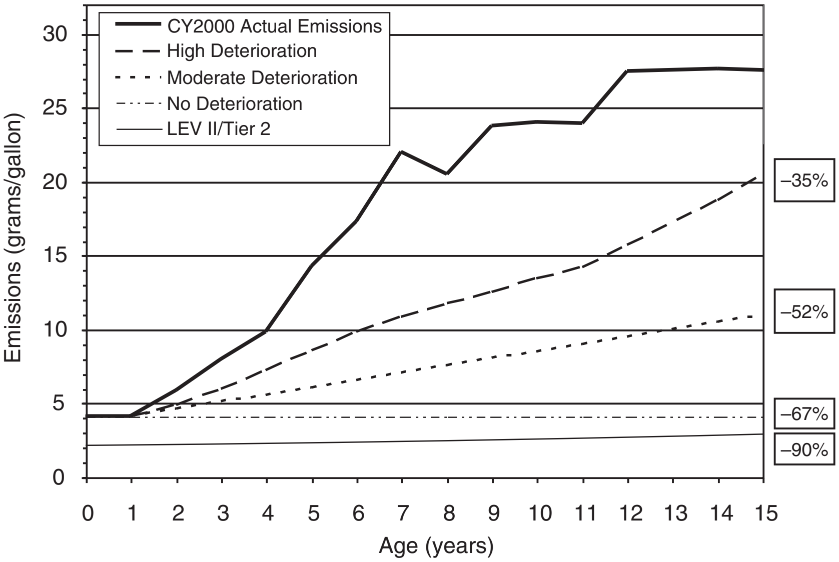
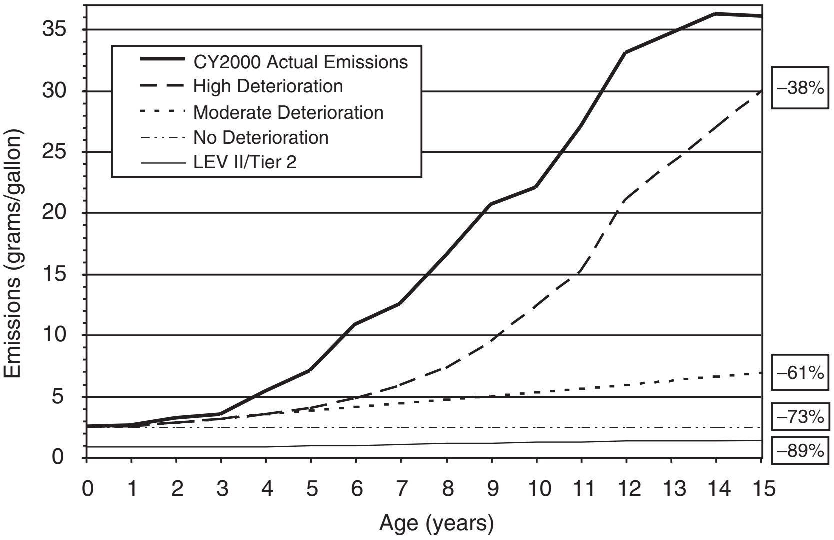


Figure 10b. Future VOC Emissions under Four Scenarios



The "Moderate Deterioration" scenario assumes linear deterioration with age, and the deterioration slope is the average of the measured deterioration slopes for MYs 1995 and 1996, based on a linear extrapolation of the data.[39] Under this scenario, fleet emissions would decline 52 percent from the level measured in CY2000.

The "No Deterioration" scenario is a completely artificial model intended to illustrate an underappreciated fact about vehicle pollution: Most emission reductions come not from making relatively low-emitting new cars just a little bit cleaner, but by reducing the rate at which emissions deteriorate with age. Under this scenario, even if vehicles' starting emissions don't fall below the MY1999 level, two-thirds of NO_x emissions are nevertheless eliminated.

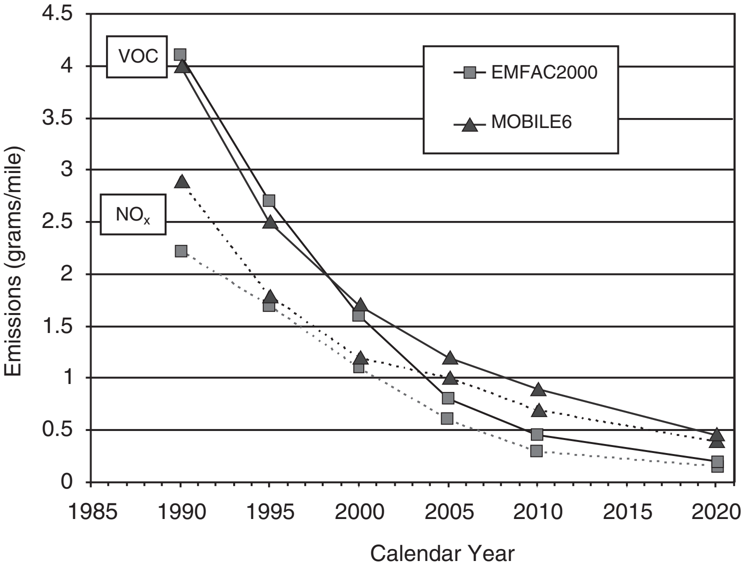
The scenario labeled "LEV II/Tier 2" is intended to project what is actually likely to happen in coming years. Emissions in this scenario are based on the maximum emissions allowed under federal Tier 2 and California LEV II standards that begin phasing in with the 2004 model-year.[40] The federal and California standards are similar, so I used the LEV II ultra-low-emission-vehicle (ULEV) standards to represent both.[41] Figure 10b displays the results of the same four scenarios for VOC emissions. Under the LEV II/Tier 2 standards, fleet-average emissions will decline about 90 percent from current levels as the current fleet is replaced with vehicles meeting LEV II/Tier 2 standards during the next twenty years or so.

Even the two unrealistically pessimistic scenarios would result in substantial improvements in vehicle emissions during the next two decades. The LEV II/Tier 2 scenario would eliminate almost all vehicle emissions by the time the fleet turned over to these vehicles. Even this scenario may be conservative, because it assumes that emissions would always be at the allowable limit. Actual emissions could be below this level if manufacturers included a safety margin to ensure they do not exceed the standards and risk fines or recalls.

The vehicle emission models used by CARB and EPA, EMFAC and MOBILE, also project large declines in future emissions, though not quite as large as one might expect by a simple comparison of current on-road emissions with the upcoming Tier 2 and LEV II emission standards. Figure 11 displays the emission trends predicted by the regulatory agencies' models.

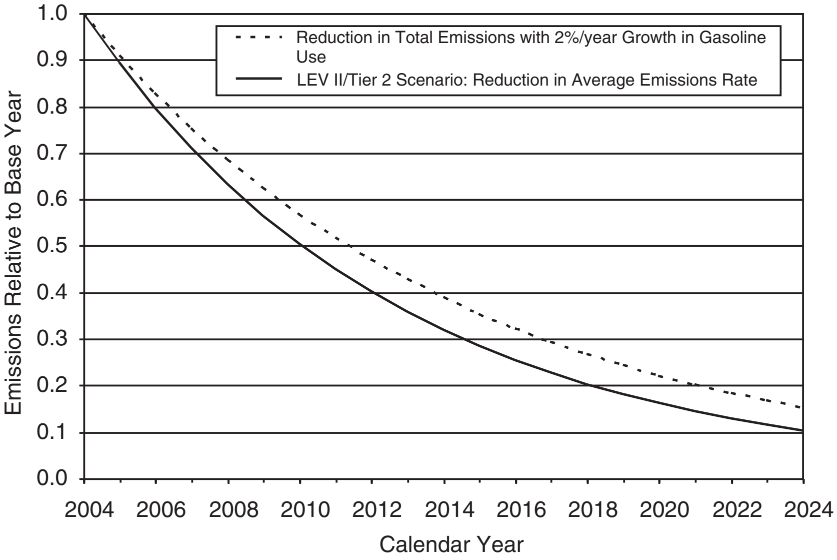
Figure 12 projects future effects of growth in vehicle travel given a 90 percent reduction in gram per gallon vehicle emissions under the LEV II/ Tier 2 scenario. The reductions are assumed to occur during a twenty-year period starting in 2004.[42] The lower curve shows the reduction in grams per gallon emissions, while the upper curve factors in a 2 percent per year growth in gasoline use, to account for increases in driving.[43] As the graph shows, growth turns a 90 percent reduction in the emission rate into an 85 percent reduction in total emissions—in other words, just as shown earlier, growth in driving will do little to offset gains from improved vehicle emissions performance. Based on declining trends in vehicle emissions and the requirements of standards that come

Figure 11. Fleet-Average Emissions Projected by CARB and EPA Mobile-Source Emissions Models



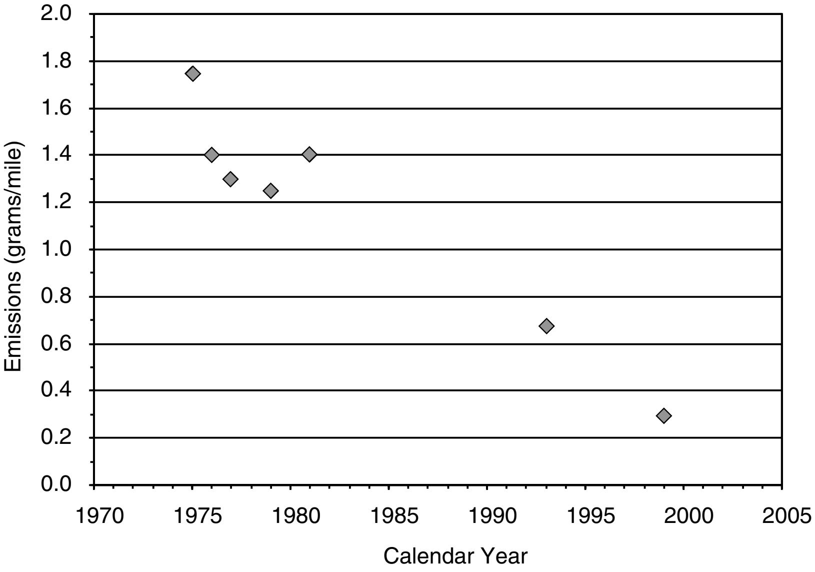
Source: T. L. Darlington et al., "Comparison of EMFAC2000 and MOBILE6," 11th CRC On-Road Vehicle Emissions Workshop, San Diego, CRC, 2001.

Figure 12. Future Emissions Under the LEV II/Tier 2 Scenario, Including Growth in Vehicle Travel



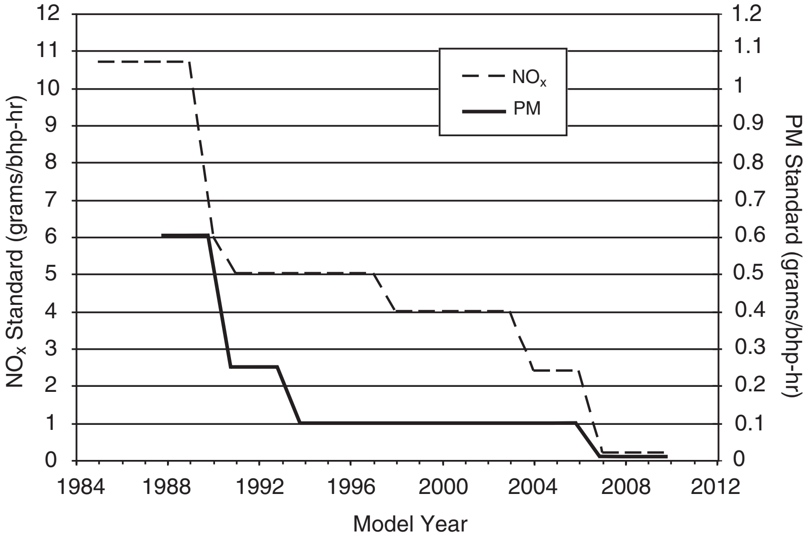
into effect starting in 2004, we should therefore conservatively expect total automobile emissions to decline more than 80 percent during the next twenty years or so.

Figure 13. Heavy-Duty Diesel Truck PM_{10} Emissions Measured in Pennsylvania Turnpike Tunnels, 1975–1999



Source: Based on data from A. W. Gertler et al., "Measurements of Mobile Source Particulate Emissions in a Highway Tunnel," *International Journal of Vehicle Design* 27 (2002): 86–93.

Figure 14. Federal NO_x and PM Standards for Heavy-Duty Diesel Trucks



Source: Based on heavy duty vehicle emissions standards in EPA, "Health Assessment Document for Diesel Engine Exhaust" (Washington, DC: May 2002): 2-16.

Diesel Trucks

Diesel trucks are a major source of NO_x emissions, and also a significant contributor to PM. On a nation-wide basis, diesel trucks account for an estimated 25 percent of total NO_x emissions.[44] Studies of particulate matter during the late 1980s to late 1990s suggest that diesel PM typically contributes a few micrograms per cubic meter to daily average PM levels, and roughly 5 to 20 percent of typical total $PM_{2.5}$ levels in metropolitan areas.[45] Diesel trucks also emit VOCs, but typically contribute only about one-sixth to one-seventh the amount from gasoline vehicles.[46]

Trend data from tunnel studies suggest that per-mile diesel truck PM emissions have declined more than 80 percent during the last twenty-five years (see figure 13).[47] Unfortunately, there are not similar long-term trend data for diesel NO_x emissions. However, measurements in the Tuscarora Mountain Tunnel in Pennsylvania in 1992 and 1999 suggest that average diesel-truck NO_x emissions *increased* almost 14 percent, even though roughly a 9 percent decline would have been expected, based on tighter diesel emission standards implemented in 1991.[48]

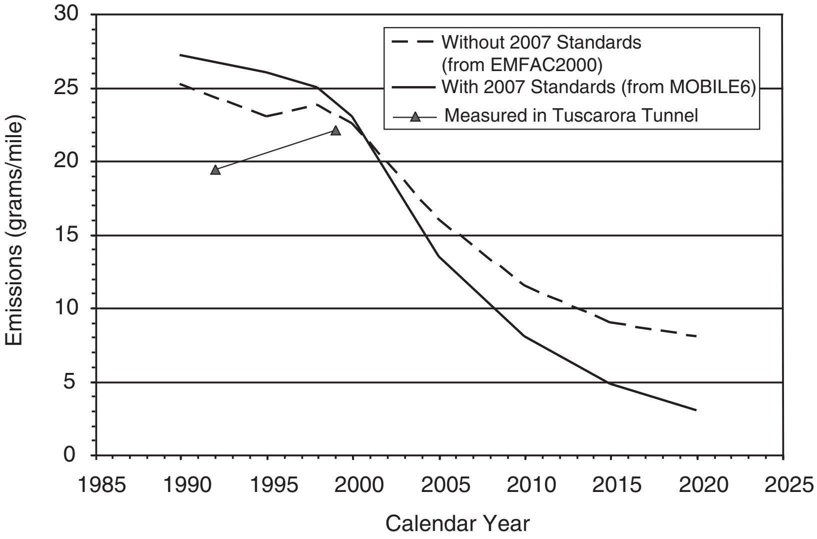
The NO_x increase can be explained as follows: The certification test for heavy-duty diesel engines does not include a steady-state cruise mode—which is the kind of driving that occurs on uncongested freeways, such as the Tuscarora Tunnel. Engine manufacturers had programmed the engine-control systems in 1990s trucks to go into a fuel-saving mode during steady-state driving; a side effect of this mode of operation was increased NO_x emissions.[49] This probably explains the observed increase in NO_x emission rates between 1992 and 1999.

EPA and CARB have since ruled that programming for fuel savings under steady-state driving violated the emission certification requirements, and have required that the affected trucks—mainly those built for the 1992 through 1998 model years—have their engine programming re-adjusted at their next engine rebuild.[50]

There are no trend measurements of emissions from diesel trucks driving under the more “transient” conditions that would occur on urban freeways and streets (and that are included in the regulatory certification test for engine emissions), but it is probable that emissions under these conditions have declined due to the tightened standards, just as was the case with diesel PM emissions. The expectation that truck NO_x emissions have declined overall is consistent with the measured decline in ambient NO_2 levels at monitoring locations around the country (see figure 1a).

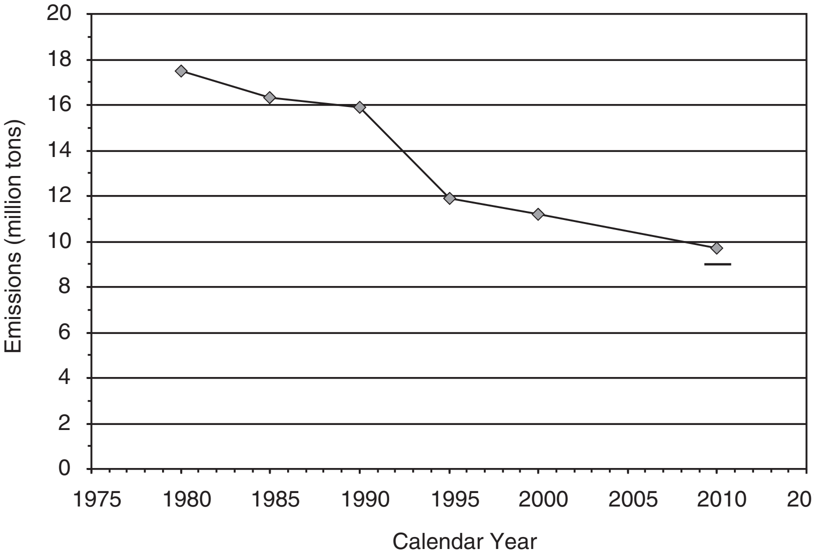
Figure 14 displays federal NO_x and PM emission certification standards for heavy-duty diesel trucks from 1986 onward.[51] Late 1990s standards are more than 60 and 80 percent below 1980s levels, respectively, for NO_x and PM. EPA in 2000 also promulgated regulations requiring an additional 90 percent reduction in PM and NO_x from current levels, starting with the 2007 model year, which would put emissions of future trucks about 99 percent below 1980s levels.[52]

Figure 15. Projections of Heavy-Duty Truck NO_x Emissions with and without CY2007 New-Vehicle Standards



Source: Based on model output reported in J. G. Heiken and T. L. Darlington, “Comparison of MOBILE6 and EMFAC2000 Heavy-Duty Diesel Emissions,” 11th CRC On-Road Vehicle Emissions Workshop, San Diego, CRC, 2001; and tunnel data reported in A. W. Gertler et al., “Trends in Emissions from In-Use Light- and Heavy-Duty Vehicles,” *Journal of the Air & Waste Management Association* (2003): submitted.

Figure 16. Power Plant Sulfur Dioxide Emissions



Source: Based on data in EPA, “EPA’s Acid Rain Program: Results of Phase I, Outlook for Phase II” (Washington, DC: October 2001).

Unlike gasoline vehicles, for which there is a wealth of information on emissions by age and model year, we have only the two Tuscarora Mountain Tunnel point estimates of fleet-average diesel-truck NO_x emissions. I have therefore relied on the CARB and EPA emission models for projections of future diesel-truck emissions. Figure 15 displays projections of average diesel-truck NO_x emission rates with and without the 2007 standards, along with the tunnel measurements.[53] These projections also include the projected effect of engine rebuilds in reducing future NO_x emissions from MY1992–MY1998 truck engines, as well as the effect of ultra-low-sulfur diesel (ULSD) fuel in reducing emissions from existing diesel trucks when ULSD becomes a national requirement in 2006.

Based on CARB's projections from the EMFAC-2000 model, per-mile truck NO_x emissions would decline by about 65 percent between 2000 and 2020 without the 2007 standards. Including the 2007 standards, EPA's MOBILE6 model projects that per-mile truck NO_x emissions will decline 87 percent between 2000 and 2020, with continued reductions beyond 2020, as pre-2007 truck engines are retired. Assuming a 50 percent increase in truck travel between 2000 and 2020, total truck emissions would decline about 80 percent under this scenario. Likewise, EPA projects a 75 percent reduction in total diesel truck PM emissions between 2000 and 2020 when the 2007 standards are included.[54]

Power Plants and Industrial Boilers

EPA estimates that about two-thirds of SO_2 emissions come from coal-fired power plants, almost all in the eastern United States, where coal is a much more common fuel for electricity generation than in the West.[55] Although SO_2 levels have been well below federal health standards for some time, some SO_2 is converted to particulate sulfate, which contributes to elevated PM levels and acid rain in the eastern United States.[56] Title IV of the Clean Air Act Amendments of 1990 requires that power-plant SO_2 emissions be reduced 50 percent below 1980 levels by 2010.[57] The reductions are achieved through a "cap-and-trade" program that, beginning in 1995, established a mandatory, annually declining cap on total SO_2 emissions, but allows utilities to trade allowances among themselves to meet the cap at the lowest possible cost.

Figure 16 displays the trend in utility SO_2 emissions from 1980 to 2000, along with reductions required by 2010 because of the continued decline in the systemwide emissions cap. The hash mark in 2010 marks the ultimate cap on SO_2 emissions that will be achieved within a few years after 2010.[58]

According to EPA's 1999 NO_x emissions inventory, utilities and industrial electricity boilers contribute about one-third of NO_x emissions in the eastern United States.[59] Under Title IV of the Clean Air Act, NO_x emissions from electric utilities were reduced 25 percent between 1990 and 2000.[60] Under EPA's "SIP Call" regulation, warm-season NO_x emissions from utilities, as well as industrial boilers, will be capped at 60 percent below current levels starting in 2004.[61]

In addition to these preexisting requirements, there is a great deal of momentum for additional federal action on power plant pollution. Compared with estimated emissions in 2000, the Bush administration's Clear Skies Initiative would reduce power plant NO_x emissions by 67 percent, and SO_2 emissions by 73 percent by 2018.[62] Senator James Jeffords's Clean Power Act would go even further, reducing NO_x by 70 percent and SO_2 by 80 percent in 2008.[63] Given the substantial bipartisan support for new power plant emission reduction requirements, it seems likely that Congress and the Bush administration will adopt legislation reducing power plant emissions below the limits set by current regulatory requirements.

Some states have already chosen to go beyond current federal requirements. For example, North Carolina's Clean Smokestacks Act requires a 77 percent reduction in NO_x emissions in 2009 and a 73 percent reduction in SO_2 emissions in 2013.[64] New York State's Department of Environmental Conservation recently adopted rules that phase in starting in 2005 and require a 50 percent reduction in SO_2 emissions below levels currently allowed under the Clean Air Act's Title IV acid rain program.[65]

Policy Implications

We can draw the following conclusions from the analysis above:

- Motor vehicle emissions will decline at least 80 percent during the next twenty years or so, as older-technology vehicles are continually replaced by more recent models that stay cleaner throughout their lives. Because most NO_x and VOC pollution comes from motor vehicles, these virtually unstoppable reductions in vehicle pollution are enough by themselves to keep air pollution in retreat for years to come.

- Average vehicle emission rates are declining much more rapidly than driving is increasing. Vehicle emissions are declining about 5 to 15 percent per year due to fleet turnover, while driving is increasing less than 2 percent per year. In other words, total vehicle emissions will continue to decline in spite of population growth, suburbanization, and other trends toward increased driving.

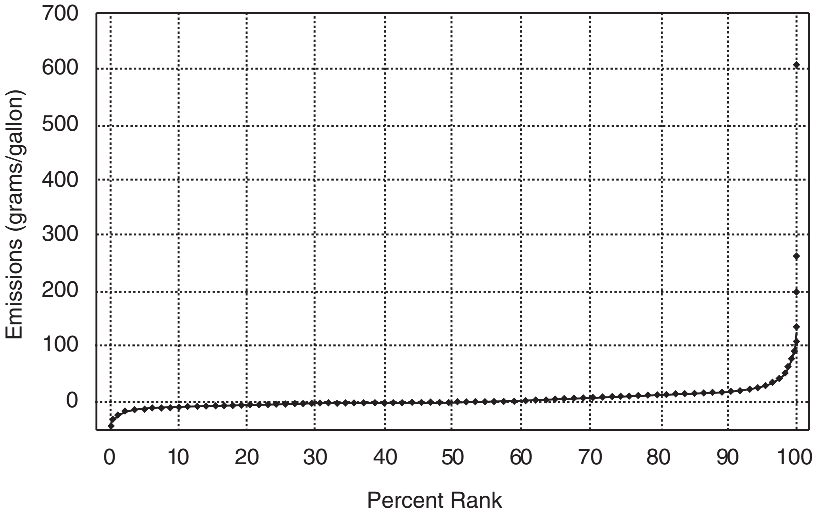
- From the late 1990s onward, the popularity of SUVs and other larger vehicles has made virtually no difference for air quality, as there is now little difference between emissions of cars and light trucks. Starting in 2004, both federal and California regulations require the same tough emission standards for all cars, SUVs, and pickups.

- Current federal laws and regulations require substantial reductions in power plant NO_x and SO_2 emissions during the next few years, and there is substantial bipartisan support for requiring even greater emissions reductions. Coal-fired power plants and industrial boilers are under declining caps on systemwide emissions that will not only prevent net increases in emissions but ensure continued decreases, regardless of changes to programs such as New Source Review. In addition, some states have already adopted new emission reduction requirements for power plants that go well beyond current federal requirements.

Corollaries to these conclusions include the following:

- The long-term problem of air pollution in America has essentially been solved by actions that have already been taken but have not yet come fully to fruition. If so, then additional air pollution regulations that impose large ongoing costs on the public could end up providing few additional benefits. Instead, policymakers should focus on ways to cost-effectively mitigate remaining near-term air pollution problems. Appropriate policies would probably best be focused on speeding the repair, retrofit, or demise of the remaining stock of older, high-emitting vehicles. Indeed, another striking result from vehicle emission studies is that a small number of “gross polluters” account for most vehicle emissions. For example, in Chicago, the worst 5 percent of vehicles generate 46 percent of all tailpipe VOC emissions, and the worst 10 percent contribute 65 percent of tailpipe VOC emissions (see figure 17).[66] A comparison of median and average emissions also shows how skewed the distribution of emissions is among different vehicles in the fleet. The median car in this dataset emits only

Figure 17. VOC Emissions from Vehicles, Ranked from Cleanest to Dirtiest, Based on Chicago Remote Sensing Data



Source: Based on remote sensing data supplied by Don Stedman and Gary Bishop, University of Denver and downloaded from www.feat.biochem.du.edu/.

Data are from calendar year 2000. Engine loads were restricted to between 5 and 15 kilowatts per metric ton to avoid bias due to load variation. Only vehicles with two or more measurements are included (1,643 vehicles). Negative values do not indicate negative emissions (which is physically impossible), but all measurements include some random scatter due to instrument noise.

3.8 grams per gallon, while the average car emits 7.7 grams per gallon. NO_x emissions are also highly skewed, but not to as great an extent as for VOC. The worst 5 percent of NO_x emitters cause 27 percent of total NO_x emissions. Data from other cities and from other types of emission tests give similar results.[67]

- Anything that makes new vehicles artificially more expensive, or that unnecessarily reduces people's disposable income—and therefore their purchasing power—could retard fleet turnover, thereby slowing the most important process for cleaning the air. CARB's zero-emission vehicle (ZEV) requirement is one such policy. According to analysis by CARB staff, ZEVs will likely cost $17,000 more than a comparable gasoline vehicle.[68] Automakers would therefore likely need to sell them at a loss in order to meet their ZEV quota. The only way to make this work financially would be to raise the price of gasoline vehicles in order to "cross-subsidize" ZEVs. The result would be reduced new-car sales and slower fleet turnover. But as shown above, the gasoline cars that ZEVs would replace will already eliminate roughly 90 percent of existing emissions from the vehicle fleet. Because of the small marginal benefits of ZEVs and their large costs (which, perversely, slow fleet turnover), the ZEV requirement risks making future air quality worse that it would otherwise be.[69]

- If growth in vehicle travel has little effect on future air pollution levels, then efforts to reduce driving through lifestyle restrictions or provision of expensive fixed-rail transit systems will do relatively little to clean the air, even if they work as intended. In addition, such measures are far more expensive than alternatives, such as dealing directly with gross-polluting vehicles, and would take far longer to implement. For example, rail projects typically cost about $1 million per ton of ozone precursors eliminated,[70] yet regulators do not consider an air pollution reduction measure to be cost effective unless it costs less than about $10,000 to $20,000 per ton of pollution eliminated.[71] This means that every dollar spent on rail would achieve at least 50 to 100 times the pollution reduction if spent on almost any other pollution reduction measure. In particular, scrapping or repairing gross polluters would achieve at least 200 times the pollution reductions from rail for each dollar spent.[72]

- A Clean Air Act provision known as transportation conformity requires that regional transportation planning and infrastructure decisions be guided by air quality goals.[73] The intent of the conformity requirement is to prevent expansion of automobile infrastructure if it is expected to increase future emissions enough to harm air quality. But if technological advances coupled with fleet turnover will solve the long-term problem of automotive air pollution, and gross-polluter identification can mitigate the short-term problem, then it is foolish to give substantial weight to air quality considerations in high-stakes transportation infrastructure decisions.

- Claims that air quality will decline in the future are not only incorrect, they are the polar opposite of what will actually occur. Emissions from motor vehicles will continue to fall by several percent per year and will be more than 80 percent below current levels within the next twenty years. Likewise, power plant and industrial emissions will continue to decline simply as a result of continuing implementation of existing laws and regulations. Together, these sources account for more than three-fourths of ozone- and PM-forming pollution. The only way air pollution could increase is if emissions from *all other sources* increased by at least a few hundred percent—a prospect that is absurd on its face and completely at odds with historical data showing declines in most emission sources over time, because of both regulations and technological advancements. Indeed, EPA and CARB already regulate emissions from virtually all sources of air pollution, and existing or planned regulations require continued reductions from these sources.[74]

More generally, public debate on air pollution policy is being driven by the false premise that air pollution will rise unless we redouble our efforts to reduce it.[75] In reality, no one can stop continued improvements in air quality in America. There is truly no way back to the smog levels of yesterday.

Appendix A
Data Analysis Methods for Vehicle Emissions

Remote Sensing Data Preparation

Remote sensing data were downloaded from a website maintained by Dr. Gary Bishop at the University of Denver Department of Chemistry (www.feat.biochem.du.edu/light_duty_vehicles.html). The data are provided by location and "campaign"—that is, the time period when the measurements were taken. Data for the Arlington Heights site in Chicago were available for calendar years 1997, 1998, 1999, and 2000 for all three pollutants (VOC, NO_x, and CO). Data for the 6th Ave./I-25 site in Denver were available for calendar years 1996, 1997, 1999, 2000, and 2001, and for the Speer Blvd. and I-25 site for 2003 for CO, while NO_x data were available only for 1999 onward.[76]

- The datasets provide emission readings in parts per million. These were converted to grams per gallon using conversion equations that are available at www.feat.biochem.du.edu/assets/reports/ftmath.pdf.

- Vehicles driving by a remote sensor can also be under a wide range of engine loads. Engine load is a function of speed, acceleration, and road grade, and is usually reported in units of kilowatts per metric ton of vehicle mass (kW/tonne). The remote sensing data include variables for speed and acceleration, while road grade is provided in reports that accompany the datasets.

- The remote sensing data include flags for whether a reading is valid for each pollutant and whether the speed/acceleration reading was valid. Only valid readings were used in the analysis for this study.

- Remote sensing data for vehicles of age zero (that is, vehicles for which the calendar year is the same as the model year) cannot be used for the following reason: Between the time a vehicle is measured with remote sensing on the road and the time its license plate is matched with state registration data a couple of months later, a few older vehicles measured on the road are scrapped, and their license plates are turned in and assigned to a new vehicle. These few old vehicles that were measured on the road then appear to be new vehicles in the remote sensing database. This creates spuriously high average emissions in new vehicles, making the zero-age vehicles unusable for analysis. Thus, for the scenarios depicted in Figures 10a and 10b, I took the conservative approach of assigning the average emissions of one-year-old vehicles to zero-age vehicles as well.

Data Analysis

Remote Sensing Data. The remote sensing data were "sliced" to provide emissions estimates categorized in various ways, including:

- Fleet-average emissions by calendar year

- Emissions vs. age by calendar year

- Emissions vs. age by model year

Because engine load affects emissions, and the load distribution varies from calendar year to calendar year, all data were adjusted to a common load distribution to allow apples-to-apples comparisons. This was done by taking averages of emissions grouped (or "binned" in research parlance) by vehicle age and load, with load divided into the following bins (in kW/tonne): –60, –5, 0, 5, 10, 15, 20, 60, where each bin falls between the listed values, and values less than –60 or greater than 60 were excluded. The average emissions in each load bin for vehicles of age X were then weighted by a load distribution for age X to get average emissions for vehicles of age X in each calendar year.

For the Chicago data, the weighting function for engine load was the average load distribution by age for the entire four years of data. For Denver, which had relatively low loads in some years (due to stop-and-go traffic as a result of construction), 2000, a calendar year with more typical average loads, was used.

To calculate fleet-average emissions for each calendar year, emissions also must be weighted by the "travel fraction"—that is, the percent of vehicles of each age driving by the remote sensor. For each city, the travel fraction was derived from the most recent calendar year's remote sensing data. Fleet-average emissions were then calculated by applying the travel-fraction weighting to the load-adjusted average emissions by age.

Remote sensing VOC data suffer from an offset that made the Denver VOC data unusable for the purposes of this study. The 1998 Chicago VOC data were not usable due to an apparent instrument malfunction. The remaining Chicago VOC data were offset-adjusted by shifting all of the VOC readings in a given calendar year so as to set the mode for that calendar year to zero.[77]

The ranked emission results presented in Figure 17 were generated using data collected in CY2000, restricting vehicle engine loads to between 5 and 15 kW/tonne, and also to vehicles with two or more measurements, and then ranking emissions for each unique vehicle from lowest to highest for a given pollutant. The load restriction was intended to ensure that the emission rankings would not be biased by systematic differences in engine load between vehicles with high and low emissions. Restricting the data to vehicles with at least two measurements controls for a statistical phenomenon called "regression to the mean."[78] When vehicles with only one emission measurement are also included, the worst 5 percent contribute 53 percent of VOC emissions, and the worst 10 percent contribute 76 percent of VOC emissions.

I/M Data. I/M data for Phoenix for calendar years 1995–2001 were provided by Tom Wenzel of Lawrence Berkeley National Laboratory. The I/M test was changed in 2000, so post-1999 data are not comparable with previous data.[79] The data are in the form of grams per mile emissions on the IM240 test—a test in which a vehicle is driven on a treadmill-like machine called a dynamometer for four minutes over a standardized driving cycle. The data were provided as averages by model year and vehicle type (car, small/medium SUV/pickup ("LDT1"), and large SUV/pickup ("LDT2")) for each calendar year, as well as weighted averages by model year for the fleet as a whole. Data were also available for 2000 and 2001 for the IM147 test—the successor to the IM240 in Phoenix.

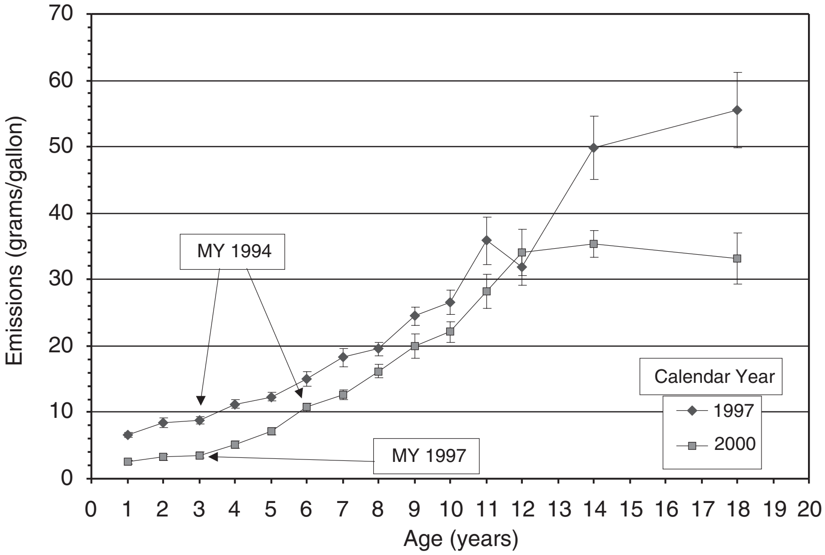
I/M data for Denver for calendar years 1996–2002 were provided by Tom Wenzel. These data were similar to the Phoenix data, except that they were divided only into "cars" and "light trucks," the latter category including all SUVs and pickups.

To generate fleet average emission rates by calendar year, the Phoenix data were weighted by a travel fraction derived from remote sensing data collected in Phoenix in 2000. Likewise, the Denver data were weighted by the 2001 remote sensing travel fraction at the 6th Ave./I-25 site in Denver.

The average emissions from a fleet of vehicles depends on how much they are driven. Older vehicles are driven fewer miles, on average, than newer vehicles, and this is reflected in a lower representation of older vehicles on the road than would be naively expected from the percentage of older vehicles calculated from vehicle registrations.

Almost all vehicles either pass or fail the IM240 test prior to completion of the full four-minute test due to use of a "fast-pass/fast-fail" algorithm used in order to shorten the time motorists spend going through the testing process (the same is true for Phoenix's IM147 test). The test data from Phoenix

Figure A-1a. VOC Emissions vs. Vehicle Age with 95 Percent Confidence Intervals, from Chicago Remote Sensing Data



Source: Remote sensing data collected by Don Stedman and Gary Bishop of the University of Denver, and downloaded from www.feat.biochem.du.edu/.

and Denver represent mainly measurements that have been statistically adjusted to full IM240 equivalent emissions. This adjustment method is not perfect and has been shown, based on comparison with random samples of vehicles given a full IM240 test, to overstate hydrocarbons (HC) and NO_x emissions of the most recent model-years.[80]

Statistical Issues

For the purposes of this analysis, there are two major statistical concerns—random error and bias. Bias can occur if the sample of vehicles for which we have emission measurements differs in some important way(s) from the full population of vehicles on the road.

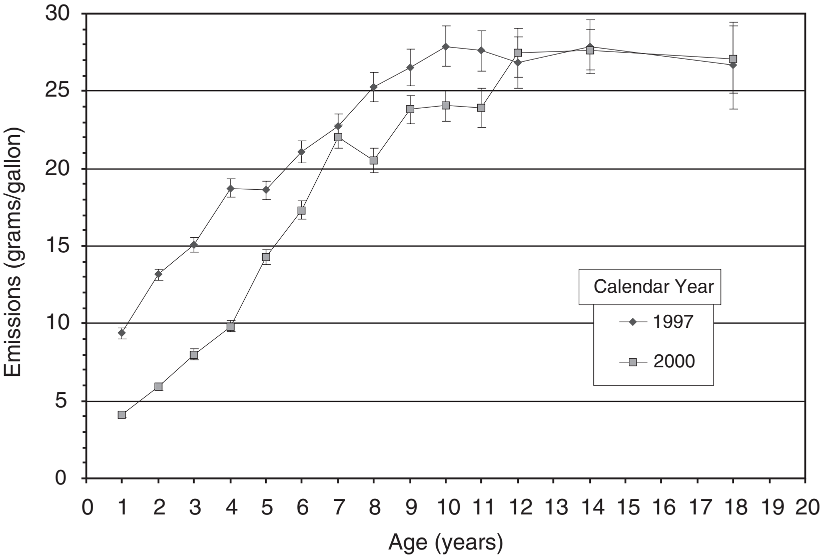
For example, although data from I/M programs are useful for assessing various aspects of vehicle emissions, they are also subject to significant sampling bias, and must be interpreted cautiously. Stedman et al. showed using on-road remote sensing measurements that after Denver's enhanced I/M program began in 1995, many motorists re-registered high-emitting cars outside the area, but continued to drive in Denver. As a result, the fleet tested in the Denver I/M program became progressively depleted in high-emitters (relative to the actual on-road fleet) during the first few years of the program. There may be other types of "gaming" that make emissions on I/M tests different from emissions on the road.[81] Also, as noted above, the algorithm to convert fast-pass/fast-fail emissions to full IM240 emissions overestimates the emissions of more recent model years relative to earlier ones, which could cause an underestimate of the rate of emission reductions. In addition, there is evidence that some vehicles' emissions during the I/M test are not representative of their true emissions on the road, because some motorists take steps to pass the test without performing lasting repairs on their vehicles.[82]

Remote sensing data are unlikely to suffer from this type of bias, because vehicles are measured at random in their unprepared on-road state. Furthermore, the data were collected at the same location and the same time of year in each calendar year. Data from different calendar years were also all adjusted to the same age and engine-load distribution to remove bias due to these factors. Nevertheless, there are other potential sources of bias in remote sensing measurements. For example, driver income has previously been shown to be inversely correlated with vehicle emissions, even after controlling for vehicle age.[83] If the income distribution of the vehicle owners driving by the remote sensor changed over time, this would introduce bias not accounted for in the analysis presented here. In addition, the remote sensing data were collected from vehicles entering or leaving freeways, which could result in undersampling of older vehicles since they are probably less likely to be driven on freeways. If such a bias exists, it would be less likely to affect emission trend estimates, since the bias would likely be similar from year to year.

While sample selection bias is always a concern, the weight of the evidence suggests it is unlikely that selection bias could be causing spurious results. All geographic locations and data collection methods gave qualitatively similar results in terms of emission trends, concentration of most emissions in a few high emitters, progressive improvement in emissions with each model year, etc.

Random error results from unavoidable random fluctuations inherent in any sampling process. If you have a large bowl filled with equal numbers of red and blue marbles and you draw ten at random, you will most often get five of each color. But sometimes the breakdown will be six to four, seven to three, etc., just due to random chance.

Figure A-1b. NO_x Emissions vs. Vehicle Age with 95 Percent Confidence Intervals, from Chicago Remote Sensing Data



Source: Remote sensing data collected by Don Stedman and Gary Bishop of the University of Denver, and downloaded from www.feat.biochem.du.edu/.

The concept of “statistical significance” addresses the concern over whether a numerical result reflects a genuine property of a population of, say, vehicles or people, or whether it is likely to have resulted from random sampling error. In this study, the concern is over whether a given difference in emissions between vehicles from different model years measured at the same age is likely to reflect a real trend in emissions over time, or to be the chance result of random fluctuations in the sample of vehicles measured in each calendar year.

By convention, a result is considered statistically significant if an appropriate statistical test suggests that the result has no more than a 5 percent likelihood of having resulted due to random sampling error, and therefore a 95 percent chance of representing a real trend in vehicle emissions. The term “statistically significant” is a term of art in statistical analysis, and the word “significant” in this context does not in any way mean “important” or “noteworthy” as it would in everyday use. The fact that a result is statistically significant thus provides no information either way on whether it is of practical significance. All other things being equal, a measured difference between two groups of vehicles is more likely to become statistically significant as the sample size gets larger and as the spread (in technical parlance, the standard deviation) of the measurements gets smaller.

One way to determine statistical significance is to determine whether the “95 percent confidence intervals” (95 percent CI) of two different measurements overlap. Figures A-1a and A-1b display the same data as figures 7a and 7b, but this time with the 95 percent CI displayed for each data point as bars jutting up and down from each data point. For each data point, there is a 95 percent chance that the true value of that data point—in this case, the average emissions of vehicles of the given age in a given calendar year—lies within the range of the 95 percent CI.[84] Differences between groups are statistically significant when their 95 percent CIs do not overlap. Thus, as the graphs show, at most ages, the differences between vehicles measured in 2000 and 1997 are statistically significant. As can be seen by the range of the 95 percent CIs, emissions differences of several percent or more are coincidentally also statistically significant.

Notes

1. Three of 557 monitoring locations exceed the CO health standard. Two of 667 monitoring locations exceed the SO_2 standard. The entire country meets the NO_2 standard. (Based on analysis of AirData pollution monitoring data reports downloaded from EPA, www.epa.gov/air/data/moncols.html?us~USA~United%20States.)

2. Based on analysis of ozone monitoring data for 1982 through 2002 downloaded from www.epa.gov/aqspubl1/select.html. EPA recently promulgated the more stringent "eight-hour" ozone standard, which is exceeded at about 40 percent of monitoring locations. The eight-hour standard is significantly more stringent than the one-hour standard.

3. $PM_{2.5}$ denotes all PM up to 2.5 micrometers in diameter. C. A. Pope et al., "Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution," *Journal of the American Medical Association* 287, no. 9 (2002): 1132–41.

4. For a more detailed analysis of air pollution trends, see J. Schwartz, "Understanding Air Pollution: Trends, Health Effects, and Current Issues" (Washington, DC: Cato, forthcoming).

5. P. Krugman, "Every Breath You Take," *New York Times,* 26 November 2002, A27.

6. See, for example, Editorial, "Christie Whitman's Tribulations," *New York Times,* 27 November, 2002, A22; Editorial, "Empty Promises," *New York Times,* 31 January 2003, A28; Editorial, "Unclear Skies," *Dallas Morning News,* 4 August, 2002, 2J; J. Kay, "EPA Plans Rollback of Clean Air Act," *San Francisco Chronicle,* 14 June 2002, A1.

7. S. Borenstein and P. Rogers, "Easing Air Rules for Power Plants Generates Scorn," *San Jose Mercury News,* 14 June 2002, A4; SaveTheCleanAirAct.org, "Stop the Attack on the Clean Air Act!" www.savethecleanairact.org/public/.

8. E. Pianin, "New Pollution Standards Prompt Suit, 9 States Challenge U.S. Decision to Relax Rules," *Washington Post,* 1 January 2003, A1. The quote is from New York State Attorney General Eliot Spitzer.

9. See, for example, Clean Air Trust, "Entering the New Millennium: Americans Want More Done to Protect the Environment," www.cleanairtrust.org/survey.environment.html; Foundation for Clean Air Progress, "Survey of Air Pollution Perceptions: Final Report," www.cleanairprogress.org/news/quorum_res_01_14_02.asp. On the role of environmental activists and the media in public misperceptions about air pollution also see J. Schwartz, "Clearing the Air," *Regulation* 26, no. 2 (2003): 22–29.

10. In metropolitan areas, on-road motor vehicles contribute about 50 to 80 percent of VOCs, 45 to 65 percent of NO_x, 40 to 60 percent of $PM_{2.5}$, and 85 to 95 percent of CO. (See, for example, G. R. Cass et al., "Determination of Fine Particle and Coarse Particle Concentrations and Chemical Composition in the Northeastern United States, 1995" (Pasadena: California Institute of Technology, December 1999); EPA, "Latest Findings on National Air Quality, 2001 Status and Trends" (Washington, DC: September 2002); South Coast Air Quality Management District, "Draft 2003 Air Quality Management Plan, Appendix III: Base and Future Year Emission Inventories" (Diamond Bar, CA: February 2003); J. G. Watson et al., "Review of Volatile Organic Compound Source Apportionment by Chemical Mass Balance," *Atmospheric Environment* 32 (2001): 1567–84; M. Zheng et al., "Source Apportionment of $PM_{2.5}$ in the Southeastern United States Using Solvent-Extractable Organic Compounds as Tracers," *Environmental Science & Technology* 36 (2002): 2361–71.

11. EPA's "Tier 1" standards were implemented in 1994, and National Low Emission Vehicle (NLEV) standards were implemented in 2000.

12. EPA, "Section 177 States Vehicle Emissions Control Requirements—Status on California Rules Adoption," undated, www.epa.gov/otaq/cert/ ststatus.pdf.

13. NO_x is a shorthand for NO_2 + NO (nitrogen dioxide and nitric oxide, respectively). Most NO_x is emitted as NO, but is converted to NO_2 in the atmosphere.

14. J. G. Watson et al., "Review of Volatile Organic Compound Source Apportionment by Chemical Mass Balance," *Atmospheric Environment* 32 (2001): 1567–84. EPA's official inventory claims that on-road motor vehicles contribute only about 30 percent of VOC, but "real-world" source-apportionment studies during the last fifteen years reviewed in Watson et al., cited above, show that EPA's official inventory underestimates the percentage contribution of motor vehicles to total VOCs, often by a large margin. I added the caveat "anthropogenic" because VOC emissions from trees and vegetation can dominate the VOC inventory in some areas, particularly in the southeastern United States. See L. M. Hagerman et al., "Characterization of Non-Methane Hydrocarbons in the Rural Southeast United States," *Atmospheric Environment* 31, no. 23 (1997): 4017–38; B. K. Pun et al., "Contribution of Biogenic Emissions to the Formation of Ozone and Particulate Matter in the Eastern United States," *Environmental Science & Technology* 36 (2002): 3586–96.

15. EPA's emissions inventory estimates were downloaded from www.epa.gov/air/data/repsst.html. As an example of a metropolitan inventory, the South Coast Air Quality Management District (SCAQMD) estimates that about 35 percent of NO_x in the Los Angeles region comes from cars and light trucks.

16. EPA, "Latest Findings on National Air Quality, 2001 Status and Trends"; South Coast Air Quality Management District, "Draft 2003 Air Quality Management Plan, Appendix III: Base and Future Year Emission Inventories" (Diamond Bar, California: February 2003).

17. Data for this chart come from A. J. Kean et al., "Trends in Exhaust Emissions from In-Use California Light-Duty Vehicles, 1994–2001" (Warrendale, Pennsylvania: Society of Automotive Engineers, 2002). In each year, sampling was done at the same time of year over a ten-day period. Researchers measure emissions of cars going through a tunnel by comparing the increase in the concentration of VOC, NO_x, CO, and CO_2 between the tunnel inlet and outlet. Measuring CO_2 allows a determination of emissions per gallon of fuel burned, because all of the carbon in the fuel must be emitted as either VOC, CO, or CO_2.

18. These percentages are the percent reduction in each year from the previous years' emission rate—the equivalent of a compounded growth (or in this case, decline) calculation. When I refer to an "annualized" percent reduction at other points in this paper, I mean the year-over-year percent reduction rate that gives the observed overall percent reduction in emissions for a given dataset. I use this method so that data from different places, collected over different time periods, can be placed on a comparable footing.

There is no obvious trend in the rate of change in emissions from year to year for any of the pollutants. HC and CO decreased more from 1995 to 1996 than in other years, probably due to the introduction of reformulated gasoline. VOC emissions declined more from 1999 to 2001 than 1997 to 1999, while the opposite was true for NO_x and CO. On the other hand, NO_x declined more (on an annualized basis) from 1997 to 1999 than in earlier years. Additional years of data will be necessary to determine whether the rate of emissions decline is changing systematically over time for any of the pollutants.

19. The Chicago remote sensing emissions data are in grams per gallon of fuel burned (grams/gallon). The Denver I/M emissions data are normally reported in grams per mile, but are in grams per gallon on the chart. I converted the Denver data from grams per mile to grams per gallon (grams/mile multiplied by miles/gallon = grams/mile). Fuel economy during the emissions test was included as part of the Denver I/M data, allowing this conversion to be made. See Appendix A for details on how the various emissions datasets were analyzed.

20. Predicted emission trends from EMFAC2000 and MOBILE6 were derived from T. L. Darlington et al., "Comparison EMFAC2000 and MOBILE6," 11th CRC On-Road Vehicle Emissions Workshop, San Diego, CRC, 2001.

21. There are also some trend data from earlier time periods. For example, based on measurements in the Van Nuys Tunnel in Los Angeles in 1987 and 1995, VOC, NO_x, and CO emissions declined 9 percent, 2.5 percent, and 6 percent per year. Based on data from the Allegheny and Tuscarora Tunnels on the Pennsylvania Turnpike, CO

emissions declined an average of 8.6 percent per year between 1973 and 1999 (almost a 90 percent decline overall). (A. W. Gertler et al., “Trends in Emissions from In-Use Light- and Heavy-Duty Vehicles,” *Journal of the Air & Waste Management Association* (2003): submitted.)

Regarding the emission models, it is worth noting that although the models are in the ballpark on the relative rate of change in emissions, the models overpredict absolute emission rates by a large margin. For example, compared with the data presented here, the models overpredict VOC and CO emission rates by factors of about 4 and 3, respectively. These data do not include cold-start and non-tailpipe emissions (except for the tunnel data, which does include non-tailpipe emissions) but the discrepancy between the data and models is several times larger than the potential effect of these excluded emissions. The models come closer on NO_x but still overpredict emissions by about a factor of 1.4.

22. Kean et al., “Trends in Exhaust Emissions from In-Use California Light-Duty Vehicles, 1994–2001”.

23. Results are similar for CO (data not shown).

24. For each model year, the reported emissions were measured during calendar year 2001 on the IM147 test (the successor to the IM240 test). The IM147 test uses the same equipment as the IM240 test, but a different driving cycle. The difference in car and SUV/pickup emissions for each model year was stable with vehicle age, so this study uses the most recent calendar year for which data were available.

25. For each model year, the reported emissions were measured during calendar year 2002. The difference in car and SUV/pickup emissions for each model year was stable with vehicle age, so this study uses the most recent calendar year for which data were available.

26. While I/M data suffer from underrepresentation of high-emitting vehicles, this likely does not have much effect on the SUV/pickup versus car analysis presented here. First, the sampling bias would presumably affect all vehicles to a similar extent. Second, most high-emitters are older vehicles. Newer vehicles rarely have excessive emissions and therefore rarely fail an I/M test. Thus, sampling bias affects mainly model years that are older at the time they are measured in an I/M program.

27. The California Bureau of Automotive Repair in 1998 and 1999 collected several thousand emissions measurements by pulling cars over at random at various roadside locations and giving them an I/M test. These data also indicate that SUV/pickup emissions have gotten much closer to car emissions in recent years (data not shown).

28. In fact, small and medium SUVs and pickups have had to meet the same standards as cars since 1994. The 2004 standards will include the largest SUVs under the same standards umbrella as other automobiles. CARB, “The California Low-Emission Vehicle Regulations” (Sacramento: May 2001); S. C. Davis and S. W. Siegel, “Transportation Energy Data Book: Edition 22” (Oak Ridge, Tennessee: Oak Ridge National Laboratory, September 2002); EPA, “Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements; Final Rule” (Washington, DC: 10 February 2000).

29. “Light truck” refers to SUVs and pickup trucks.

30. EPA generally phases new standards in over a period of three to four years. For example, 40 percent of vehicles had to meet Tier 1 standards in model-year 1994, 80 percent in 1995, and 100 percent in 1996. For Tier 2, 25 percent must meet the standards in model year 2004, 50 percent in 2005, 75 percent in 2006, and 100 percent in 2007.

31. The standards in Figures 6a and 6b are the 50,000-mile standards. EPA also included a 100,000-mile durability requirement for vehicles built to Tier 1 standards, which took effect in 1994. EPA’s new Tier 2 requirements, which begin phasing in starting with the 2004 model year, include a 120,000-mile durability requirement. These longer-term durability requirements allow emissions to rise by up to about 50 percent above the 50,000-mile caps.

32. Note that Figure 2b showed that, despite an aggregate decline in NO_x emissions from 1997 to 2000, fleet-average NO_x emissions in this dataset increased slightly from CY1998 to CY1999, and the average for each of these calendar years falls in between those for CY1997 and CY2000. Thus, if figures 7a and 7b included curves for CY1998 and CY1999, those curves would fall between the curves for CY1997 and CY2000, and would be relatively close together at any given age.

33. To my knowledge, Peter McClintock of Applied Analysis, Inc. was the first person to create this type of graphic for presenting vehicle emissions data.

34. Figure 8a displays NO_x data back to MY 1993. The Chicago remote sensing data suggest little improvement

in NO_x emissions with model years before the early 1990s. Phoenix I/M data give similar results; however, the Denver I/M data suggest some progressive improvement in NO_x for 1980s model years (data not shown).

35. CO emissions follow a similar trend to NO_x and VOC (data not shown).

36. Personal communication with Tom Wenzel, Lawrence Berkeley National Laboratory.

37. Emissions at age zero were set equal to emissions at age one in both figures 11a and 11b. See appendix A for a discussion of this.

38. At each age, the deterioration slope is derived from the deterioration rate of vehicles of the given age that were measured by remote sensing. For example, the deterioration rate for vehicles at four years of age is the average deterioration slope for all model years that were measured at four years of age—in this case MY1993–MY1996 (see Figure 8a for a graphic representation). Likewise, the deterioration slope for ten-year-old vehicles is the average deterioration slope measured for MY1987–MY1990, and so on.

39. Figure 8a displays NO_x emissions deterioration vs. age for MYs 1995 and 1996.

40. The phase-in schedule is 25 percent in 2004, 50 percent in 2005, 75 percent in 2006, and 100 percent meeting LEV II/Tier 2 standards in 2007.

41. The LEV II/ULEV standards require NO_x to be below 0.05 gram/mile at 50,000 miles, and below 0.07 gram/mile at 120,000 miles. The corresponding values for VOCs are 0.04 and 0.055. To be conservative, I assumed that emissions started out at the 50,000-mile level until four years of age, rose linearly up to the 120,000-mile level at ten years of age, and continued rising linearly with age afterwards. To put these grams/mile emissions into grams/gallon, I assumed an average fuel economy of 23 miles/gallon.

42. Of course, actual future emissions would not decline along a smooth exponential curve as projected here. Future emissions will depend on regulatory and macroeconomic factors that affect the rate at which motorists purchase new vehicles and retire old ones, so the real trend will be "bumpy" (see figure 3 for an example of an actual trend).

43. EPA assumed a 1.7 percent per year increase in driving when modeling future vehicle emissions for its Tier 2 regulation, so this estimate is more conservative than EPA's (EPA, "Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements; Final Rule").

44. Two caveats here: First, this is a national inventory. Local and regional contributions of diesel trucks likely differ from the national average. For example, electricity generation contributes about a third of NO_x emissions in the eastern United States, but only 10 to 15 percent in the western United States, and less than 2 percent in California. Thus, diesel trucks account for a relatively greater percentage of NO_x in the West than in the East. Also, in metropolitan areas, gasoline vehicles—mainly cars, light trucks, and delivery trucks—likely contribute a greater fraction of NO_x, relative to diesel trucks, than would be expected based on the national inventory. This is because much truck travel occurs on rural highways and interstates, and these emissions are included in the national inventory, while gasoline vehicles log relatively more of their miles within metropolitan areas.

Second, EPA's official national NO_x inventory for 1999 has only 14 percent of NO_x coming from diesel trucks—just over half the contribution claimed here. Recent research on "real-world" emissions of diesel vehicles indicates that EPA has underestimated diesel truck NO_x emissions by a factor of 2 in its official inventory, while overestimating emissions from off-road diesel equipment by a factor of about 2.2. To derive the 25 percent contribution from diesel trucks, this study took the official EPA inventory breakdown and adjusted the on- and off-road diesel contributions based on these real-world estimates, while implicitly assuming that other portions of the official inventory are accurate. (A. J. Kean et al., "A Fuel-Based Assessment of Off-Road Diesel Engine Emissions," *Journal of the Air & Waste Management Association* 50 (2000): 1929–39.)

45. J. C. Chow and J. G. Watson, "Review of $PM_{2.5}$ and PM_{10} Apportionment for Fossil Fuel Combustion and Other Sources by the Chemical Mass Balance Receptor Model," *Energy & Fuels* 16 (2002): 222-60; A. C. Lloyd and T. A. Cackette, "Diesel Engines: Environmental Impact and Control," *Journal of the Air & Waste Management Association* 51 (2001): 809–47.

46. Watson et al., "Review of Volatile Organic Compound Source Apportionment by Chemical Mass Balance."

47. A. W. Gertler et al., "Trends in Emissions from In-Use Light- and Heavy-Duty Vehicles," *Journal of the Air & Waste Management Association* (2003): submitted.

48. Ibid.

49. See www.epa.gov/compliance/civil/programs/caa/diesel/ for more information.

50. Ibid.

51. Heavy-duty diesel emission standards are denoted in units of grams per brake-horsepower-hour (grams/bhp-hr), which means emissions per unit of power output (horsepower) and time (hours). Thus, an engine operating at 200 horsepower that emits 1 gram/bhp-hr would emit 200 grams per hour.

52. EPA, "Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements" (Washington, DC: December 2000).

53. J. G. Heiken and T. L. Darlington, "Comparison of MOBILE6 and EMFAC2000 Heavy-Duty Diesel Emissions," 11th CRC On-Road Vehicle Emissions Workshop, San Diego, CRC, 2001. The two projections come from two different emission models, and therefore differ in a number of ways besides inclusion of the 2007 standards.

54. EPA, "Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements."

55. EPA's pollutant emissions inventory estimates were downloaded from www.epa.gov/air/data/repsst.html.

56. EPA, "Latest Findings on National Air Quality, 2001 Status and Trends."

57. EPA, "EPA's Acid Rain Program: Results of Phase I, Outlook for Phase II" (Washington, DC: October 2001).

58. The final cap won't be reached until a few years after 2010, because utilities are allowed to "bank" some SO_2 credits generated in a given year for use in a future year. It will likely take a few years for these banked credits to be depleted after 2010.

59. Coal is much less common in the West, and, according to EPA's inventory, electricity generation contributes only 10 to 15 percent of NO_x emissions in the West. In California, power plants account for only about 2 percent of NO_x. (The western NO_x inventory breakdown comes from EPA's 1999 emission inventory. CARB estimates that only about 2 percent of NO_x emissions in southern California and the Central Valley come from electricity generation. California regional emission inventories can be downloaded from www.arb.ca.gov/emisinv/maps/statemap/abmap.htm. For sources of electricity in California, see California Energy Commission, "California Gross System Electricity Production for 2001," www.energy.ca.gov/electricity/gross_system_power.html.)

As for diesel truck NO_x emissions, the value presented here is based on the EPA inventory, but modified by the Kean et al. adjustment factors for actual NO_x emissions from on- and off-road diesel sources. (A. J. Kean et al., "A Fuel-Based Assessment of Off-Road Diesel Engine Emissions," *Journal of the Air & Waste Management Association* 50 (2000): 1929–39.)

60. EPA, "EPA's Acid Rain Program: Results of Phase I, Outlook for Phase II" (Washington, DC: October 2001).

61. EPA, "Addendum to the Regulatory Impact Analysis for the NO_x SIP Call, FIP, and Section 126 Petitions" (Washington, DC: September 1998). The rationale for capping only warm-season (May– September) NO_x emissions is that NO_x contributes to ozone formation, but at least in the East it is a minor contributor to PM.

62. The Clear Skies Initiative is Senate Bill 485 and House of Representatives Bill 999.

63. The Clean Power Act is embodied in Senate Bill 366.

64. The percentage reductions are relative to 1998 levels. Information on the Clean Smokestacks Act can be downloaded from the North Carolina Department of Environment and Natural Resources at daq.state.nc.us/news/leg/.

65. K. Johnson, "Rules Approved to Reduce Pollutants at Power Plants," *New York Times*, 27 March 2003.

66. Recent remote sensing data for other cities, such as Phoenix, Arizona and Riverside, California, show a similarly skewed distribution of emissions among vehicles (data not shown). The highly skewed nature of vehicle emissions is a general property of all vehicle fleets and has been demonstrated using all types of vehicle emission tests (see, for example, D. R. Lawson, "The Costs of 'M' in I/M—Reflections on Inspection/Maintenance Programs," *Journal of the Air & Waste Management Association* 45 (1995): 465–76; J. Schwartz, "Clarification of Misconceptions Regarding the Sacramento RSD Pilot

Program" (Sacramento: California I/M Review Committee, 31 March 1995). In addition, the skewed nature of the emissions distribution has increased with time. For fleets measured during the early 1990s, the worst 10 percent of VOC emitters typically contributed about 50 percent of total VOC emissions (D. H. Stedman et al., "On-Road Remote Sensing of CO and HC Emissions in California—Final Report" (Sacramento: California Air Resources Board, February 1994).

67. See previous footnote.

68. CARB, "Description and Rationale for Staff's Additional Proposed Modifications to the January 10, 2003 ZEV Regulatory Proposal" (Sacramento, CA: 2003).

69. H. Gruenspecht, "Zero Emission Vehicles: A Dirty Little Secret," *Resources* (Winter 2001): 7–10. See also L. Dixon et al., "Driving Emissions to Zero: Are the Benefits of California's Zero Emission Vehicle Program Worth the Cost?" (Santa Monica, CA: RAND, 2002).

70. Calculated based on capital and operating costs and estimated emission reductions for a sample of rail projects. Data were obtained from the Federal Transportation Administration's "Annual Report on New Starts," downloaded from www.fta.dot.gov/library/policy/ns/annreports.htm. Capital and operating costs were included in the cost effectiveness calculation, on the assumption of a 40-year amortization of capital costs and a 7 percent interest rate.

71. For example, EPA estimated that measures needed to comply with the new eight-hour ozone standard would have a cost effectiveness averaging about $13,000 for NO_x and $5,000 for VOC. Measures proposed in the latest plan to clean up Southern California's air range in cost effectiveness from a few hundred dollars up to $20,000 per ton. Voluntary scrap programs using age or failure of an emissions inspection test as eligibility criteria have an estimated cost effectiveness of about $5,000 per ton in reducing ozone precursors. A pilot program that used remote sensing to identify high-emitting vehicles for repair had a similar cost effectiveness. (Eastern Research Group, "Overview of Voluntary Vehicle Scrap Programs for Reducing in-Use Vehicle Emissions" (Austin, Texas: June 2002); EPA, "Regulatory Impact Analysis: Tier 2/Gasoline Sulfur Final Rulemaking" (Washington, DC: December 1999); D. R. Lawson et al., "Program for the Use of Remote Sensing Devices to Detect High-Emitting Vehicles, Prepared for the South Coast Air Quality Management District" (Reno: Desert Research Institute, 16 April 1996); South Coast Air Quality Management District, "Draft 2003 Air Quality Management Plan" (Diamond Bar, CA: February 2003).

72. Previous scrap programs have estimated cost effectiveness to be about $5,000 per ton of ozone precursors eliminated. These programs generally used age as the eligibility criterion. A program that targeted the highest emitters based on remote sensing would likely have even better cost effectiveness.

73. See 40 CFR 93 Subparts A and B of the Code of Federal Regulations.

74. Regulations that EPA has already adopted can be browsed and downloaded from www.epa.gov/docs/epacfr40/chapt-I.info/subch-C.htm. EPA's agenda for future proposed air pollution control rules and information about the proposed rules can be downloaded from ciir.cs.umass.edu/ua/Spring2003/tables/ENVIRONMENTAL_PROTECTION_AGENCY_(EPA).html.

75. See notes 5 through 9 for examples.

76. NO_x measurements were collected in 1996 and 1997, but these data suffer from VOC interference and are therefore biased high (personal communication with Professor Don Stedman, University of Denver).

77. Personal communication with Professor Don Stedman, University of Denver. The mode is the most common value in a given set of data.

78. Regression to the mean occurs whenever one selects the extreme values in a distribution, say, the highest-emitting 10 percent of vehicles, or students scoring in the lowest 10 percent on a test, and retests them. If either of these groups are retested, their scores will, on average, be closer to the population mean on the retest. For a lucid explanation of why regression to the mean occurs, see trochim.human.cornell.edu/kb/regrmean.htm.

79. However, the 2001 Phoenix data were used to determine the ratio of emissions of light trucks to cars, since comparability with other calendar years wasn't an issue for that analysis.

80. Eastern Research Group, "Analysis of Historical Remote Sensing and I/M Emissions Data in Arizona" (Austin, TX: 2002).

81. D. H. Stedman et al., "On-Road Evaluation of an Automobile Emission Test Program," *Environmental*

Science & Technology 31, no. 3 (1997): 927–31; D. H. Stedman et al., “Repair Avoidance and Evaluating Inspection and Maintenance Programs,” *Environmental Science & Technology* 32, no. 10 (1998): 1544–45.

82. D.R. Lawson, “Passing the Test-Human Behavior and California’s Smog Check Program,” *Journal of the Air & Waste Management Association* 43 (1993): 1567–75.

83. B. C. Singer et al., “A Fuel-Based Assessment of Motor Vehicle Emissions in Southern California,” *Journal of the Air & Waste Management Association* 49 (1999): 125–35.

84. It is worth stressing again that the idea of statistical significance and the 95 percent CI is premised on the assumption that the samples of vehicles are drawn at random from the on-road vehicle population. The 95 percent CI represents the uncertainty solely due to random sampling variation and does not provide any information on whether the sampling method itself suffers from systematic bias.

About the Author

Joel Schwartz is an independent scientist and policy researcher, and an adjunct fellow at the American Enterprise Institute.

Mr. Schwartz formerly directed the Reason Public Policy Institute's Air Quality Project and has also published studies on chemical risks and extended producer responsibility. Prior to joining Reason, he was Executive Officer of the California Inspection and Maintenance Review Committee, a government agency charged with evaluating California's vehicle emissions inspection program and making recommendations to the legislature and Governor on program improvements. He has also worked at the RAND Corporation, the South Coast Air Quality Management District, and the Coalition for Clean Air.

Mr. Schwartz received his bachelor's degree in chemistry from Cornell University and his master's degree in planetary science from the California Institute of Technology. He was a German Marshall Fund fellow in 1993, during which he studied European approaches to transportation and air quality policy. He lives and works in Sacramento, California.

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