1995

Playing with Fire, Science and Politics of Air Pollution from Cars

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UNIVERSITY OF DENVER

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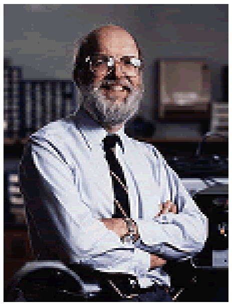
Playing with Fire

Science and Politics of Air Pollution from Cars



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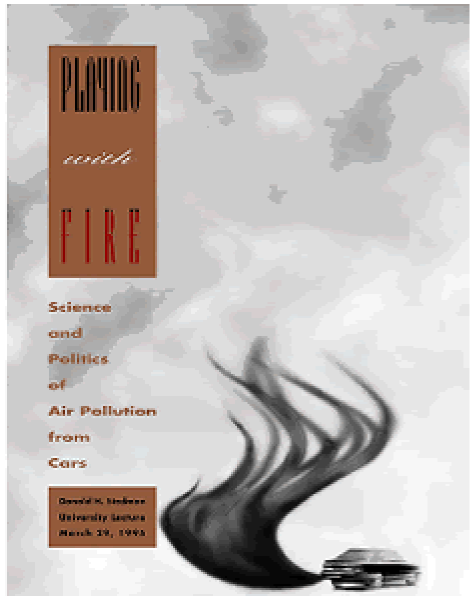
"To our surprise, our data, Federal Test Data, indeed all the data we could find showed half the pollution from less than 10% of the vehicles. These vehicles we call gross polluters."



The back page shows the individuals and agencies whose financial support has been vital. Academic support from my mentors, Dr. Michael Clyne and Dr. Donald Setser, laid the groundwork. Research support from students and staff has been essential: They do the work, and I get to talk about it. Above all, my wife, Hazel, supports me.

Science

Pollutants found in car exhaust are formed in a number of different ways, depending on the pollutant. Consider a flame from a candle, a not-too-hot blowtorch, or a Bunsen burner. A fly screen or wire gauze lowered into the flame extinguishes it above the gauze even though fuel and air are present. Taking the heat away puts the flame out. In the same way, the cold walls of the cylinder in a car engine extinguish the flame in a layer (the quench layer) within a millimeter or so of the walls. The rising piston scrapes this layer of unburned air/fuel mixture off the walls. For this reason, a car without a catalytic convertor is bound to emit some unburned fuel in its exhaust.

Carbon monoxide formation depends on chemistry. Fuel can be regarded as containing about two hydrogens for every carbon (CH2). This crude approximation obscures all the fascinating chemistry of real fuels just as the formula CH2O for a tree or a human being obscures a good deal of biology and individuality. However, CH2O is adequate to operate a wood stove or a crematorium, thus we will use CH2 for "fuel." Air is approximately one oxygen and four nitrogens, thus O2 + 4N2. The majority of exhaust is therefore nitrogen, and the chemistry of a properly operating (stoichiometric) car is as follows:

$$CH_2 + 1.5(O_2 + 4N_2) \rightarrow CO_2 + H_2O + 6N_2$$

If the water is not counted, one seventh of the exhaust, 14%, is carbon dioxide (CO2), the rest nitrogen. Modern cars have an oxygen sensor and computer system that, when hot, carefully measure a small excess of oxygen in the exhaust and meter the fuel so as to maintain close to exact stoichiometry. The extra hydrocarbon caused by the cold walls is burned on the catalyst by the small excess of oxygen.

When a vehicle is operating exactly at stoichiometry, the chemical equation stated previously can be used to calculate the pounds of air used to burn a pound of fuel. The result of this calculation is 14.7. Thus, when you fill your car up with 50 pounds (about eight gallons) of gasoline, this enables your car to process almost 750 pounds of air. Imagine how sluggish your car would be if it had to carry those 750 pounds of air. Electric cars have to carry around all the energy it takes for their propulsion. That is why electric cars have such a short range.

If the car's computer and oxygen sensor system are not working, then either there is too much air (fuel lean), or too little (fuel rich). Lean mixtures often cause misfiring, hesitation, "coughing," and thus poor fuel economy and poor performance. Rich mixtures allow cars to perform well except for loss of fuel economy and higher emissions. Vehicles that break are often programmed to go intentionally to rich mixtures. Suppose somehow 33% less air gets to the engine. The 1.5 (O2+4N2) becomes just (O2+4N2). The combustion equation then becomes the following:

$$CH_2 + O_2 + 4N_2 \rightarrow CO + H_2O + 4N_2$$

All the carbon dioxide has gone and has been replaced by 20% carbon monoxide (CO). Most cars cannot run that rich, but notice how a relatively small deficit in air (or excess of fuel) leads to a 100% increase in CO. Even 10% CO is enough to kill someone breathing it in a few minutes.

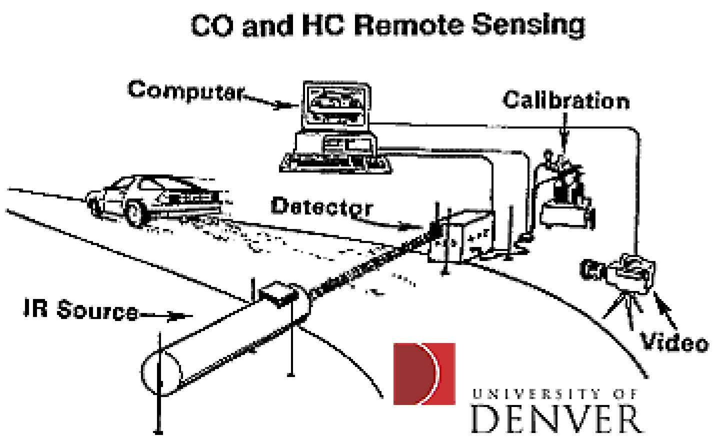
The other automobile generated pollutant, nitric oxide (NO) contributes to smog/ozone when mixed with hydrocarbons and subjected to sunlight. NO is formed mostly under heavy load, when the engine is running a little lean and when the catalyst and other NO control measures are not operating.

Smoke (usually white) behind a gasoline powered vehicle is not normally caused by air/fuel mixture chemistry, but rather by crank case oil leaking past valve stems or piston rings and being blown out of the exhaust.

Diesel powered vehicles, when properly tuned, emit very low CO and HC because they operate at high temperatures with a lot of excess air. Nitrogen oxide emissions are therefore often elevated. When more than the normal amount of fuel is injected into a diesel engine, power output increases, but black soot smoke (probably carcinogenic) is emitted.

Automobile manufacturers have known all these things for a long time. We have had to learn them relatively recently. Thankfully, books such as John Heywood's Internal Combustion Engine Fundamentals are a great source of information. We have had to learn this material because we invented a device (Stedman and Bishop, "Apparatus for Remote Analysis of Vehicle Emissions," U.S. Patent No. 5,210,702, May 11,1993) that measures the exhaust emissions from each car as it passes by using remote sensing. Figure 1 shows a diagram of the system. The video camera takes a picture of the rear of each passing vehicle, from which the license plate can be identified.

Technologically, the remote sensor is not different from a conventional tailpipe emission test. In a conventional test, the exhaust is pumped from the tailpipe into an instrument. A source of Infra-red (IR) light shines through an optical cell in the instrument. At the other end of the cell, detectors measure the



absorption of the IR and thus determine the pollutant concentrations. Effectively, we have taken a hack saw to the box, placed the IR light on one side of the road, the detector on the other, and allowed the car to drive through. The system has been tested since 1987 and at speeds between 2 and 152 miles per hour. In 1991 in California, the CO readings were found independently to be within 95% of correct, while the HC were within 85% (Lawson and Gunderson, 1991 Report to California I/M Review Committee).

We measured passing cars on southbound Rosemead Boulevard in El Monte, Calif., in a roadside pull-over program. When we identified an apparent gross polluter, we radioed ahead for a California Highway Patrol officer to pull it over for a roadside Smog-Check test. Two teams of testers were used. The USEPA also had a portable dynamometer (treadmill) set up for a test called IM240 (now familiar to Coloradans) in the roadside park. In 10 days, the remote sensor was able to take 60,487 emission readings from 58,063 vehicles. Two SMog-Check teams were able to measure 340 while one IM240 system measured only 80. Although we are not professional economists, it seems to us that there must be some cost/benefit implications when a single remote sensor can measure tailpipe emission from 58,063 vehicles, without inconveniencing the drivers, during the same time period that two teams can do 307 traditional inspections and EPA can carry out 80 of their new test.

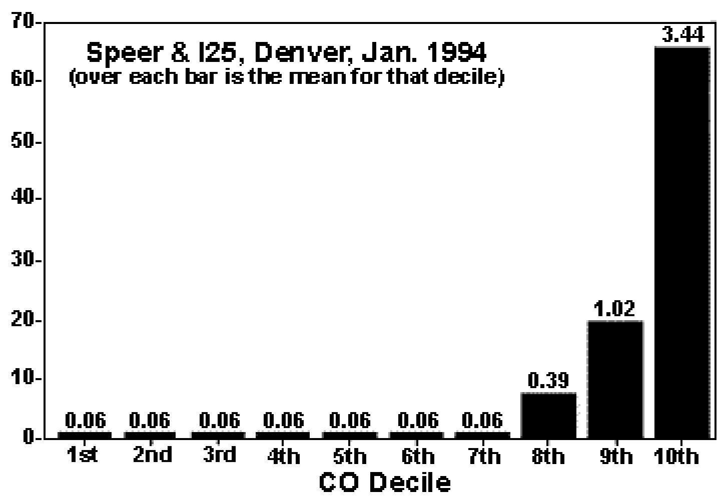


Figure 2. Each of the ten bars has a height that matches the average CO emissions of 10% of the cars in Denver.

In Colorado, the entire $40 million Envirotest testing facility, 15 stations with 54 lanes, measures 4,000 vehicles per day (Rocky Mountain News, March, 1995). A single remote sensor can measure more!

With so many cars easily measured, we started to look into the statistics. To our surprise, our data, Federal Test Data, indeed all the data we could find showed half the pollution from less than 10% of the vehicles. These vehicles we call gross polluters. Figure 2 shows 10 bars whose height matches the average CO emissions of 10% of the cars in Denver. Notice how much higher emitting are the gross polluters than the majority of the cars. Very few new cars are gross polluters (about 2% of two-year-old cars), but even among the oldest cars (1974 and older, all without catalysts) the majority (60%) are not gross polluters.

When a distribution this skewed is observed, it is easy to justify an air pollution program that identifies the gross polluters and targets them for treatment. It is correspondingly hard to justify programs that treat all cars as equal (oxygenated fuels, periodic mandatory emission testing, ride-sharing, etc.)

In 1989, we added a video camera that takes pictures of the rear of the vehicle for license plate information. From the license plate, we can obtain the vehicle make and model year. By now, we have measured more than two million vehicles in 20 countries.

Results from three countries are shown in Figure 3. The filled squares are data from 1991 in Los Angeles. New vehicles have low average emissions. As the vehicles get older, the average emissions increase. Notice that there is no discernable break in 1974 or 1980 when new technologies (catalysts, 1974; closed-loop computer systems, 1980) were introduced. The line close to the L.A. data was obtained in 1991 in Sweden. Sweden introduced catalysts 50% in 1987 and 100% in 1988. The break is clearly discernable, and Swedish catalyst-equipped cars have lower average emissions (by half) than similarly equipped vehicles in Los Angeles. There are a number of social/personal reasons to expect better car maintenance in Sweden. Not the least of which, my Swedish friends assure me, is that there is no word in Swedish for "tampering" with your emission control equipment.

If, as we believe, good maintenance is even more important than catalysts, then as L.A. cars age, one might expect to see the (apparently badly maintained) catalyst-equipped cars in L.A. having higher emissions than non-catalyst cars in Sweden. This effect is observed in the 1975-81 model years. Contrasting with the lower two lines is the upper line of data from the United Kingdom. The U.K. introduced catalysts in 1990, but it is apparent that my home country suffers from a fatal combination of both poor technology and poor maintenance.

In fact, we have seen few places worse than the U.K. Mexico City and Kathmandhu are two; however, in Mexico City they are trying to do something about their problem. One of the most elegant results of remote sensing programs to date shows the Mexico City success. Figure 4 shows as "91" symbols data from 1991 and as "94" data from the same locations in 1994. The emissions reductions are readily apparent. We believe that the major cause is the introduction of closed-loop catalyst systems on the (mostly VW Beetle) taxi cab fleet.

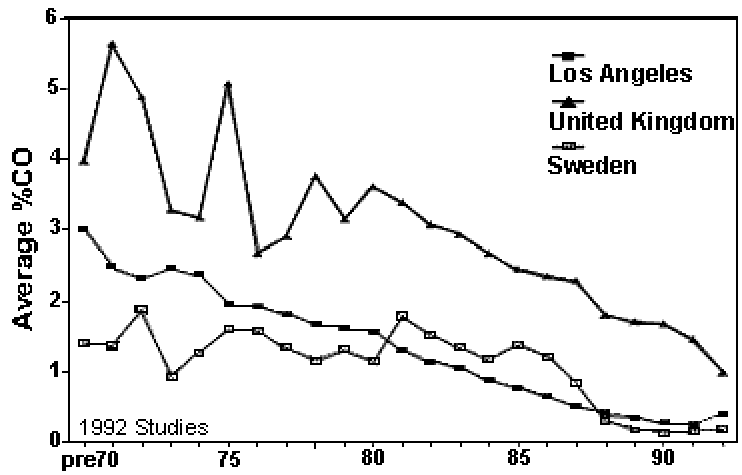


Figure 3. This graph represents carbon monoxide emissions versus model year, with results from three countries: filled squares, Los Angeles, Calif., U.S.A.; open squares, Gothenberg, Sweden; filled triangles, various locations in the U.K.

Despite these research results, there remain critics who believe that our results are random (Pittsburgh Tribune Review, May 15, 1995). This is hard to believe since we routinely show new cars averaging lower emissions than old cars. The video camera and license plate data are independent of the emissions data, thus these results could not be obtained with a random detector.

So far, I have shown carbon monoxide data with older cars (on average) higher emitters than new cars. This result is observed everywhere and is independent of speed/load. The same age effects are observed for HC ("On-Road Carbon Monoxide and Hydrocarbon Remote Sensing in the Chicago Area in 1992," (ILENR/RE-AQ-91/15 and "On-Road Hydrocarbon Remote Sensing in the Denver Area," Zhang et al., Env. Sci. Tech, vol. 27, 1885-91, 1993), and NO ("Enhancement of Remote Sensing for Mobile Source Nitric Oxide," Zhang, et al, J.Air, Waste Mgmt. Assoc, 1995), but in both cases, the averages depend on vehicle speed and load.

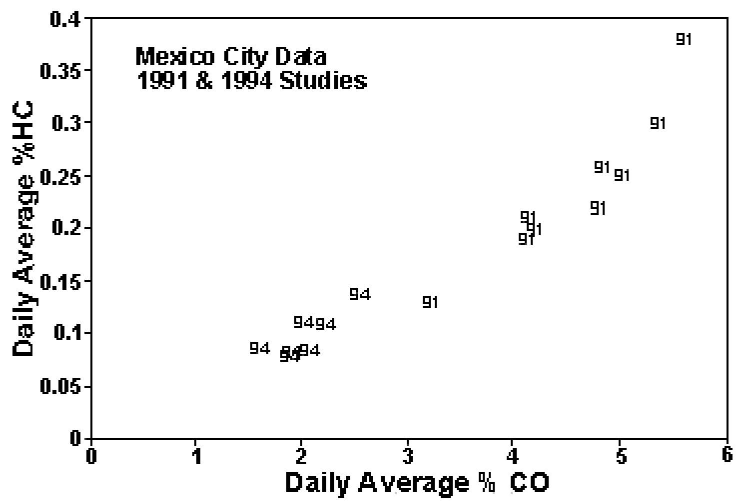
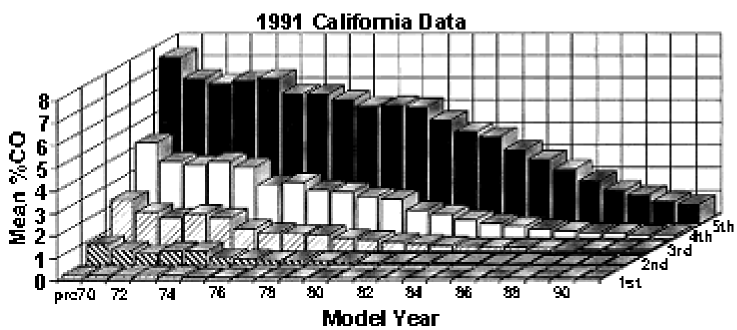
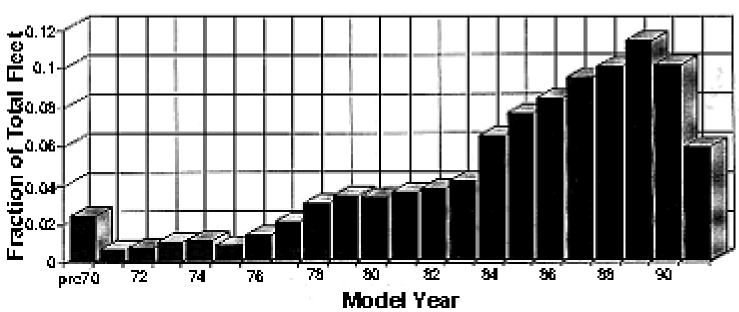


Figure 4. In this graph, "91" symbols show 1991 HC versus CO data from several sites in Mexico City, and "94" symbols show data mostly from the same sites in 1994. The letter D shows the current Denver average.

In all cases, the average readings tend to obscure as much as they illuminate. When we use our large on-road data bases to divide up each model year into five groups (quintiles) from lowest to highest emitting, a more startling result appears. The observed effect of increasing average age on increasing average emissions is overshadowed by the dramatic differences between well and badly maintained cars in a given model year. Thus, 20% of the early 1970's cars have lower emissions than the broken 1990's cars.

These results are illustrated for CO and HC in Figures 5 and 6. We believe these graphs can be used to show that a number of programs currently proposed or underway are not cost effective. These programs include alternative and reformulated fuels (which treat all cars as equal); scrappage programs that treat all old cars as gross polluters (which they are in the EPA computer model, but are not in reality); tighter new car standards that attempt to lower the already negligible emissions of well maintained new vehicles; and scheduled emission testing programs that also inconvenience all drivers in an attempt to influence the behavior of a few. Most of these points are amplified more quantitatively in the Policy Review section of the journal Science, May 19, 1995.





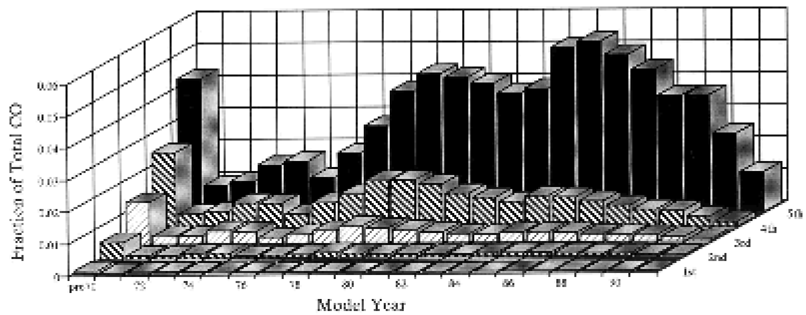
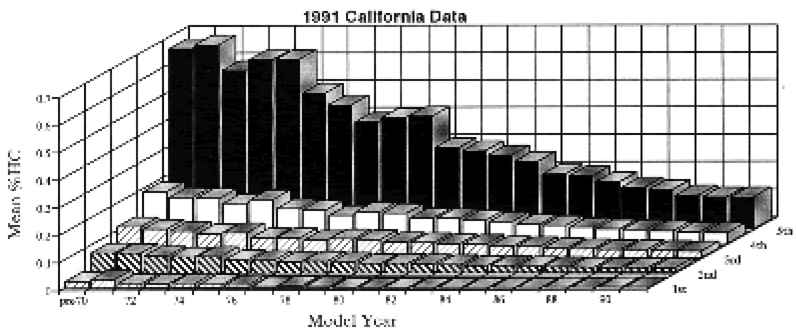
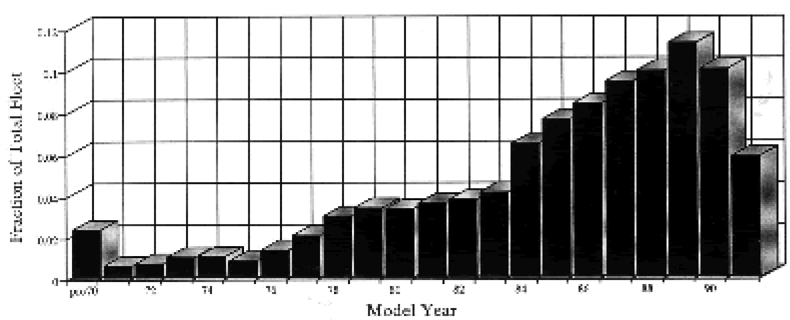


Figure 5. These graphs represent California data for CO from more than 50,000 vehicles presented as (top) emissions factors by model year divided into quintiles, (middle) fleet distribution by model year, and (bottom) the product of the top and middle graphs showing the on-road contributions from each vehicle group.





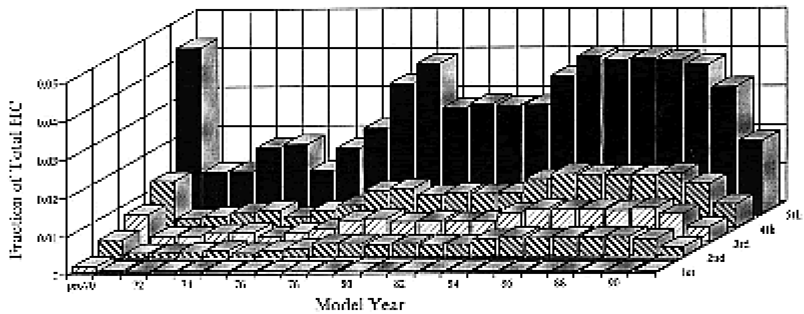


Figure 6. These graphs are the same as Figure 5, but for HC as propane.

Politics

Politics and business have been important in the development of this system. The business dealings have been both complex and confusing. I am often asked, "Why is your instrument owned by Envirotest?" The slightly flippant answer is, "If you saw a product that could put your main product line out of business, wouldn't you want to own it?" One day I hope to convince them that they can make more profit per dollar invested by selling twenty-five cent tests at 1000 per hour, than twenty-five dollar tests at 10 per hour. A more complex answer goes into the details of how we got where we are.

The steps by which the DU technology became owned by Envirotest were quite complex. The original license agreement was with a consortium: Sun Electric in Chicago, which makes garage analyzers for exhaust gases, and Systems Control of Sunnyvale, Calif., which carries out centralized testing. These two corporations already had formed a consortium, namely Vehicle Testing Technology Inc. (VTTI), which ran the emission testing program in Seattle. Within a few years, Systems Control was sold to ETC and in turn to Hamilton Test/Enviro-test, and Sun Electric was sold to Snap-On Tools. This could have been a stable situation, but VTTI was left 100% with

Sun/Snap-On to avoid monopolistic restraint of trade in the centralized I/M (emissions inspection and maintainence) business. Thus, when major programs for centralized testing were up for bid, VTTI and Envirotest were bidding against each other. Next thing you know, there is a lawsuit, and, as part of the out-of-court settlement, 100% of the remote sensing consortium goes to Envirotest.

The politics have been just as curious as the business aspects. In 1989-90, we measured vehicle CO emissions close to the El Paso-Teller County Boundary. These measurements were intended to justify a proposed state law (subsequently enacted) requiring vehicles that commute into an I/M area to have an emission sticker. The measurements actually showed almost no difference between the emissions of vehicles with El Paso and Teller registrations.

This result (now repeated at many other locations) shocked the local establishment. The headline "State Pooh-Pooh's Auto Emissions Study" (Rocky Mountain News, Jan. 27, 1989) summarizes the reaction of the Colorado Department of Health. This reaction has been repeated many times by agencies whose cherished (and revenue producing) emission test programs have been found to be failures. The most recent example is from Minnesota.

Huel Scherrer and David Kittleson of the University of Minnesota studied the air quality before and after the imposition of a centralized emission testing program in Minnesota. The results (published as SAE 940302) showed no detectable change in the steady decline of emissions as newer cars entered the fleet. In their March 23, 1995, testimony to the U.S. Congress they said, "If we want to maintain public support for programs that claim to reduce air pollution, those programs must do what they claim in the real world, not just the virtual world of the (EPA) computer model."

The political situation was further complicated when I wrote an op-ed in the Wall Street Journal in the fall of 1990, which pointed out that EPA's own data showed that fuel oxygenation made no sense compared to the repair of broken cars. I strongly recommend this method of publication. The article was submitted on a Monday, accepted by Wednesday, rewritten and all the numbers and references checked by their excellent editorial staff on Friday, published the following Monday, and I got paid! The scientific journals in which our studies are normally published do not meet any of those criteria.

This article, which included the fact that we could identify those vehicles needing repair without inconveniencing the owners of the others, was read by Texas Congressman Joseph Barton (R-Ennis, Texas, one of a handful who never bounced a check). As a member of the House Commerce and Environment Committee, he introduced an amendment to the 1990 Clean Air Act Amendments that included the phrase "... including on-road emission monitors" at two locations where mandatory emission testing was legislated. These eight words in a 750 page act apparently did not please the USEPA, which tried to remove them with a felt pen as a technical amendment (as if they were a misprint). They were caught by the congressman's aide's girlfriend.

After the act was signed into law (President Bush, Nov. 1990), the EPA decided to removed the words by "interpretation." Interpretation proceeded in two steps. In the first step, on-road monitoring was defined as roadside pull-overs and tailpipe tests, or remote sensing, or on-board emission monitors on the passenger seat and plugged into the tailpipe, or any other "on-road" program the states could devise, and in any case they would get no credit from the EPA computer model.

For those of you who have not read the Clean Air Act in detail (which I recommend to no one) you may not realize that it does not require states to clean the air, rather it requires them to propose a program that satisfies the EPA computer model that it will clean the air by sometime in the future. If a state wants to carry out a program that is not in the model, then they get no credit from the model so they might as well not do it. An example that may have been rectified by now is auto mechanic training. All the evidence points to the fact that repairs are the Achilles' heel of I/M programs, yet states that tried to better train their mechanics got no emissions credit because such credits were not in the model.

The second step in the interpretation comes in the EPA I/M rulemaking (about 150 pages of which were generated from about 15 pages of the Clean Air Act). In this rulemaking, it was spelled out that on-road monitoring must be used on 0.5% of the eligible vehicles, or 20,000, whichever is the least, and still no credit was available. For obvious reasons, most states have yet to do any of this "required" on-road monitoring. When asked at a public hearing why only 0.5% (which could easily be done for the whole U.S.A. by one mobile remote sensor!) was the required number, the EPA representative replied that any more than 0.5% would be too expensive for the pull-over or on-board programs and since EPA did not want to force a narrow, remote-sensing-only interpretation of the act, 0.5 was the number-a clever interpretation since the Congress itself clearly intended remote sensing to be used since, on the day the amendment was voted on, we were demonstrating the remote sensing system on the driveway outside their hearing rooms. That program identified a Washington taxi that emitted more than its own weight of pollution per year. An Exxon master mechanic hired the vehicle for the rest of the day and fixed its problems for $450. A journalist for Wards Automotive Report once asked at the EPA Mobile Source Division in Ann Arbor why they were so opposed to remote sensing and was amazed that the reply was "because the inventor would become rich." The same office wrote to a Louisiana senator that the USEPA could not support a patented device. The EPA's own rules for hazardous site investigation contain requirements for the use of several patented devices.

These problems were certainly brought on myself by a certain lack of tact. I have pointed out that not only does the emperor have no clothes, but also his tailor has several thousand employees. The EPA Office of Mobile Sources in Ann Arbor writes the air pollution rules, enforces the rules, evaluates how well the rules are working, and writes the computer model that predicts how well the rules will work in the future. This situation is just as much a conflict of interest as if I were asked to evaluate the ability of my own students in chemistry every year, without any external checks. If an optimistic error of only three percent is made each year for 20 years, then predictions are off by a factor of more than two. That is about how wrong the then-current version of the EPA model was found to be when compared independently to urban on-road motor vehicle emissions (W.R. Pierson, A.W. Gertler, and R.L. Bradow, J., Air Waste Manage. Assoc., 40, 1495, 1990).

This remote sensor of car emissions is about my fifth invention. The others have taken off all on their own and are widely used in the small fields where they are important. Eight years later we are still promoting remote sensing as an emission test. Why has it taken so long? The amazingly large investments of human and dollar capital in the status quo are partly to blame. In 1990, the state of California obtained data that showed their emission test program was without detectable effect on emissions of cars. My data showed the same thing, but I was regarded by then as a reasonably harmless heretic. Their data was withheld from their oversight committee for two years until they could decide what to do with it. The California emission testing program costs about $450 million per year and uses 21,000 employees in 9,000 emission texting stations. When something like that does not work, you can not just shut it off. Too many operators', bureaucrats', and consultants' employment income depend on the revenue therefrom.

Ontario, Canada, is experimenting with a remote sensor to screen out the low-emitting vehicles and send them home without having to stop at the test center. Sydney, Australia, has a system and some new ideas how to use it. The state of California's new program will probably use a considerable amount of remote sensing, but is constrained by EPA on one side, which wants as much centralized treadmill testing as possible, and the 21,000 employees of the current system, who want to keep their jobs despite the evidence of their lack of success.

Meanwhile we are still trying new things. We have a proposal pending to measure smoke emissions from trucks crossing between the Mexico-California border. We have a program underway to place an emissions information billboard (the politically correct term is "variable message sign") at the Speer Boulevard-I-25 interchange ramp, and we are still measuring DU employee vehicles and doing a small repair program to show that we can obtain 20 to 50 times more CO emissions reductions that way than by converting janitors' trucks to natural gas fuels. If we identify your car, please participate. The program is both convenient and free.

As my last illustration for this lecture, I thought that I should show that beliefs based on little or no scientific evidence are not the sole perquisite of government bureaucrats in distant places. As illustration, I set on the screen two quotations, the first from Carol Browner of the USEPA, the second from the DU Core Curriculum Committee. They are reproduced below:

> Carol M. Browner, Administrator, USEPA, to Jim Folsom, Governor of Alabama, Dec. 24, 1994. "We continue to believe that an enhanced test-only program using high-technology testing equipment is one of the most cost-effective ways for states to improve air quality."

> Core Curriculum Committee, University of Denver, Oct. 14, 1994. "We believe that integrated learning, an important aspect of critical thinking, is a habit of mind that needs to be addressed directly throughout the undergraduate curriculum."

The best compliment I heard as I left the room was that the last slide alone was worth the price of admission.

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