On-Road Vehicle Emissions: Regulations, Costs, and Benefits

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In response to continuing pollution problems, in 1990 Congress passed the Clean Air Act Amendments, many parts of which deal with motor vehicles. Motor vehicles are the primary source of urban carbon monoxide (CO) and are an important source of the hydrocarbons (HC) and oxides of nitrogen (NO_x) that are responsible for the formation of photochemical smog and ground-level ozone (*1*). Cost estimates for implementing the act's mobile source provisions range up to \$12 billion annually (*2*). Thus it is important to analyze the scientific basis for these legislative programs (*1*).

For any region violating air quality standards, a State Implementation Plan (SIP) must be submitted to and approved by the U.S. Environmental Protection Agency (EPA). In approving the SIP, EPA grants credit for each portion of the plan, including new vehicle emission standards, new fuels, vehicle scrappage, and inspection and maintenance (IM) programs, on the basis of predictions from a spreadsheet computer model (*3*). This EPA model treats all cars of a given model year as having the same odometer reading, the same annual mileage accumulation, and an equal likelihood of emission control system problems. The model has had little success in predicting urban on-road vehicle emissions (*4*), and the use of unverified computer models as the sole guide for public policy decisions is controversial (*5*). Calvert *et al.* (*6*) criticized the model and recommended in-use surveillance programs to identify high-emission vehicles and to monitor progress in emissions reduction. We present such a study and discuss its policy implications.

The California Study

During the summer of 1991, we placed an on-road remote sensor of exhaust CO and HC emissions (*7*) at various urban locations throughout California. We identified 66,053 different vehicles for which we collected 91,679 records with valid HC and CO measurements (*8*). The emission distribution is highly skewed; the half of the fleet with the lowest emissions contributed less than 10% of the CO and HC, while a few high-emission vehicles dominated the mean values. In this instance, 7% of the vehicles accounted for 50% of the on-road CO emissions, and 10% of the vehicles accounted for 50% of the on-road HC emissions. These vehicles we call gross polluters. About 5% of the vehicles were gross polluters for both HC and CO (*9*).

It is often assumed that gross polluters are simply old vehicles. In fact, all model years of vehicles we have measured on the road include some proportion of gross polluters, as shown in Fig. 1. We found that the highest emitting 20% of the newest cars were worse polluters than the lowest emitting 40% of vehicles from any model year, even those from model years before the advent of catalytic converters (1970 and earlier). These data are typical of CO and HC results across the United States and at many other locations worldwide (*10*): Differences in emissions within a model year are greater than differences between the averages of the various model years. Correlation of average on-road emissions and vehicle age shows that these results cannot be dismissed as random samples of normal vehicle behavior (*11*).

For 2 weeks during the California study, we operated two remote sensors on Rosemead Boulevard in South El Monte near Los Angeles (*12*). Vehicles identified by these sensors as gross polluters were immediately pulled over, and a voluntary California Smog Check—an emission control system inspection and tailpipe test—was administered. The remote sensors measured 58,063 unique vehicles, and we obtained Smog Check data on 307 of these vehicles. Of these, 126 (41%) showed deliberate tampering, and another 77 (25%) had defective or missing equipment that may not have been the result of tampering (for example, missing air pump belts). Overall, 282 (92%) failed the inspection even though all had valid registrations. Thus, less than 8% of the vehicles identified as gross polluters by remote sensing passed an immediate roadside test. When random pullover studies were carried out by the California Bureau of Automotive Repair and the California Air Resources Board, approximately 60% of the vehicles passed the roadside test, whether or not they were registered in a region of California with a scheduled IM program (*13*). Of the vehicles inspected in the present study, 76 were recruited for an immediate IM240 test (a loaded-mode dynamometer test) and their emissions were compared with EPA-recommended pass-fail values. All but three vehicles failed the IM240 test, and these three had already failed the roadside Smog Check (*14*). These data show that vehicles identified as gross polluters by the remote sensors were poorly maintained or had been tampered with (the majority apparently illegally); they were not a subset of normally maintained vehicles that were temporarily emitting more pollutants because their engines were cold or they were accelerating hard (*11*). If we could have inspected all 3271 gross polluters identified by the remote sensors, we estimate that only 266 of the 58,063 vehicles (0.5%) would have passed the roadside inspection.

This study indicates that the large difference between the majority of cars and the few gross polluters (the front-to-back difference in Fig. 1) is caused by poor maintenance or tampering. The smaller depen-

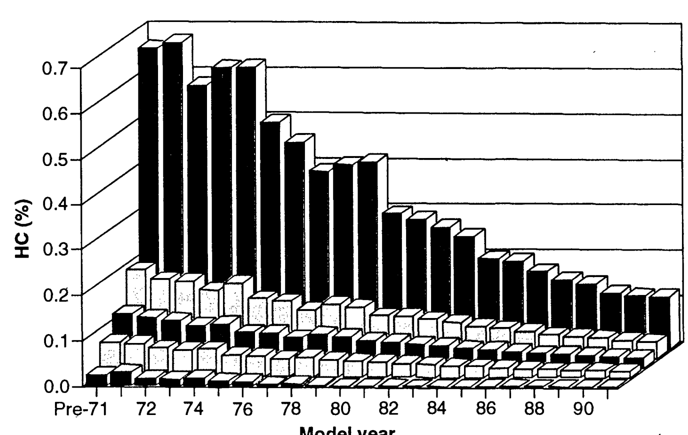

Fig. 1. Average HC exhaust emissions of the vehicles measured in California, reported as the HC percentage equivalent to propane and corrected for water and any excess air present in the exhaust. The emissions for each model year were sorted and divided into five groups (quintiles). The average emissions of the five quintiles for each model year are plotted from front to back, lowest to highest. Pre-71 includes all 1970 and older vehicles.

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dence of average emissions on vehicle age may be the combined result of deterioration, older technology, and poorer maintenance of older vehicles.

Implications for Emission Control Policy and Cost Effectiveness

On-road emissions must be controlled to reduce ambient pollutants. The skewed distributions shown in Fig. 1 imply that policies that treat all vehicles equally, or that target new vehicles, are likely to be less cost-effective than those that recognize the overriding importance of maintenance and that target poorly maintained vehicles regardless of their age. We used the California data to estimate the cost effectiveness of several proposed or hypothetical programs. Our only assumption in the cost analysis was that the data in Fig. 1 adequately represent all of California.

Tighter new car emission standards exemplify a national policy that attempts to achieve benefits by further reducing the already low emissions of new vehicles, at a cost of approximately $2 billion annually (*2*). It is plausible, based on reasonable assumptions regarding price increases and demand elasticity (neither of which are included in the EPA model), that such a policy could actually lead to increased on-road emissions (*15*).

Transportation control measures such as mandated employee car pools exemplify a policy that treats all vehicles as equal. These measures are modeled by the EPA as removing an average car from daily use. The actual improvement will be lower, because a car used for commuting is usually the best maintained car available to the driver (*16*). If the removed vehicle resembles the median rather than the average, then the actual CO and HC reductions are one-quarter and one-half of the EPA-predicted reductions, respectively (*8*).

Alternative and reformulated fuel programs also treat all vehicles equally, regardless of their state of repair. The estimated costs and pollution reduction benefits of California's reformulated fuel program (*17*) are shown in Table 1. By comparison, EPA data from a fleet of 84 vehicles testing various fuel formulations (*18*) indicate that if a single gross polluter (a 1984 Nissan Sentra) is repaired so that it matches the average emissions of the three other 1984 Nissan Sentras in this fleet, the resulting reduction in HC and CO emissions is more than can be obtained by fuel alterations to all 84 vehicles combined.

Scrappage programs operate on the assumption that older vehicles are more likely to be gross polluters. The industries that buy and scrap these older vehicles are typically in need of pollutant emission credits, and their participation in these programs may be supported by taxpayer dollars. The vehicle scrapped may have received little or no use, and the emission status of its replacement is unknown. In the EPA model, a newer replacement vehicle—even if it is just 1 year newer—is always considered to produce lower emissions than the older vehicle. The data in Fig. 1 show that this often may not be the case. Only if the older vehicle was a gross polluter for its model year is the replacement vehicle likely to be a low emitter. For instance, in the most recent Unocal program (*19*), a 1977 Toyota was scrapped that met the 1993 new car standards for exhaust emissions.

Scrapping all vehicles older than 1980 and replacing them with vehicles whose average age and emissions match those of the newer remainder of the fleet would cost $2.2 billion. We calculate that the benefits of this action would be a 33% reduction in HC emissions and a 42% reduction in CO emissions. Stated another way, this is a 15% reduction in total HC emissions and a 19% reduction in total CO emissions per billion dollars spent. If all vehicles older than 1988 were scrapped and replaced in the same way—an extreme measure (*20*)—the result would be a 44% reduction in HC emissions and a 67% reduction in CO emissions at a cost of $17 billion. If IM programs controlled emissions as intended (*13*), scrappage programs would be less cost-effective than estimated here, because the emissions of older vehicles would not be as high.

In a targeted repair program, the worst 20% of all vehicles from each model year (the back row in Fig. 1) would be repaired to achieve the average emissions of the remaining 80% of the same model year. This action would result in a 50% reduction in HC emissions and a 61% reduction in CO emissions. Scrappage programs pay $700 to $1000 per vehicle, whereas the repairs necessary to move a gross polluter to the lower emission categories average around $200 (*21*). The result is a 57% reduction in HC emissions and a 69% reduction in CO emissions per billion dollars spent. The full cost of this identification and repair program could be raised over a 4-year period by means of an annual $11 fee per vehicle (*22*). Because the pullover study showed that about half of the gross polluters had been illegally tampered with, the cost of the program would be cut in half if the owners of these vehicles were required to pay for their own repairs. Even if repair costs were as high as $400 per vehicle, the targeted, subsidized repair program is still estimated to be the most cost-effective option.

Table 1. Estimated costs and benefits of various mobile-source HC and CO emission reduction strategies as applied to the California fleet measured in 1991.

Action	Millions of vehicles affected	Percent reduction		Estimated cost (billions of dollars)*	Percent reduction per billion dollars spent	
		HC	CO		HC	CO
Switch to reformulated fuels*	20 (100%)	17	11	1.5	11	7.3
Scrap pre-1980 vehicles	3.2 (16%)	33	42	2.2	15	19
Scrap pre-1988 vehicles	14.6 (73%)	44	67	17	2.6	3.9
Repair worst 20% of vehicles	4 (20%)	50	61	0.88	57	69
Repair worst 40% of vehicles	8 (40%)	68	83	1.76	39	47

*Reformulated fuels were estimated to cost consumers an extra $0.15 per gallon, or $75 per year for a 20-mpg car driven 10,000 miles per year. Scrappage costs per vehicle were conservatively estimated at $700 for pre-1980 cars and $1000 to $2000 for cars built from 1980 to 1988. Average repair costs were estimated at $200 per vehicle.

Conclusion

Vehicle exhaust emission measurements show that most vehicles, when properly maintained, are relatively small contributors to exhaust pollution in comparison to poorly maintained vehicles. Although poor maintenance correlates with increasing vehicle age, different states of maintenance among vehicles of a given model year far outweigh the average effect of age. Because of this factor, regulatory policies based on a computer model that targets all vehicles equally, without recognizing the overriding importance of individual maintenance, may not be cost-effective or may be ineffective.

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7. The remote sensor takes a 0.5-s snapshot of the infrared absorption of CO_2, CO, and HC in the exhaust gases behind a moving vehicle to determine the percent of these gases in the undiluted exhaust. A video camera records each license plate number so that the make and model year can be determined through state motor vehicle records [G. A. Bishop, J. R. Starkey, A. Ihlenfeldt, W. J. Williams, D. H. Stedman, *Anal. Chem.* **61**, 671A (1989); L. L. Ashbaugh *et al.*, in (*23*), pp. 885–898; D. R. Lawson, P. J. Groblicki, D. H. Stedman, G. A. Bishop, P. L. Guenther, *J. Air Waste Manage. Assoc.* **40**, 1096 (1990)].
8. D. H. Stedman *et al.*, "On-Road Remote Sensing of CO and HC Emissions in California" (Final Report, Contract A032-093, California Air Resources Board Research Division, February 1994).
9. Diesel-powered vehicles with ground-level exhaust systems were also measured by the remote sensor; they are always low emitters of CO and HC because the diesel combustion process occurs in the presence of excess air. We pulled over several gross polluters that were registered as diesel-powered (and thus exempt from the IM program) but were actually gasoline-powered and lacked any of the required emission controls. Heavy-duty diesel vehicles with elevated exhaust systems were not measured.
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15. Increased vehicle prices may lead to decreased new car purchases, which may lead in turn to an older fleet. On average, older fleets produce higher emissions. Chrysler Corporation has stated that it will impose a surcharge that could exceed $2000 on all its new vehicles sold in California in 1998; the surcharge would allow Chrysler to offer a $45,000 electric minivan for around $18,000 so that Chrysler could sell enough of them to satisfy state laws ("Chrysler Electric Surcharge," *Rocky Mountain News*, 1 October 1994. p. 63A). Even electric vehicles, whose tailpipe emissions are zero, require electric power generation and have expensive batteries that require eventual replacement. Electric vehicle owners who continue to drive with weak batteries will cause traffic congestion, leading to an increase in the per mile emissions of the gasoline-powered vehicles in the fleet. This possibility is not considered in any model of future emissions from fleets containing realistically maintained electric vehicles.
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17. California Environmental Protection Agency, "Air Resources Board Staff Report, Proposed Amendments to the California Phase 2 Reformulated Gasoline Regulations, Including Amendments Providing for the Use of a Predictive Model" (22 April 1994).
18. OXY_EF_2 data provided by the Mobile Source Division, U.S. Environmental Protection Agency, Ann Arbor, MI.
19. "SCRAP, a Clean Air Initiative from UNOCAL" (Unocal Co., 1991); "SCRAP2" (Report to South Coast Air Quality Management District, 1994).
20. This is a conservative estimate. We assume that all pre-1980 vehicles can be purchased for only $700 each, the next 8 million newer vehicles for $1000 each, and the newest 3.4 million vehicles for $2000 each.
21. G. A. Bishop, D. H. Stedman, J. E. Peterson, T. J. Hosick, P. L. Guenther, *J. Air Waste Manage. Assoc.* **42**, 2 (1993).
22. The cost of on-road monitoring is assumed to be $20 per gross polluter identified, on the basis of a cost of $0.50 per remote sensing test and a two-test identification requirement. Economies of scale may bring testing costs down to $0.16 per test when only gross polluters need to be identified [W. Harrington and V. D. McConnell, in *Cost Effective Control of Urban Smog* (Federal Reserve Bank of Chicago, November 1993), pp. 53–75].
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Environmental Implications of Electric Cars

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California and the Northeast states have passed laws requiring that 2% of model year 1998 cars must be "zero emissions" vehicles—that is, electric cars (*1*). Required sales of electric cars are to increase after 1998. Electric vehicle technology has the advantage that it produces no air pollution at the point of use, so that if the electricity is generated in a distant place, electric cars are a means of switching the location of environmental discharges. A large crowded city such as Los Angeles or New York has large amounts of discharges, even if care is taken to protect the environment, because the millions of gasoline-powered vehicles in such cities emit large quantities of carbon monoxide, nitrogen oxides, and volatile organic compounds. Electric vehicle technology can move emissions to less crowded and less polluted locations. Centralized electric generation plants may also be able to achieve fewer emissions per vehicle mile than do internal combustion engines in vehicles (*2*).

The environmental effects of internal combustion engines are well known. Pollution controls have lowered emissions from a controlled car by 98% as compared with those from an uncontrolled car. For electric vehicles, generating electricity for recharging batteries can cause considerable environmental harm (*3*). Analyses have been done on the environmental effects of gasoline as compared with those of electricity generation (*2*). In response to the electric vehicle mandate, automakers have proposed ultralow emissions vehicles.

We focus on the environmental consequences of producing and reprocessing large quantities of batteries to power electric cars. For vehicles that are to be mass produced in late 1997, lead-acid batteries are likely to be the only practical technology. Smelting and recycling the lead for these batteries will result in substantial releases of lead to the environment. Lead is a neurotoxin, causing reduced cognitive function and behavioral problems, even at low levels in the blood (*4*). Environmental discharges of lead are a major concern. For example, eliminating tetraethyl lead (TEL) from U.S. gasoline greatly reduced blood-lead levels in children (*5*).

Alternative battery technologies that are currently available include nickel-cadmium and nickel metal hydride batteries, which are much more expensive than lead-acid batteries. In addition, nickel and cadmium are highly toxic to humans and the environment. Technologies such as sodium-sulfur and lithium-polymer batteries are unlikely to be commercially available for years.

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