Final Report

PERFORMANCE AUDIT OF THE COLORADO AUTOMOBILE INSPECTION AND READJUSTMENT (AIR) PROGRAM

Prepared for

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The purpose of this performance audit is to review the Colorado Automobile Inspection and Readjustment (AIR) Program as required by Section 42-4-316, Colorado Revised Statutes (C.R.S.). According to statute, this audit must be completed by January 1, 2004 and should address the following:

> In such audits, the determination as to whether an ongoing public need for the program has been demonstrated shall take into consideration the following factors, among others:
>
> (I) The demonstrable effect on ambient air quality of the program;
> (II) The cost to the public of the program;
> (III) The cost-effectiveness of the program relative to other air pollution control programs;
> (IV) The need, if any, for further reduction of air pollution caused by mobile sources to attain or maintain compliance with national ambient air quality standards;
> (V) The application of the program to assure compliance with legally required warranties covering air pollution control equipment.

This report provides an evaluation of the benefits and costs of the AIR Program, discusses current and estimated future air quality and the need for the Program, and discusses potential modifications and alternatives to the current Program. This Executive Summary provides the main findings and recommendations from the audit. The main body of the report includes extensive discussions of the methods used and more detailed results.

DESCRIPTION OF THE AIR PROGRAM

Colorado has had a vehicle inspection and maintenance (I/M) program since 1980; the program was established to reduce vehicle emissions to meet National Ambient Air Quality Standards established by the U.S. Environmental Protection Agency (EPA). If a State fails to meet these standards it receives a “nonattainment” designation by the EPA and must develop emission control measures. The AIR Program currently operating in the Denver area began in 1995. In the AIR Program, exhaust emissions from automobiles and gasoline trucks are measured and vehicles with excessive emissions are required to be repaired. The Program is operated in the seven-county Denver metropolitan area and three other front range counties that include Colorado Springs, Ft. Collins, and Greeley. This audit report is limited to evaluation of the effectiveness of the Denver area enhanced program. In 2000, approximately 765,000 Denver area vehicles were inspected by the AIR Program. Of these, nine percent (68,000) failed the initial test. About 86 percent (59,000) of the failed vehicles returned and subsequently passed the test or received a waiver, and the remaining 14 percent (9,000) of the failed vehicles never passed.

The Colorado Department of Revenue and the Colorado Department of Public Health and Environment (CDPHE) contract with Environmental Systems Products, Inc., to perform the emissions inspections for all vehicles in the AIR Program at 15 centralized testing facilities located throughout the Denver metropolitan area. There are also independent testing stations in the Denver area that test 1981 and older vehicles. The inspection includes a test of vehicle tailpipe emissions, a visual inspection to determine if any original emissions controls have been tampered with or are missing, and, if applicable, a visual inspection of the "check engine light" on the dashboard. A vehicle must pass inspection in order to be registered with the State. The frequency of inspection depends on the age and type of vehicle. All new vehicles are exempt from the regular inspection during their first four years. Model year 1981 and older light-duty cars and trucks, as well as all heavy-duty gasoline trucks (those trucks in excess of 8500 lbs gross vehicle weight rating), are required to be tested every year, while 1982 and newer cars and trucks are subject to a biennial inspection. In addition to the regular annual or biennial inspection, every vehicle must also be inspected prior to its sale, or upon initial registration in Colorado, regardless of its age.

There are two types of inspection test procedures in the AIR Program – the IM240 test and the two-speed idle test. The IM240 test (referred to as the enhanced test) is given to 1982 and newer vehicles. In this test, vehicle emissions are measured on a dynamometer that simulates actual driving conditions; emissions (in grams per mile) of carbon monoxide, hydrocarbons, nitrogen oxides, and carbon dioxide are measured. The two-speed idle test is given to 1981 and older cars and trucks and all heavy trucks. It consists of putting the transmission in neutral or park and testing its emissions while the engine is idling and is operated at 2500 rpm; in this test hydrocarbon and carbon monoxide emissions are measured.

CDPHE's plans are to incorporate a remote sensing clean screen component into the AIR Program; develop a high emitter identification program; and re-focus the AIR Program to control hydrocarbon emissions more effectively. CDPHE has received approval from the EPA to implement a "Clean Screen" Program. The Clean Screen Program identifies vehicles using "remote sensing" units that measure tailpipe exhaust emissions as vehicles drive by sensors. A photo is taken of each vehicle's license plate so that owners of vehicles with low emissions can be notified of the opportunity to opt out of their next scheduled emissions inspection. Air Program convenience is improved for the motorists by reducing the number of vehicles required to go to an emissions test facility for inspection. CDPHE expects to have the remote sensing devices in place in the Denver metro area by late summer of 2003. The Denver Clean Screen Program builds on the Department's North Front Range Clean Screen Program experience.

Building on the framework of the Clean Screen Program, the Department is investigating the use of remote sensing to identify high emitting vehicles. CDPHE in partnership with the Regional Air Quality Council (RAQC) has started a pilot project, the "Repair Your Air Campaign." In this project, remote sensing devices are used to identify high emitting hydrocarbon vehicles. Two hundred-fifty high emitting hydrocarbon vehicles are expected to undergo repairs of up to $500 each. Funding for repairs is provided by a grant to the RAQC from the Colorado Department of Transportation Congestion Management Air Quality funds. Vehicles will undergo confirmatory emissions and diagnostics testing at CDPHE's technical facilities. The goal of this pilot project is to gain information that can be used to design a high emitter identification program on a larger scale; the ultimate goal is to reduce summer hydrocarbon emissions to reduce ozone. The Department is also in the initial stages of developing the Denver high emitting vehicle pilot program. This program will build on the

"Clean Your Air" project, and will be a continuing step in developing a high emitter program. It will identify the actions needed to move forward with an operational high emitter identification program.

COSTS OF THE AIR PROGRAM

Overall, we found that the AIR Program in the Denver area cost the State and the public about $44.4 million in the year 2000. This amount includes the following five types of costs:

- Administrative costs incurred by CDPHE and the Department of Revenue.
- Inspection costs incurred by Environmental Systems Products, Inc. (Note: We were unable to obtain information on revenues earned by ESP, Inc.).
- Repair costs (net of associated fuel savings) incurred by vehicle owners.
- Motorist time and convenience costs.
- Lost value to owners of vehicles that were scrapped or left the area because they failed the emissions inspection.

Table ES-1 shows a breakdown of the specific types of costs. As can be seen in the table, inspections and repairs represent the largest portion of these costs.

Table ES-1. Cost components of the AIR Program in year 2000.

Cost Component	Millions $
Administrative costs	**3.8**
Costs of Identifying and Repairing Vehicles	**33.5**
Inspection costs	17.6
Repair costs and fuel economy savings	10.4
Motorists' time and inconvenience	5.5
Costs from lost value of vehicles that leave the region	**7.0**
Total Costs	**44.4**

Source: ENVIRON's analysis of data provided by the CDPHE and Black Book data on the value of vehicles for the Denver area.

We also estimated the cost-effectiveness of the AIR Program, defined as the average cost per ton of emissions reduced. Overall, we found that it cost about $1,300 per ton of carbon monoxide reductions and $12,700 per ton of hydrocarbon reductions.

AIR QUALITY IN THE DENVER AREA

The EPA has established National Ambient Air Quality Standards to protect human health and the environment. Cars, trucks, power plants, factories, other combustion sources, solvents, wood burning stoves, and many other sources emit air pollution that can create unhealthy air. Air pollution can vary from year to year – changing weather patterns, periods of air stagnation, and other meteorological factors affect air quality levels. Poor air quality can contribute to breathing problems, reduced lung function, asthma, irritated eyes, throat irritation, stuffy nose, and other health effects. Air pollution also damages crops, plants, and trees and can cause reduced visibility.

The Denver metropolitan area is in substantive attainment of all national standards for carbon monoxide, ozone, and particulate matter air quality. Specifically, Denver has not violated the national standard for carbon monoxide since 1995[1], ozone since 1990, and particulate matter (PM10) since 1993. We believe there is little chance of the Denver area violating national standards related to carbon monoxide in the future. This is because carbon monoxide emissions are primarily (about 85 percent) from on-road vehicles, and average on-road vehicle emissions have been and will continue to decline with the replacement of older vehicles with newer, cleaner vehicles with more advanced emissions control technology.

There are two new air quality standards, however, for ozone (8-hour ozone) and fine particulate matter (PM2.5) with which Denver must comply. Attainment status with respect to these two new standards has not yet been officially determined. This is expected to occur in April 2004, based on the most recent three years of data.

The original national standard for ozone was based on daily maximum one-hour concentrations. The EPA is currently in the process of transitioning from this one-hour standard to a new, stricter 8-hour standard. We found that 8-hour ozone concentrations have been above or very close to the national standard at several of the nine Denver area ozone monitoring stations in recent years. Monitoring stations are required by the EPA for each type of pollutant and are located throughout the Denver area. Locations are based on criteria established by EPA and includes factors such as population density and volume of traffic. Because the national 8-hour ozone standard allows some exceedances, if Denver were classified today, it would be in attainment. However, any future increases in hydrocarbons could cause the Denver area to violate the 8-hour ozone standard. Because of this concern, the Regional Air Quality Council has carried out a Voluntary Ozone Reduction Program for the past four years and has just begun to conduct ozone modeling for the Denver area under an EPA program known as the Early Action Compact (EAC). This EAC program requires a modeling demonstration to show attainment of the 8-hour ozone standard by December 2007.

We also looked at fine particulate matter (PM2.5) levels in the Denver area relative to the new national standards for 24-hour and annual averages. Although the Denver area has not exceeded the PM2.5 annual average standard, the 24-hour standard has been exceeded several times. However, because the national standard allows some exceedances, we believe it is unlikely that the Denver area will be in violation of this standard when the initial attainment/non-attainment determinations are made in April 2004.

ESTIMATED AIR PROGRAM BENEFITS

In order to assess the benefit of the AIR Program, we used on-road emissions measurements and Program data for all vehicles tested in 1999 and 2000 to analyze the changes in emissions before and after vehicles were repaired or removed from the region. Because we estimate the

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[1] Denver exceeded the carbon monoxide standard in November 1999, but the EPA allows this to happen one time per year.

benefits from the program for the year following testing, our estimates of Program benefits are roughly for the year July 2000 through June 2001. Specifically, we looked at:

- Vehicles that failed their initial inspection, were repaired, and then passed on retest; and
- Vehicles that failed their initial inspection and did not pass a retest, most of which were permanently removed from the region.

We estimated the emission reduction for each vehicle tested in the AIR Program. We then calculated the percent reduction from the estimated total emissions of the on-road vehicle fleet, including vehicles exempt from or not participating in the AIR Program. Overall, we found that the AIR Program has reduced carbon monoxide emissions by about 16 percent and hydrocarbons by about 18 percent. However, we found that when repairs were made, nitrogen oxides emissions increased slightly (0.5 percent on average). We also found that the Program has helped reduce fuel usage by 0.2 percent. Table ES-2 shows the percent change in emissions and fuel use attributable to the AIR Program, by vehicle type (heavy truck, light truck, and car).

Table ES-2. Estimated percent reduction attributable to the Denver area AIR Program, by vehicle type.

Estimated AIR Program Benefits (Percent Change)				
Vehicle Type	**Hydrocarbons**	**Carbon Monoxide**	**Nitrogen Oxides**	**Fuel Savings**
Heavy trucks	-20%	-7%	NA	NA
Light trucks	-16%	-18%	1%	0%
Cars	-19%	-16%	0%	0%
Total	-18%	-16%	0%	0%

Note: Heavy trucks are greater than 8500 lbs gross vehicle weight rating. Light trucks include passenger trucks and sport utility vehicles.
Source: ENVIRON's analysis of AIR Program data provided by CDPHE.

Figures ES-1 through ES-4 show the estimated tonnage reductions by vehicle type and model year. In general, most of the carbon monoxide and hydrocarbon emissions benefits are from cars and light trucks, and the benefits by age are similar for cars and light trucks. Heavy trucks account for a very small portion of the carbon monoxide benefits, and a larger portion of the hydrocarbon benefits; older heavy trucks account for a relatively large proportion of the older vehicle hydrocarbon benefits. The largest carbon monoxide and hydrocarbon benefits are for mid-1980s model year vehicles, which have less advanced emission control systems than more recent model years, and hence have higher base emissions. Specifically, we found that 1986 and older vehicles, which make up about 20 percent of the Denver area fleet, account for about 50 percent of the carbon monoxide and hydrocarbon benefits, and about 30 percent of the fuel savings. The oldest half of vehicles (1991 and older) account for about 85 percent of the carbon monoxide and hydrocarbon benefits, and 50 percent of the fuel savings. On the other hand, the newest 40 percent of vehicles tested (1994 and newer) account for only 10 percent of the carbon monoxide and hydrocarbon benefits.

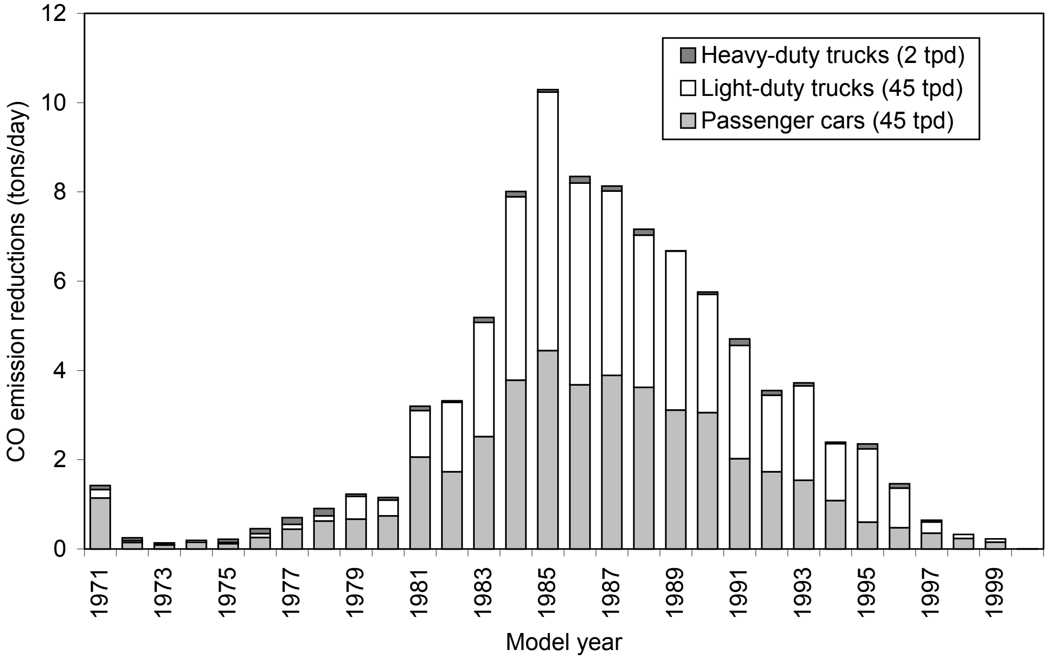

Figure ES-1. Best estimate of AIR Program carbon monoxide benefits (tons/day), by vehicle type and model year. Source: ENVIRON analysis of AIR Program data provided by CDPHE.

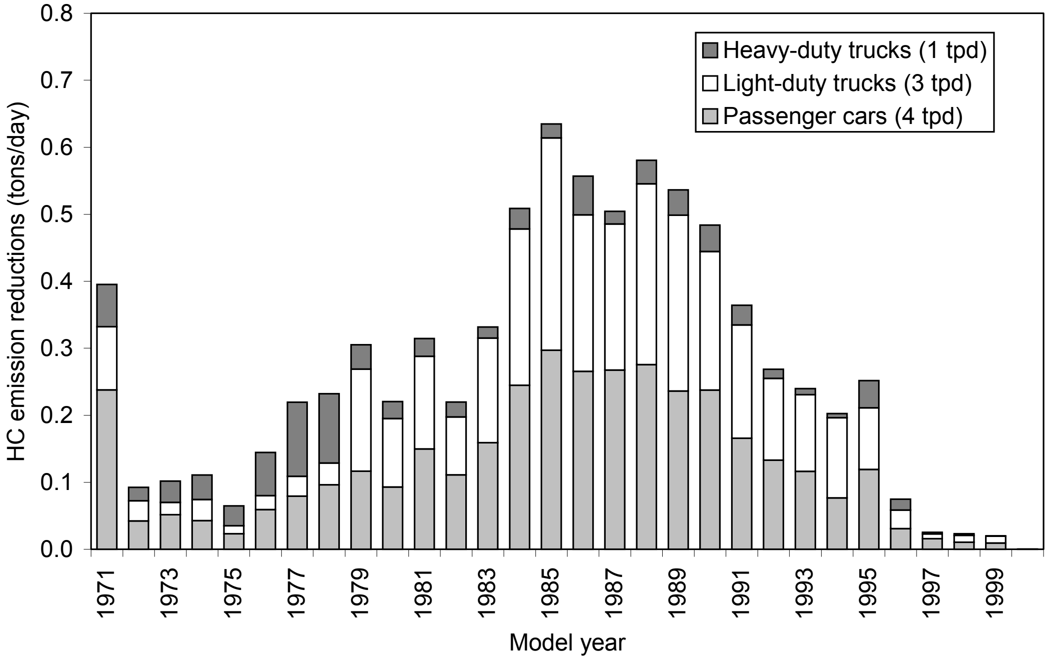

Figure ES-2. Best estimate of AIR Program hydrocarbon benefits (tons/day), by vehicle type and model year. Source: ENVIRON analysis of AIR Program data provided by CDPHE.

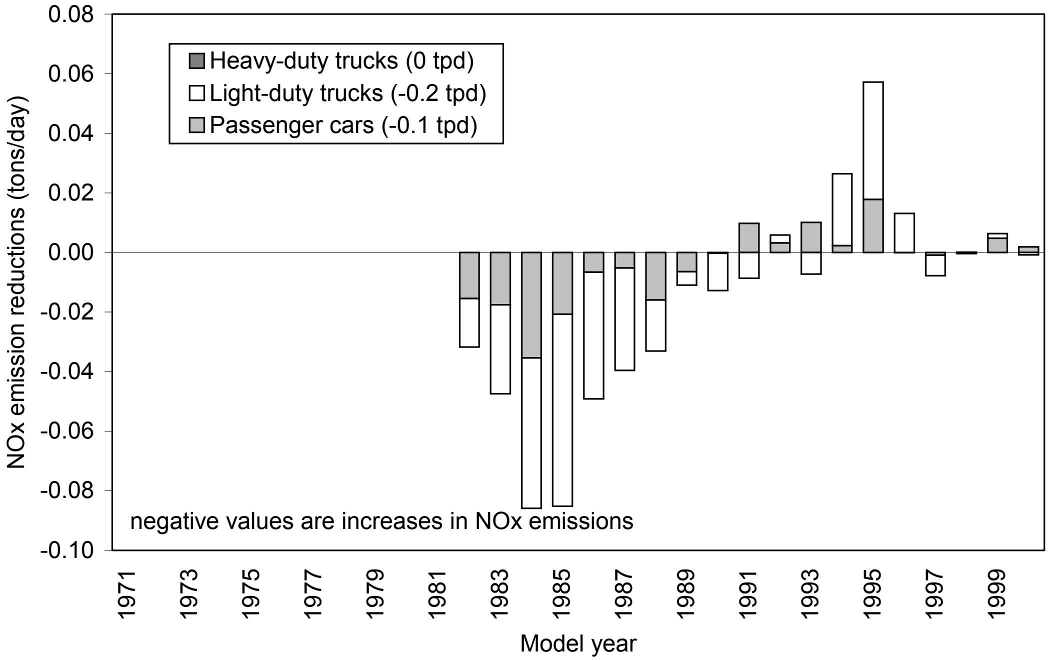

Figure ES-3. Best estimate of AIR Program nitrogen oxides benefits (tons/day), by vehicle type and model year. Source: ENVIRON analysis of AIR Program data provided by CDPHE.

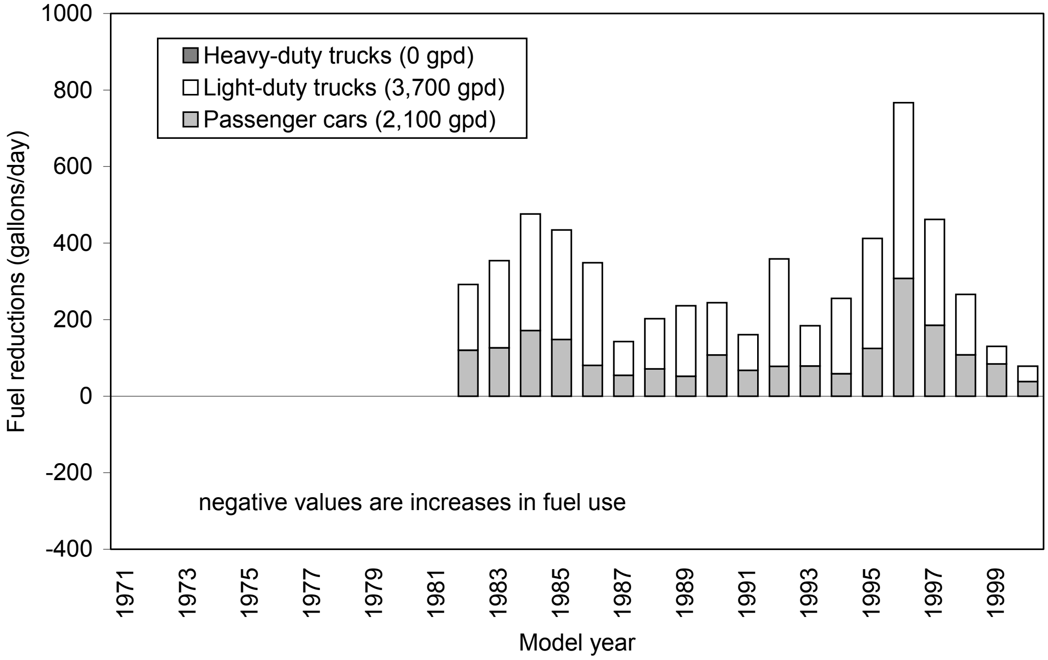

Figure ES-4. Best estimate of AIR Program fuel benefits (gallons/day), by vehicle type and model year. Source: ENVIRON analysis of AIR Program data provided by CDPHE.

FUTURE NEED FOR THE AIR PROGRAM

Vehicle emissions have been declining for many years, and will continue to decline. The EPA has implemented a series of progressively more stringent vehicle emissions standards and durability regulations, and manufacturers have continually improved emissions performance and durability in response. In fact, the automobile manufacturers agreed to a voluntary National Low Emission Vehicles Program, which began in most of the country with model year 2001 vehicles. Therefore, as older vehicles are retired, they are replaced by newer models that start out cleaner and stay cleaner as they age.

Using AIR Program data and on-road emissions measurements, we found that in the Denver area, the average carbon monoxide emissions declined more than 50 percent between 1996 and 2002. Hydrocarbons declined about 45 percent, while nitrogen oxides declined about 25 percent. Data for individual model years show that each successive vehicle model year has average emissions lower than earlier model years, both in terms of initial emissions and long-term durability.

We used the AIR Program data and on-road emissions measurements to forecast future emissions for the Denver area vehicle fleet without the AIR Program. Because there are uncertainties in the data, we developed optimistic and conservative projections. Figure ES-5 shows the actual emissions with the AIR Program and conservative projected emissions without an I/M program for all three pollutants. We expect to see a continued decline in emissions as older vehicles are replaced by newer vehicles, even without the AIR Program. We predict that emissions of all pollutants will decline somewhat in the near-term, with a much larger decline in the longer-term. We also looked at emission trends using MOBILE6, the Environmental Protection Agency's approved, on-road mobile-source emissions model. Using this model, we found similar results, although MOBILE6 predicts larger hydrocarbon emission reductions than our forecasts.

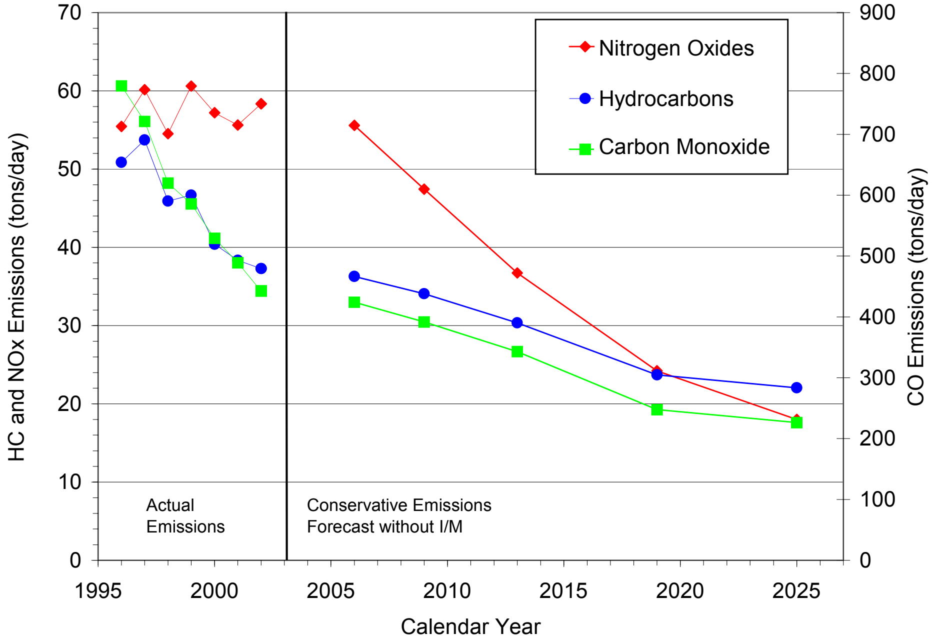

Figure ES-5. Projected emissions for Denver area light-duty vehicles (cars and trucks).

Carbon Monoxide

The AIR Program was originally established to reduce carbon monoxide concentrations in the Denver area. As mentioned previously, the Denver area has not violated carbon monoxide air quality standards since 1995. In addition, ambient carbon monoxide has been declining, and is projected to continue to decline as older vehicles are replaced with newer, cleaner vehicles that have more advanced emissions control technology. With or without the AIR Program, we believe there is little chance that the Denver area will violate national air quality standards for carbon monoxide in the future. As a result, we believe that the AIR Program in its current form is no longer needed for reducing ambient carbon monoxide levels. While eliminating the program completely could save the State and the citizens of Colorado about $44 million per year (based on our analysis of 2000/2001 data), either the current AIR Program or some variation of the program may be needed to reduce 8-hour ozone concentrations. If that is found to be the case, then the Program would continue in some form. In addition, we recognize that the current Program is a part of the Colorado State Implementation Plan for carbon monoxide. In order to change or discontinue the current Program, the State would have to prepare and submit a new State Implementation Plan to the EPA for approval, and the Department would need to terminate or modify its contract with Environmental System Products, Inc. Terminating or modifying the ESP contract would not be problematic, as the contract is written such that “the contractor assumes the risk of revision or repeal of the program or the implementing laws and regulations during the term of the contract.”

Ozone

Ozone forms in the atmosphere as the result of a series of reactions involving hydrocarbons and nitrogen oxides. As mentioned previously, we found that 8-hour ozone concentrations have been above or very close to the national standard at several of the Denver area monitoring stations in recent years. Ozone causes breathing problems, reduced lung function, asthma, irritated eyes, stuffy nose, reduced resistance to colds and other infections, and may speed up aging of lung tissue. Ozone can also damage crops, plants and trees, and is associated with reduced visibility. Although both hydrocarbons and nitrogen oxides contribute to ozone formation, ozone in the Denver area is most likely to be affected by reductions in hydrocarbon emissions. Our projections show that hydrocarbon emissions from on-road vehicles should continue to decline either with or without the AIR Program due to the replacement of older vehicles with newer ones. However, on-road vehicle emissions are only a portion of emissions in the Denver area that contribute to ozone formation, and emissions from other sources may increase. Therefore, some type of hydrocarbon controls may be needed to demonstrate attainment of the 8-hour ozone standard.

As noted previously, the Regional Air Quality Council (Council) has had a Voluntary Ozone Reduction Program in place for several years, and is now beginning ozone modeling for the Denver area under EPA’s Early Action Compact Program (EAC). Under the EAC Program, if Colorado develops and implements an Ozone Action Plan aimed at attaining the 8-hour standard by December 31, 2007, any potential nonattainment designation is deferred. It is anticipated that air quality modeling for the Early Action Compact, including evaluation of a variety of potential control programs, will be completed by the end of 2003. The Council is currently reviewing potential ozone control strategies, and the modeling just initiated will indicate what types of controls are likely to be most effective. In addition, the Council is holding stakeholder meetings where possible control measures are being discussed. The Department of Public Health and Environment should use this information to determine what type of program is needed to reduce ozone emissions and meet national standards. The Department should also continue to review and revise the Denver area emission inventories for hydrocarbon and nitrogen oxides using as much local data as possible.

Recommendation No. 1:

The Department of Public Health and Environment should assess the current AIR Program and determine the most appropriate method of reducing ozone concentrations in the Denver area. The following steps should be taken:

a. Review and revise estimates of hydrocarbon and nitrogen oxides sources and emissions using as much local real-world or ambient data as possible.

b. Conduct a thorough analysis of potential ozone control measures identified through the Early Action Compact Program and attendant stakeholder process. Compare the emission reductions, total costs, and cost-effectiveness of these measures to those of the current AIR Program.

c. Use the results of the analysis completed in part b to propose new ozone control measures for the Early Action Compact State Implementation Plan to be submitted to the Environmental Protection Agency by December 2004.

d. After December 2004, develop a plan for expeditiously phasing out unneeded components of the AIR Program. Prepare and submit a revised State Implementation Plan for carbon monoxide to the Environmental Protection Agency with the unneeded components removed.

Department of Public Health and Environment Response:

The Department agrees and has already begun reevaluation of the AIR Program to better address the metro area's ozone problem while de-emphasizing the program's carbon monoxide focus. The goal is to achieve the mobile source emissions reductions needed to address the ozone problem in the most cost effective means possible.

Mobile source hydrocarbon and nitrogen oxide emissions are projected to decrease over the long term; however, attainment of the eight-hour ozone standard is not assured in the near term. Even though the present focus of the AIR Program is carbon monoxide, the Denver area also receives a hydrocarbon benefit, estimated by this audit to be 17.8%. This Department is working to improve the hydrocarbon benefit in response to the need for further ozone control. The Department sees the need for a comprehensive approach for addressing ozone and believes that any significant change to the program should occur only after an integrated ozone plan is developed. Specifically, the Department has implemented and plans to implement the following comprehensive approach in response to the recommendations:

a.) **Agree.** Implementation: January 2004. Prior to the announcement of revised federal ozone standards in 1997, the Department had renewed its efforts to identify specific sources of hydrocarbon and oxides of nitrogen emissions in Colorado that contribute to ozone formation. At present, inventory development is underway using Colorado-specific data from all local sources of ozone precursors, based on emissions in the summer of 2002. The modeling for this inventory work should be complete by January 2004. This work is being performed as part of the Early Action Compact and will continue to be revised as sources evolve in the future.

b.) **Agree.** Implementation: September 2004. Through the Early Action Compact and its stakeholder process, steps are underway using local data to identify the control options that may be utilized in addressing the ozone problem. One of the required milestones was a June 16, 2003 report submitted to the Environmental Protection Agency detailing a list of potential strategies for ozone precursor emissions reduction. In addition to emissions reduction potential, costs, and cost effectiveness, the feasibility of implementing control options will be considered. For the near and medium term, pollutants from the mobile source contribution to the ozone problem may be easier to control than those from non-mobile sources, given statutory, State Implementation Plan, infrastructure and implementation lead-time issues. Depending upon the ambient air quality monitoring results, these findings will be available by September 2004 in preparation of the Early Action Compact-Ozone Action Plan submittal of December 2004 to the Environmental Protection Agency.

c.) **Agree.** Implementation: December 2004. The June 2003 report "Potential Strategies for Consideration During Local Planning Process", required under the Early Action Compact, is the first milestone in the proposal of new ozone precursor control strategies. Using the stakeholder process during the next 12-18 months, the Department and the Denver Regional Air Quality Council will prioritize the best options for ozone control. Through a public hearing process, the Air Quality Control Commission will consider and select those options to be submitted as part of the Early Action Compact and Ozone State Implementation Plan in December 2004.

d.) **Agree.** Implementation: Ongoing. The Department plans to re-evaluate the Denver carbon monoxide attainment/maintenance plan, incorporating the stakeholder/public review process, during the next 14 months. Because of the ozone reduction benefits received from the existing AIR program, the Department agrees that revisions to the Carbon Monoxide State Implementation Plan should be coordinated with development of the overall ozone precursor control strategies to be included in the December 2004 Early Action Compact. In this effort the Department and the Denver Regional Air Quality Council will evaluate current emission control strategies in the Denver area, as well as other potential strategy combinations to ensure compliance with national ambient air quality standards for carbon monoxide, ozone, and particulate matter. A full evaluation will consider restructuring the vehicle inspection and maintenance program and reducing requirements, if appropriate. The legislature has recently revised the Colorado statutes to exempt emissions testing on vehicle change of ownership, and has provided the Air Quality Control Commission (AQCC) authority to increase the number of model year exemptions and modify the boundaries of the program area. In addition, the AQCC recently removed the "check engine light" illuminated as an automatic failure of the program. The program has also begun implementing remote sensing clean screen in the

Denver area. Further, the AQCC will consider proposals to discontinue the vehicle emissions testing programs in Fort Collins, Greeley, and Colorado Springs in the next several months.

PROGRAM ALTERNATIVES

As discussed above, we believe the AIR Program in its current form is no longer necessary for reducing ambient carbon monoxide levels, but the Program or some modification may be needed for control of 8-hour ozone levels. We evaluated the following alternatives to the current AIR Program that could help reduce costs, while allowing the Denver area to maintain air quality consistent with national standards. These alternatives should be evaluated as part of the thorough analysis of potential ozone control measures discussed above.

- **Exempt additional model years of vehicles from scheduled inspections and eliminate the inspection requirement when there is a change of ownership or when new vehicles are initially registered in Colorado.** As mentioned previously, new vehicles are not required to have an inspection for their first four years unless there is a change of ownership or upon their initial registration in Colorado. However, House Bill 03-1016, which was passed during the 2003 Legislative Session, gives the Air Quality Control Commission the authority to increase the number of model year exemptions, subject to legislative review. It also eliminates the change of ownership inspection requirement for vehicles sold during their first four years if their emissions certification does not expire within the next 12 months. As the following table shows, increasing the number of years a new vehicle is exempt to 10 years would reduce inspection and repair costs by 46 percent, while reducing emissions benefits by 25 percent for carbon monoxide and 21 percent for hydrocarbons. Exempting a fewer number of years would still result in substantial cost savings, with a relatively small loss of emissions benefits.

Table ES-3. Estimated costs, emissions, and cost-effectiveness for additional model year exemptions. Except for the current Program, inspection at change of ownership and on initial registration from out of state would not be required.

Model Years Exempted	Repair-related Costs[1]	Cumulative % Reduction in Costs	Cumulative % Loss in Hydrocarbon Reduction	Cumulative % Loss in Carbon Monoxide Reduction	Carbon Monoxide Cost Effectiveness ($/ton) [2]	Ozone Cost Effectiveness ($/ton) [3]
Current program	$33M				$1,300	$12,000
4 years	$29M	13%	1%	2%	$1,100	$10,500
6 years	$25M	25%	6%	7%	$1,000	$9,400
8 years	$21M	35%	12%	14%	$900	$8,800
10 years	$18M	46%	21%	25%	$900	$8,200

Source: ENVIRON's analysis of data provided by CDPHE.

[1] Total costs of the current I/M program are $44 million. The costs considered here are only the repair related costs including inspection costs, motorists' costs and repair costs.

[2] CO cost effectiveness (repair costs +inspection costs + motorists costs)/emissions reductions.

[3] Ozone cost effectiveness (total repair related cost /(HC+CO/60)).

- **Implement a "clean screen" program in which vehicles that have low emissions are exempted from their next scheduled emissions inspection (similar to the program that was recently approved but has not yet started).** Low-emitting vehicles will be identified using devices that measure tailpipe exhaust emissions as the vehicle drives past a sensor. A photo is taken of the vehicle's license plate and owners of "clean" vehicles are notified of the opportunity to opt out of their next scheduled inspection. However, these vehicles must still pay the inspection fee as part of their registration payment to fund the additional contractor costs for the clean screen program. Our analysis indicates that adding this type of program will result in slightly reduced costs and emissions benefits compared to the current AIR Program. Specifically, we found that this type of program will increase the contractor's costs by about $4 million. However, these costs will be offset by the savings incurred from inspecting fewer vehicles. In addition, owners of the "clean" vehicles will save money because they do not have to make inspection trips. The percent of the vehicles in the Denver area that would be exempted from inspection depends on many factors such as the number of remote sensing devices in use and the number of valid remote sensing readings. A complete assessment of the cost effectiveness of the clean screen program should be conducted once the program is underway.

- **Implement a program that uses on-road remote sensing to identify the highest emitting vehicles, and requires owners to bring in these vehicles for inspection and possible repair.** Remote sensing devices would be used to identify high emitting vehicles. Owners would then be notified that they must bring their vehicles in for inspection and possible repair. This type of program would have significantly lower costs than the current AIR Program. However, the emissions benefits would also be much lower. Looking only at administrative, testing, and repair-related costs (i.e., not including costs and benefits of vehicles leaving the area), the costs of this type of program would be 9 to 13 percent of the costs of the current AIR Program and the emissions benefits would be 14 to 17 percent of the current program. A "scrappage" component could also be added to this alternative. Under this scenario, the State would pay the owners of the highest emitting vehicles to "scrap" or retire their vehicle. For purposes of this analysis, we evaluated a scrap program in which the owner is offered $1,000 to scrap the vehicle, in lieu of having it repaired, and we assumed that 20 percent of the owners of high emitting vehicles accepted the offer. Adding the scrappage component would increase the emissions benefits and would be slightly more cost-effective than the high emitter program on its own. A complete assessment of the cost effectiveness of a high emitter program with and without a scrappage component should be conducted once the clean screen and "Repair Your Air" programs are underway.

Recommendation No. 2:

The Department of Public Health and Environment should evaluate and consider the following alternatives when determining what air quality control measures would be the most cost-effective for the Denver area and provide the most emissions benefits:

- Exempt additional model years of vehicles from scheduled inspections and eliminate the inspection requirement when there is a change of ownership or when new vehicles are initially register in Colorado.

- Implement a "clean screen" program in which vehicles that have low emissions are exempted from their next scheduled emissions inspection (similar to the program that was recently approved but has not yet started).

- Implement a program that uses on-road, remote sensing to identify the highest emitting vehicles, and requires owners to bring in these vehicles for inspection and possible repair. This alternative could also include a “scrappage” component to buy these vehicles and remove them from the road.

Department of Public Health and Environment Response:

Agree. Implementation: Implemented and ongoing. The Department continues to evaluate and is pursuing the most cost-effective means to modify the AIR Program to address Colorado’s future air quality requirements. The Department has taken steps to remove vehicles that make up the clean portion of the fleet from the periodic inspection program. In response to each alternative recommended for consideration, the Department has implemented and plans to implement the following actions:

- During the last legislative session, passage of Colorado House Bill 03-1016 removed the requirement for inspection upon change of ownership for those vehicles within their new-vehicle exemption time period, unless the change of ownership takes place with less than twelve months remaining in the exemption period. Pursuant to legislative direction, amendments to the vehicle emissions inspection program to implement the change of ownership provisions are scheduled for Air Quality Control Commission (AQCC) public hearing in September 2003. Colorado House Bill 03-1016 also grants authority to the AQCC to add more vehicle model years to the model years already exempt from the program requirements. The Department, the AQCC, and the Denver Regional Air Quality Council will be evaluating the effects and costs associated with increasing model year exemptions as part of efforts to evaluate State Implementation Plan emissions control stratagies in the Denver metro area for carbon monoxide, ozone, and particulate matter. Amendments to the State Implementation Plans will require approval by the Colorado General Assembly and the Environmental Protection Agency.

- “Clean Screen” remote sensing began in the North Front Range in May 2002 after a year of data collection. Legislation to establish the Clean Screen Authority and a funding mechanism was passed in the 2001 and 2002 legislative sessions. These actions provide the framework for a clean screen program to kickoff in the Denver Metropolitan area in August 2003. Currently, the program is collecting data with actual clean screening to begin in the fall of 2003. This program, included in the State

Implementation Plan, will remove a significant portion of the fleet from the requirement of a regularly scheduled inspection at an emissions testing center.

- The first steps are underway to implement a remote sensing high emitter identification project, called “Repair Your Air,” in the Denver Metropolitan area through a joint effort with the Denver Regional Air Quality Council. A “Congestion Mitigation/Air Quality” grant provided by the Federal Highway Administration pays for the repair of high emitting hydrocarbon vehicles. Data collected by the Department from this project will provide the basis for an expanded high emitter identification pilot program. The Department is in the process of developing a remote sensing high emitter identification plan that will outline needed steps and identify potential barriers, such as funding and enforcement, to implement a high emitter identification program. The Department will present this plan to the Air Quality Control Commission in November 2003.

RECOMMENDATION LOCATOR

Rec. No.	Page No.	Recommendation Summary	Agency Addressed	Agency Response	Implementation Date
1	ES 10	Review and revise estimates of hydrocarbon and nitrogen oxides sources and emissions using local data; thoroughly analyze potential ozone control measures identified through the Early Action Compact Program; propose new ozone control measures in the Early Action Compact State Implementation Plan and revise plan for carbon monoxide; develop a plan to expeditiously phase out unneeded components of the AIR Program.	Department of Public Health and Environment	Agree	December 2004
2	ES 13	Evaluate and consider alternatives when determining what control measures would be the most cost-effective and provide the most emissions benefit.	Department of Public Health and Environment	Agree	Implemented and Ongoing

1.0 INTRODUCTION AND BACKGROUND

Colorado statute, Section 42-4-316, C.R.S., requires periodic audits of the Colorado Automobile Inspection and Readjustment (AIR) Program. The Office Of The Colorado State Auditor contracted with ENVIRON International Corporation to perform the 2003 audit of the AIR Program. This report provides an estimate of the benefits and costs of the AIR Program, discusses current and estimated future air quality and the need for the program, and discusses potential modifications and alternatives to the current program. In this section we provide a description of the AIR Program, and then describe the contents of the remaining sections of the report.

1.1 DESCRIPTION OF THE AIR PROGRAM

The Colorado enhanced Inspection and Maintenance (I/M) program, or AIR Program, began in January 1995. The Program requires that all light- and heavy-duty gasoline powered vehicles in the greater Denver metropolitan area to regularly submit to an inspection of the vehicle's emissions controls. (A separate I/M program is operated in other areas of the state; this audit is limited to the effectiveness of the Denver enhanced I/M program). The inspection includes a test of the vehicle's tailpipe emissions, a visual inspection to determine if any original emissions controls have been tampered with or are missing, and, if applicable, a visual inspection of the "check engine light" on the dashboard. Model year 1981 and older light-duty vehicles (includes all cars, passenger trucks, and sport utility vehicles), as well as all heavy-duty vehicles (includes trucks greater than 8500 pounds gross vehicle weight rating), are required to be tested every year, while 1982 and newer light-duty vehicles are subject to a biennial inspection, every other year. A vehicle must pass its required inspection in order to be registered. New vehicles are exempted from the regular inspection for the first four years. In addition to the regular annual or biennial inspection, every vehicle must also be inspected prior to its sale to another owner, or upon initial registration in Colorado, regardless of its model year. Once a vehicle passes its regular or change-of-ownership inspection, its emissions "clock" is reset, and it does not need to be tested again for another two years (or one year, if it is only required to get an annual test). All heavy-duty gasoline trucks are required to be tested, regardless of their gross vehicle weight rating; motorcycles and diesel vehicles are exempted from the AIR Program.

A single contractor, Environmental Systems Products, Inc. (ESP), performs the emissions inspections for all vehicles in the AIR program at a network of 15 centralized testing facilities located throughout the Denver metropolitan area. Model year 1981 and older vehicles also can be tested at an independent testing station in the enhanced I/M area. If a tested vehicle's measured emissions exceed the program's emissions standards, or "cut points", it fails the inspection and must be repaired until it meets the cut points. A vehicle can also fail the visual inspection of emission control components or if the check engine light is lit.[1] Once a vehicle has failed its emissions inspection, it must be repaired at an independent repair facility, and then retested to ensure that emissions have been reduced to below the test cut points. Vehicles must continue to be repaired and retested until they pass a retest. Vehicle owners who pay at

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[1] In April 2003 the program discontinued the inspection of the check engine light.

least $450 in repairs without fixing the vehicle can apply for a one-time repair cost waiver, which allows them to register and continue driving the vehicle until its next scheduled inspection.[2]

Vehicles in the biennial program are given an IM240 test, which measures mass carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), and carbon dioxide (CO2) emissions as the vehicle is operated for up to 240 seconds at a prescribed set of speeds on a treadmill-like device called a dynamometer. Vehicles with emissions lower than the cut points can "fast-pass" the IM240 test in as little as 30 seconds. ESP software projects what the emissions of the "fast-pass" vehicles would have been if they were tested over the full 240 seconds. ESP calculates the fuel economy (miles/gallon) of each vehicle based on their CO2, CO and HC emissions. However, ESP does not project what fuel economy would be over a full IM240 test for vehicles that are fast-passed. Vehicles that fail the full IM240 test but are within a certain range of the cut points receive an immediate retest over the full IM240 cycle.

Vehicles in the annual program are given a two-speed idle test, which consists of putting the transmission in neutral or park and testing its emissions while the engine is idling and is operated at 2500 rpm. Because idle testing measures CO and HC emissions only, and at very specific engine conditions, it is not considered as accurate an indication of a vehicle's emissions in normal operation as the IM240 test (which attempts to replicate a portion of the Federal Test Procedure used to certify the emissions of new vehicles). In addition, the idle test measures CO and HC emissions in terms of concentrations of the gasses in the exhaust (percent CO and parts per million, or ppm, HC), as opposed to the IM240 which measures the absolute mass of pollutants emitted (in grams per mile traveled). For all of these reasons the results from the two types of test are not comparable.

Tables 1-1 and 1-2 show how the IM240 cut points for 1982 and newer light-duty vehicles have been changed over time. Changes to the cut points for individual model years are in bold. Idle cut points have not changed since the onset of the enhanced AIR program; the idle cut points are shown in Table 1-3. The cut points in italics in Table 1-3 are used for the small number of 1982 and newer cars and light trucks that cannot be tested on ESP's IM240 dynamometer, and are therefore given a two-speed idle test.

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[2] In January 2003 CHECK the repair cost limit waiver was increased from $450 to $715.

Table 1-1. Colorado IM240 cut points in grams/mile for passenger cars, by pollutant, calendar year and model year. Cutpoints that changed from one year to the next are noted in bold.

Model Year	Passenger cars											
	HC				CO				NOx			
	1996	1997-98	1999-01	2002	1996	1997-98	1999-01	2002	1996	1997-98	1999-01	2002
1982	5.0	5.0	**4.0**	4.0	75	**65**	**45**	45	8.0	8.0	8.0	8.0
1983	5.0	5.0	**4.0**	4.0	60	**50**	**30**	30	8.0	8.0	8.0	8.0
1984	5.0	5.0	**4.0**	4.0	60	**50**	**30**	30	8.0	8.0	8.0	8.0
1985	5.0	5.0	**4.0**	4.0	30	**25**	**20**	20	8.0	8.0	8.0	8.0
1986	4.0	4.0	**3.0**	3.0	30	**25**	**20**	20	6.0	6.0	6.0	6.0
1987	4.0	4.0	**3.0**	3.0	30	**25**	**20**	20	6.0	6.0	6.0	6.0
1988	4.0	4.0	**3.0**	3.0	30	**25**	**20**	20	6.0	6.0	6.0	6.0
1989	4.0	4.0	**3.0**	3.0	30	**25**	**20**	20	6.0	6.0	6.0	6.0
1990	4.0	4.0	**3.0**	3.0	30	**25**	**20**	20	6.0	6.0	6.0	6.0
1991	4.0	4.0	**2.5**	2.5	20	20	20	20	6.0	6.0	6.0	6.0
1992	4.0	4.0	**2.5**	2.5	20	20	20	20	6.0	6.0	6.0	6.0
1993	4.0	4.0	**2.5**	2.5	20	20	20	20	6.0	6.0	6.0	6.0
1994	4.0	4.0	**2.0**	2.0	20	20	20	20	6.0	6.0	6.0	6.0
1995	4.0	4.0	**2.0**	2.0	20	20	20	20	4.0	4.0	4.0	4.0
1996	4.0	4.0	**2.0**	**1.2**	20	20	20	20	4.0	4.0	4.0	**3.0**

Source: of CDPHE data.

Table 1-2. Colorado IM240 cut points in grams/mile for light-duty trucks, by pollutant, calendar year and model year. Cutpoints that changed from one year to the next are noted in bold.

Model Year	Light-duty trucks											
	HC				CO				NOx			
	1996	1997-98	1999-01	2002	1996	1997-98	1999-01	2002	1996	1997-98	1999-01	2002
1982	8.0	8.0	8.0	8.0	130	**107**	**65**	65	12.0	12.0	12.0	12.0
1983	8.0	8.0	6.0	6.0	130	**107**	**65**	65	12.0	12.0	12.0	12.0
1984	8.0	8.0	6.0	6.0	90	**80**	**55**	55	12.0	12.0	12.0	12.0
1985	8.0	8.0	6.0	6.0	90	**80**	**45**	45	12.0	12.0	12.0	12.0
1986	6.0	6.0	6.0	6.0	90	**67**	**40**	40	9.0	9.0	9.0	9.0
1987	6.0	6.0	**4.0**	4.0	90	**67**	**30**	30	9.0	9.0	9.0	9.0
1988	6.0	6.0	**4.0**	4.0	90	**67**	**25**	25	9.0	9.0	9.0	9.0
1989	6.0	6.0	**4.0**	4.0	90	**67**	**25**	25	9.0	9.0	9.0	9.0
1990	6.0	6.0	**4.0**	4.0	90	**67**	**25**	25	9.0	9.0	9.0	9.0
1991	6.0	6.0	**4.0**	4.0	70	**53**	**25**	25	9.0	9.0	9.0	9.0
1992	6.0	6.0	**4.0**	4.0	70	**53**	**25**	25	9.0	9.0	9.0	9.0
1993	6.0	6.0	**4.0**	4.0	70	**53**	**25**	25	9.0	9.0	9.0	9.0
1994	6.0	6.0	**4.0**	4.0	70	**53**	**20**	20	9.0	9.0	9.0	9.0
1995	6.0	6.0	**4.0**	4.0	70	**53**	**20**	20	9.0	9.0	9.0	9.0
1996	6.0	6.0	**4.0**	4.0	70	**53**	**20**	20	9.0	9.0	9.0	9.0

Source: CDPHE.

Table 1-3. Colorado two-speed idle cut points by pollutant, vehicle type and model year (same cut points used over all calendar years).

	HC (ppm)		CO (percent)	
Model year	**Heavy trucks**	**Light trucks and cars**	**Heavy trucks**	**Light trucks and cars**
1967 and older	1500	1000	7.0	5.5
1968-69	1200	1000	6.5	5.5
1970	1200	1000	6.0	5.5
1971-74	1200	1000	6.0	4.5
1975-76	1200	600	6.0	3.5
1977-78	1200	400	6.0	3.0
1979	1000	400	5.0	2.0
1980	1000	400	4.0	1.5
1981-85	800	*400*	3.5	*1.5*
1986-88	300	*400*	3.0	*1.5*
1989 and newer	300	*220*	3.0	*1.2*

Source: CDPHE.

Only vehicles from odd model years were required to be tested in the biennial program when the program started in 1995; all even model years were required to be tested in 1996. However, over time the number of vehicles tested in "off " calendar years has increased, as the number of vehicles migrating in from other states, vehicles subjected to change-of-ownership testing, and the inclusion of new model years has diluted the even/odd model year distinction.

Colorado recently approved a "clean screen" program in which vehicles that are expected to have low emissions are exempted from their next scheduled emissions inspection. The clean screen program identifies clean vehicles using “remote sensing” units that measure tailpipe exhaust emissions as vehicles drive by the sensors. A photo is taken of each vehicle’s license plate so that owners of clean vehicles can be notified of the opportunity to opt out of the next scheduled inspection. The Colorado Department of Public Health and Environment (CDPHE) plans to have the clean screen program operating within the next few months.

1.2 REPORT ORGANIZATION

This report is organized into the following sections:

Section 2, Air Quality Data in The Denver Area, provides graphs and discussion of air quality data from 1990 to 2002 from monitoring sites located in the metropolitan Denver enhanced I/M program area. Air quality trends are shown for carbon monoxide, ozone, and particulate matter.

Section 3, Denver Vehicle Fleet Characteristics, describes current federal vehicle emissions controls, and provides information on the composition of the Denver vehicle fleet that is used in the benefits and cost estimates calculations.

Section 4, Estimated Emission Reduction Benefits Of Air Program, describes the methodology for estimating emissions reductions from analysis of the extensive AIR Program data base that we received from CPDHE. Estimated reductions by vehicle class and model year are provided for the three pollutants measured (CO, HC, and NO_X), and also for fuel economy.

Section 5, MOBILE6 Estimates Of Air Program Benefits, describes the modeling performed for estimating the emissions benefits of the AIR program using EPA's approved, on-road mobile-source emissions regulatory model. MOBILE6 estimated benefits are compared to benefits estimated from AIR program data, and MOBILE6 projected benefits through calendar year 2025 are also shown.

Section 6, Projection Of Future Fleet Emissions, discusses our analysis approach for projecting emissions from now through calendar year 2025 under a number of scenarios, using AIR Program data and remote sensing data collected in the Denver area in the last several years. The projections developed from these data sources are compared to MOBILE6 projections.

Section 7, Costs And Cost Effectiveness Of The Air Program, summarizes the results of our analysis of the costs and cost-effectiveness of the current AIR program in the enhanced I/M area of the Denver region for the year 2000. Each of the cost components evaluated is described, along with assumptions needed to develop the cost estimates. Cost effectiveness ($/ton) results are also provided.

Section 8, Modifications And Alternatives To The Current Program, provides cost and cost effectiveness estimates for several possible modifications and alternatives to the current AIR program. These include exemptions for additional model years, remote sensing clean screening, and remote sensing for identifying high emitting vehicles with and without a scrappage program.

Section 9, Alternative Control Strategies, provides a brief summary of potential control measures that could be implemented in addition to or instead of the AIR Program. The focus is on hydrocarbon control measures, for reasons that are explained in the report.

Section 10, Legal Issues, discusses Clean Air Act requirements and future year emissions projections relative to regulatory requirements. Issues related to preparation of State Implementation Plans (SIPs) and transportation conformity analyses are discussed.

Six appendices are included in this report. They provide more details on aspects of the benefits and cost/cost-effectiveness estimates.

2.0 AIR QUALITY IN THE DENVER AREA

This section summarizes the current ambient air quality status of monitoring locations within the Colorado enhanced I/M program area with respect to carbon monoxide (CO), ozone (O3), and particulate matter (PM10 and PM2.5). We also briefly present and describe historical trends in these pollutants. This section is based on annual air quality summary statistics prepared by the Colorado Department of Public Health and Environment (CDPHE). We use data for the period 1990 – 2002 from sites located in the seven counties included in the Denver metropolitan enhanced I/M program area (Denver, Jefferson, Boulder, Douglas, Arapahoe, Adams, and Broomfield). In some instances data were only available through 2001.

2.1 SUMMARY

The Denver metropolitan area (Denver) is in substantive attainment of all National Ambient Air Quality Standards (NAAQS)) and the Environmental Protection Agency (EPA) has redesignated Denver to "attainment" for carbon monoxide, ozone, and PM10. Specifically, Denver has not violated the national standard for carbon monoxide since 1995, ozone since 1990, and particulate matter (PM10) since 1993. We believe there is little chance of the Denver area violating national standards related to carbon monoxide in the future. This is because carbon monoxide emissions are primarily (about 85 percent) from on-road vehicles, and average on-road vehicle emissions have been and will continue to decline with the replacement of older vehicles with newer, cleaner vehicles with more advanced emissions control technology.

There are two new air quality standards for ozone (8-hour) and fine particulate matter (PM2.5) with which Denver must comply. Attainment status with respect to these two standards has not yet been officially determined by the EPA. This is expected to occur in April 2004, based on the most recent three years of data.

The original national standard for ozone was based on daily maximum one-hour concentrations. The EPA is currently in the process of transitioning from this one-hour standard to a new, stricter 8-hour standard. We found that 8-hour ozone concentrations have been above or very close to the national standard at several of the Denver area monitoring stations in recent years. Because the national standards allow some exceedances, if Denver were classified today, it would be in attainment. However, any future increases in hydrocarbons could cause the Denver area to violate the 8-hour ozone standard.

We also looked at fine particulate matter (PM2.5) levels in the Denver area relative to the new national standards for 24-hour and annual averages. Although the Denver area has not exceeded the PM2.5 annual average standard, the 24-hour standard has been exceeded several times. However, because the national standard allows some exceedances, we believe it is unlikely that the Denver area will be in violation of this standard when the initial attainment/non-attainment determinations are made.

2.2 CARBON MONOXIDE

The National Ambient Air Quality Standard (NAAQS) for CO limits peak 1-hour concentrations to 35 ppm and 8-hour averages to 9 ppm (both rounded to the nearest ppm) and specifies that these levels are not to be exceeded more than once per year. In Denver as elsewhere the 8-hour average is the limiting standard. A violation of the 8-hour standard occurs when the annual second highest non-overlapping 8-hour running average concentration during any two year period (which is commonly referred to as the 8-hour design value) is greater than or equal to 9.5 ppm.

Figure 2-1 shows trends in the annual second highest 1-hour average and annual second highest 8-hour non-overlapping running average CO concentrations at each monitoring site within the enhanced I/M program area for the period 1990 - 2002.[1] No 1-hour CO levels above 35.5 ppm were recorded during this period. In addition, the annual second highest 8-hour average has not exceeded the level of the NAAQS since 1995. Visual inspection of Figure 2-1 shows strong evidence of declining trends in 8-hour CO design values at all sites between 1990 and 2002. Nevertheless, high CO levels still occur occasionally. For example, in November 1999, an 8-hour average value of 9.5 ppm was recorded at the Denver Blake St. monitor and in January 2000, an 8-hour average value of 8.5 was recorded at the Denver CAMP monitoring station.

For the 2001 – 2002 period, the maximum 8-hour design value in the enhanced I/M program area is 4.1 ppm. Under a simple linear rollback model, this implies that CO emissions would have to increase by a factor of 2.3 (= 9.5/4.1) to produce a violation of the NAAQS. Of course, this rollback calculation is based on meteorological conditions occurring during 2001-2002 and does not account for the long-term frequency of severe stagnation episodes that can produce high CO levels. As indicated by the preceding discussion of peak 8-hour values observed in 1999 and 2000, there still exists some potential for a violation of the NAAQS, at least under emission levels experienced during these two years. Nevertheless, the fact that there has been no violation of the NAAQS since 1995, together with the strong downward trends in CO concentrations in recent years and expected continuing downward trends in the near future, indicates that there is little chance of a violation of the CO NAAQS in the enhanced I/M program area in the future.

2.3 OZONE

The NAAQS for ozone limits daily maximum 1-hour concentrations to 0.12 ppm (rounded to the nearest 0.01 ppm). In July 1997, EPA promulgated a new 8-hour ozone standard that limits the daily maximum 8-hour average concentration to 0.08 ppm (again, rounded to the nearest 0.01 ppm). The 8-hour standard was subsequently withdrawn due to legal challenges before being reinstated after it was upheld by the Supreme Court. EPA is currently in the process of transitioning from the old 1-hour standard to the new 8-hour standard.

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[1] Annual second highest values are reported regardless of whether or not data for the year meet EPA completeness criteria. However, CO data completeness meets these criteria for most site-years.

Denver is currently in attainment of the 1-hour ozone standard and has an ozone maintenance plan in place. In addition, for the past four years the Regional Air Quality Council (RAQC) has carried out a Voluntary Ozone Reduction Program. In 2002, this program included the following elements (RAQC, 2003):

- Continuation of the Ozone Action alert system
- Voluntary gasoline volatility reductions
- Distribution of "stop at the click" stickers to gas stations
- "Mow Down Pollution" lawnmower exchange program
- Partnerships with local groups to sponsor voluntary gas cap tests at local events
- Continuation of the "Put a Cap on Gas" gas cap replacement program
- Clean air public service announcements in local movie theaters
- Other public outreach via local media and special events
- Voluntary actions by local government agencies including: practicing "stop at the click" refueling practices, limiting use of gas powered lawn and gardening equipment, avoiding vehicle idling, email notices of Ozone Action alerts and other employee outreach programs.

For the 1-hour standard, the design value is defined as the fourth highest daily maximum concentration in three years, although the annual second highest daily maximum is frequently used to track year-to-year progress with respect to the standard. For the 8-hour standard, the design value is defined as the average over three consecutive years of the annual 4th highest daily maximum 8-hour average. However, it is useful to track year-to-year progress with respect to this standard by examining the 4th highest value in each year. A summary of recent ozone conditions and historical trends in the Denver metropolitan area has been compiled by the Regional Air Quality Council (RAQC, 2002).

Figure 2-2 shows trends in the annual second highest 1-hour and fourth highest 8-hour average ozone concentrations at each monitoring site in the enhanced I/M program area for the period 1990 - 2002.[2] The 1-hour average has not exceeded the level of the NAAQS at any location during this period. The annual fourth highest 8-hour average exceeded the level of the NAAQS in 1998 at several sites and again in 2002 at Rocky Flats. A review of the 3-year averages of the annual fourth highest daily maximum 8-hour averages (i.e., the three year 8-hour design value) shows that no locations other than Rocky Flats experienced a violation during any three year period during which data were collected since a value of 0.087 ppm was observed at Highland Reservoir in 1990. At Rocky Flats, the 1998-1999 and 2001-2002 averages of the annual fourth highest daily maximum 8-hour concentration both exceeded the NAAQS but data for 2000 were reported as missing. Visual inspection of Figure 2-2 shows no indication of a negative or positive trend in either 1-hour or 8-hour ozone since 1990. This, coupled with the fact that annual fourth highest 8-hour averages are at or just above the level of the NAAQS at Rocky Flats and only slightly below this level at the National Renewable Energy Laboratory and Chatfield Reservoir sites, suggests that any future increases in emissions could result in a violation of the 8-hour standard.

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[2] Annual second/fourth highest values are reported regardless of whether or not data for the year meet EPA completeness criteria. However, ozone data completeness meets these criteria for most site-years.

Since ozone is not directly emitted but forms in the atmosphere as a result of a complex series of non-linear reactions involving reactive hydrocarbons and nitrogen oxides, there is no direct linear relationship between emissions and ozone. In simple terms, the daily maximum ozone concentration observed at a monitoring site is not only a function of the total amount of hydrocarbon and NOx emissions in the metropolitan area, but also of the HC/NOx ratio and of the spatial and temporal distribution of the emissions, as well as meteorology. This makes it much more complicated to project the likely response of ozone to future changes in emissions. Furthermore, on-road mobile sources, although very significant, do not dominate the total HC and NOx emissions budgets of the metropolitan area to the same extent as they impact the CO budget.

Denver cannot afford significant increases in HC emissions because of its contribution to ozone production. An analysis of emissions and ozone data led an ad hoc committee formed in November 1998 by the RAQC and the Air Pollution Control Division to tentatively conclude that the region is HC limited (Dilley, 1999). This means that ozone levels are more responsive to HC emissions than NOx emissions. Measurements of ozone, VOC, and NOx collected by the CDPHE near the center of the Denver urban area show low VOC/NOx ratios (around 1:1) and reasonably low average ozone levels (Pierce, 1998). Analysis of the regional emission inventory shows a similar ratio (Dilley, 1999), thus suggesting a VOC limited regime. While these results are not sufficient to unequivocally conclude that maximum ozone concentrations downwind of Denver will respond most efficiently to gradual reductions in VOC emissions, they are consistent with a VOC limited regime, which would put Denver in the same regime as other large western U.S. cities. Thus, any future increases in VOC emissions in the Denver area could be cause for concern with respect to continued attainment of the 8-hour NAAQS.

A complete photochemical modeling study with projected VOC and NOx emissions from all sources would be required to obtain credible estimates of future ozone levels in Denver. Such an analysis is beyond the scope of the current audit. However ENVIRON has just been hired by the RAQC to conduct ozone Early Action Compact (EAC) modeling for the Denver area. Denver has volunteered to participate in the EAC protocol process for the purpose of deferring the effective date of a nonattainment designation for the Denver area if a violation of the 8-hour ozone NAAQS occurs in the future. The EAC protocol process (Cooke, 2002) requires a photochemical dispersion modeling demonstration to show attainment of the 8-hour ozone standard by December 2007. Any controls necessary are to be implemented by 2005. The basic principals of the EAC Protocol are:

- Early emission reductions to attain the 8-hour ozone standard;
- Local control, with broad-based public input;
- State support to ensure technical integrity of the early action plan;
- Early action plan incorporated into the SIP;
- Effective date of nonattainment designation and/or designation requirements is deferred (as long as all EAC terms and milestones are met);
- Safeguards to return to a traditional SIP requirements if EAC terms and/or milestones are not met.

2.4 PARTICULATE MATTER (PM)

Under the PM10 NAAQS, maximum 24-hour average concentrations are limited to 150 μg/m^3 not to be exceeded more than once per year and annual averages are limited to 50 μg/m^3. Figure 2-3 shows trends in annual maximum 24-hour average and the annual average PM10 for the period 1990 – 2002 for sites in the enhanced I/M area.[3] Annual averages did not exceed the NAAQS during this period; the annual maximum 24-hour average PM10 concentration exceeded the NAAQS during three years (1992, 1993, and 1999). However, the annual second highest daily maximum PM10 concentration did not exceed the NAAQS at any location in the enhanced I/M area. Visual inspection of Figure 2-3 indicates some evidence of a downward trend in daily maximum PM10 since 1990 but there is a large amount of year-to-year variability. Annual averages show little evidence of any significant trend. PM10 concentrations can be influenced by exceptional events such as wild fires, etc. which complicates trend detection and analysis. Overall, there is no indication in these data of a potential for PM10 violations in the enhanced I/M area.

EPA promulgated a new standard for PM2.5 mass in July 1997. The standard was withdrawn due to legal challenges before being reinstated after being upheld by the Supreme Court. While EPA is currently reviewing the scientific underpinnings of all of the PM standards, implementation of the new PM2.5 standard is scheduled to begin over the next few years. The new standard limits 24-hour averages to 65 ug/m3 and annual averages to 15 ug/m3. For the 24-hour standard, the appropriate design value is defined as the 98th percentile of the distribution of daily (24-hour) average concentrations in each year, averaged over three consecutive years. For the annual average, the appropriate design value is defined as the average of three consecutive valid annual averages, where each annual average is built up from quarterly averages.

Monitoring for the new PM2.5 standard was phased in starting in 1999; full implementation of the new monitoring network was achieved as of April 2000. Annual maximum 24-hour average, annual 98th percentile of the 24-hour averages, and annual arithmetic averages for all sites in the enhanced I/M area (including sites which may have operated only during portions of some years) are shown in Figure 2-4. No exceedances of the annual average NAAQS have been recorded at any location. The maximum annual average for the 1999-2002 period compiled by CDPHE was 13.5 ug/m3 at the Denver NJH. Exceedances of the 24-hour standard level were observed on individual days at Arapahoe (in 1999) and Denver CAMP site (in 2001) but in no case did the annual 98th percentile of the daily averages exceed the NAAQs.[4] The maximum 24-hour design value was 57.3 ug/m3 recorded at Adams City in 2001. However, the Denver CAMP monitor recorded two days with concentrations just above 65 ug/m3 (68.4 and 68.0, both in February, 2001). Thus, a violation could occur in Denver under current or increased emission loadings if meteorological conditions similar to those associated with the high values observed in February 2001 were to reoccur, but the frequency of occurrence would have to be much greater than has been observed thus far.

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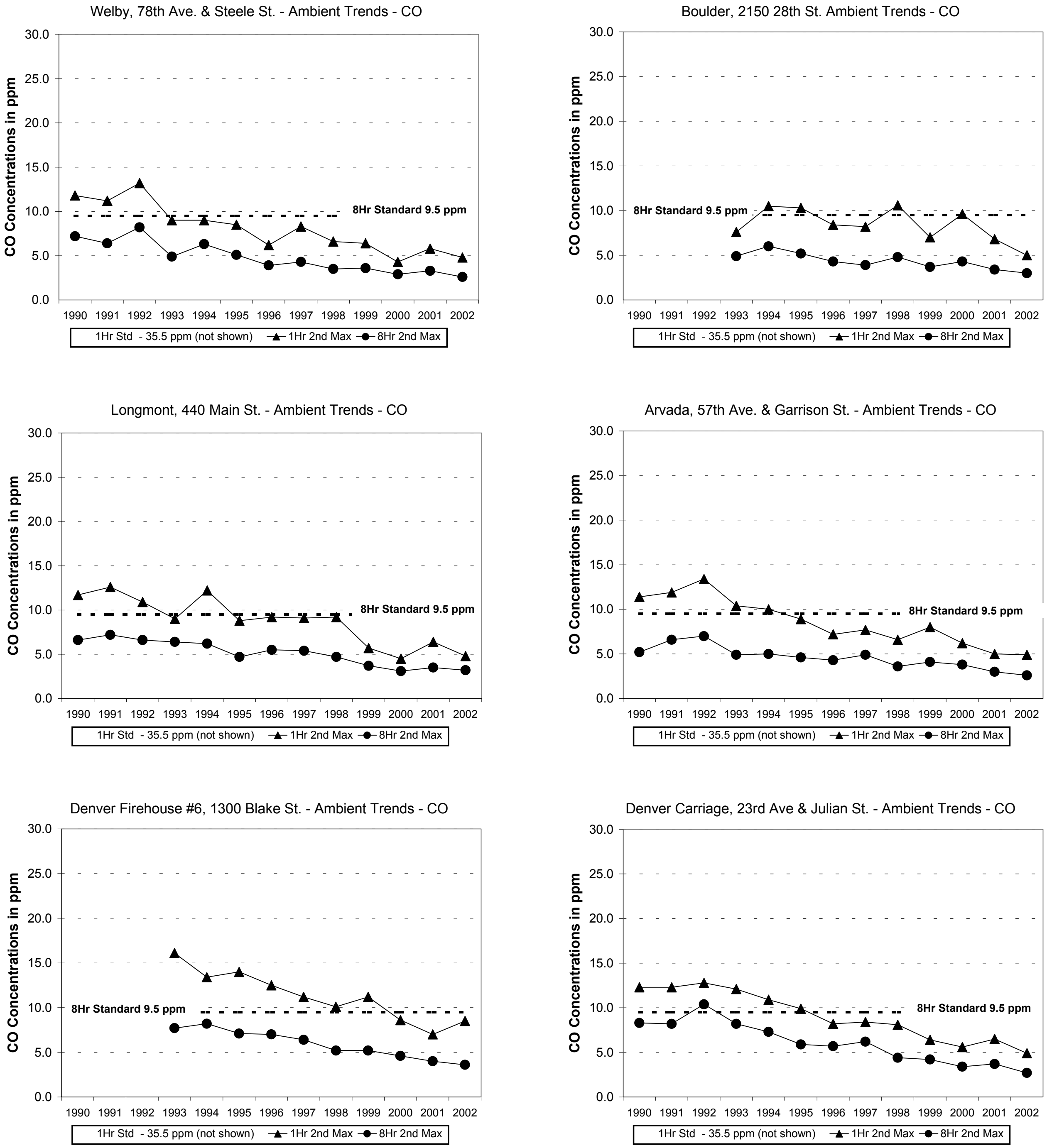
[3] Annual averages are based on all available data; in some cases, data completeness may be less than required by EPA for a valid annual average (75% in each calendar quarter).

[4] The PM2.5 standard specifies that the design value for the 24-hour standard is the 98th percentile of the annual distribution of the daily averages averaged over three consecutive years.

Since monitoring of PM2.5 began only in 1999 (and the complete network of monitoring stations was not in place until 2000), there is generally speaking a fair amount of missing data during the most recently available three year period and it is not possible to discern any trends in PM2.5 at this time. However, the monitoring results summarized above suggest that the Denver area is not likely to be found in violation of the PM2.5 NAAQS when the initial attainment/nonattainment determinations are made in April 2004.

In most metropolitan U.S. locations, the annual PM2.5 NAAQS is the limiting standard. Within the enhanced I/M area, the highest 3-year average concentration reported thus far for sites with data reported in each of three consecutive years is 10.9 $\mu g/m^3$ (at Denver CAMP) which is well below the 15 $\mu g/m^3$ NAAQS. This suggests a fairly significant increase in emissions would be required to produce a violation. As noted above, however, the monitoring record is as yet fairly incomplete and this conclusion may have to be revised as more data become available.

PM2.5 mass is dominated by secondary particles to a much greater extent than is the case with PM10. As shown in Figure 2-5 from a Denver receptor modeling study, a significant fraction of these secondary particles are formed from mobile source (combined on-road and off-road) exhaust emissions. As with ozone, formation of secondary PM takes place via complex non-linear processes that renders simple rollback models invalid. Advanced atmospheric models similar to those used for ozone are thus needed to estimate the impact of future emission changes on ambient PM2.5; application of these models is beyond the scope of the current audit. However, given the large contribution of mobile sources to PM2.5, any future changes in mobile source emissions can be expected to have a non-negligible impact on ambient PM2.5 levels.



Welby, 78th Ave. & Steele St. - Ambient Trends - CO

Boulder, 2150 28th St. Ambient Trends - CO

Longmont, 440 Main St. - Ambient Trends - CO

Arvada, 57th Ave. & Garrison St. - Ambient Trends - CO

Denver Firehouse #6, 1300 Blake St. - Ambient Trends - CO

Denver Carriage, 23rd Ave & Julian St. - Ambient Trends - CO

Figure 2-1. Ambient CO trends at sites in enhanced I/M program counties.

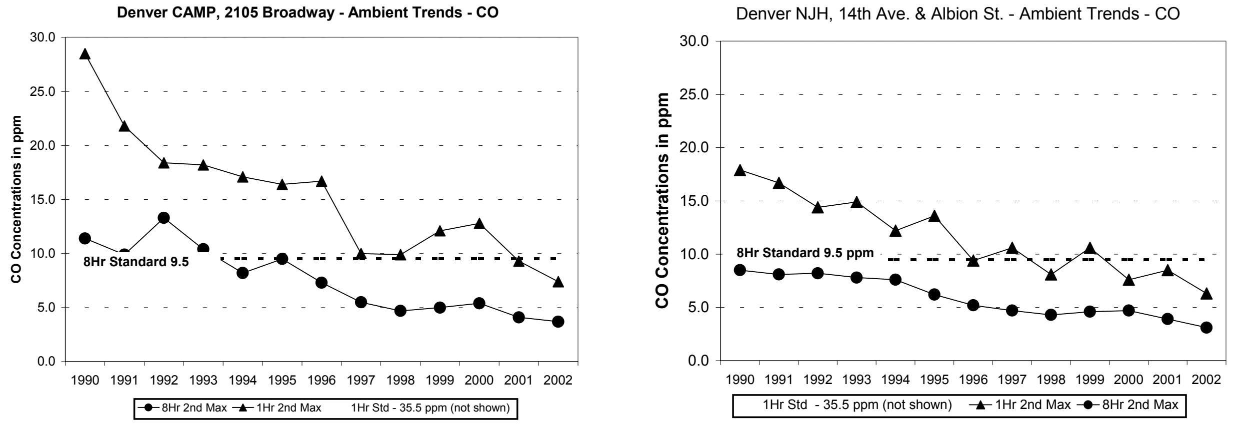
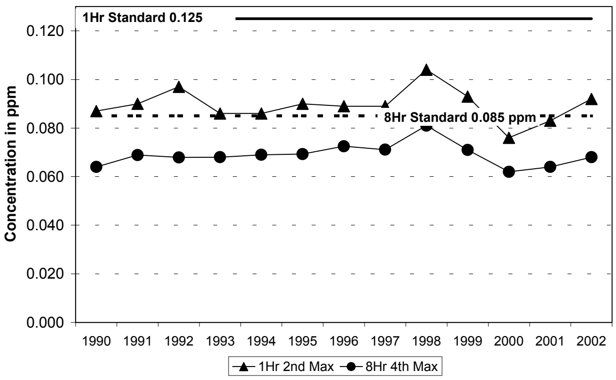
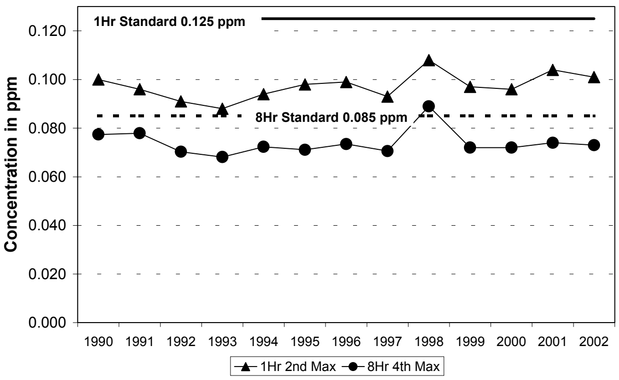


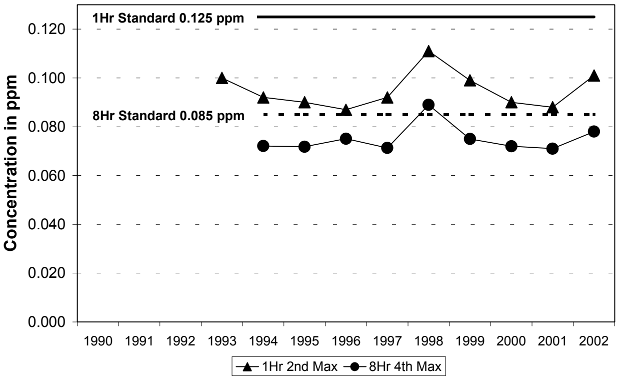
Figure 2-1. concluded.



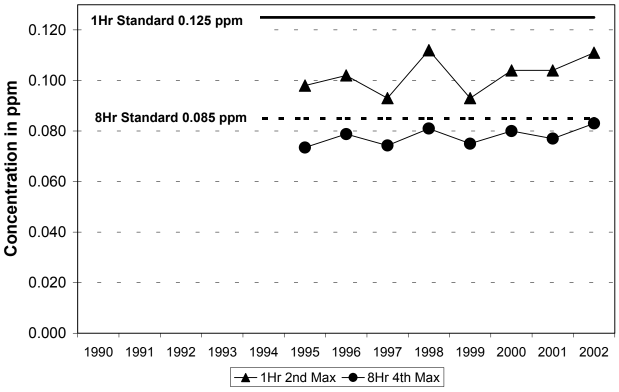
Welby, 78th Ave. & Steele St. - Ambient Trends - Ozone



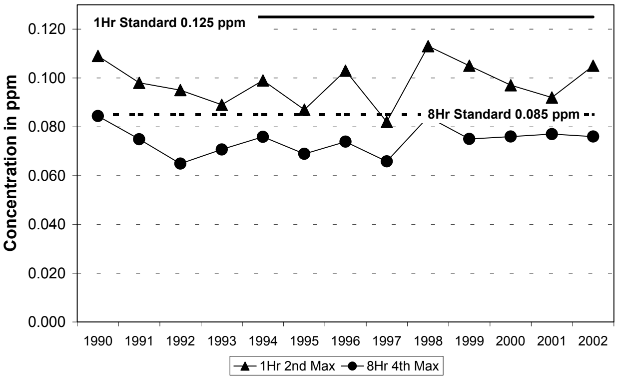
Arvada, 57th Ave. & Garrison St. - Ambient Trends - Ozone



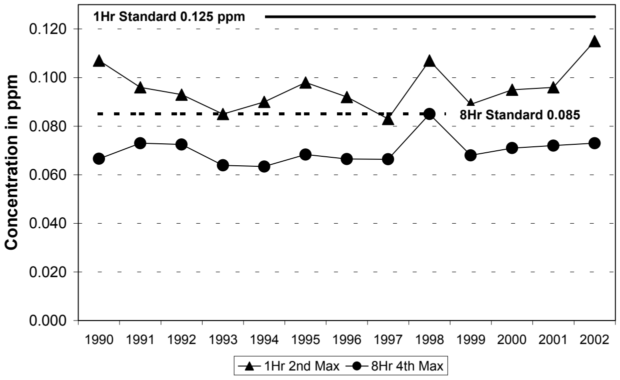
Boulder, 1405 1/2 Foothills Blvd. - Ambient Trends - Ozone



Chatfield Reservoir, Roxborough Pk Rd. - Ambient Trends - Ozone

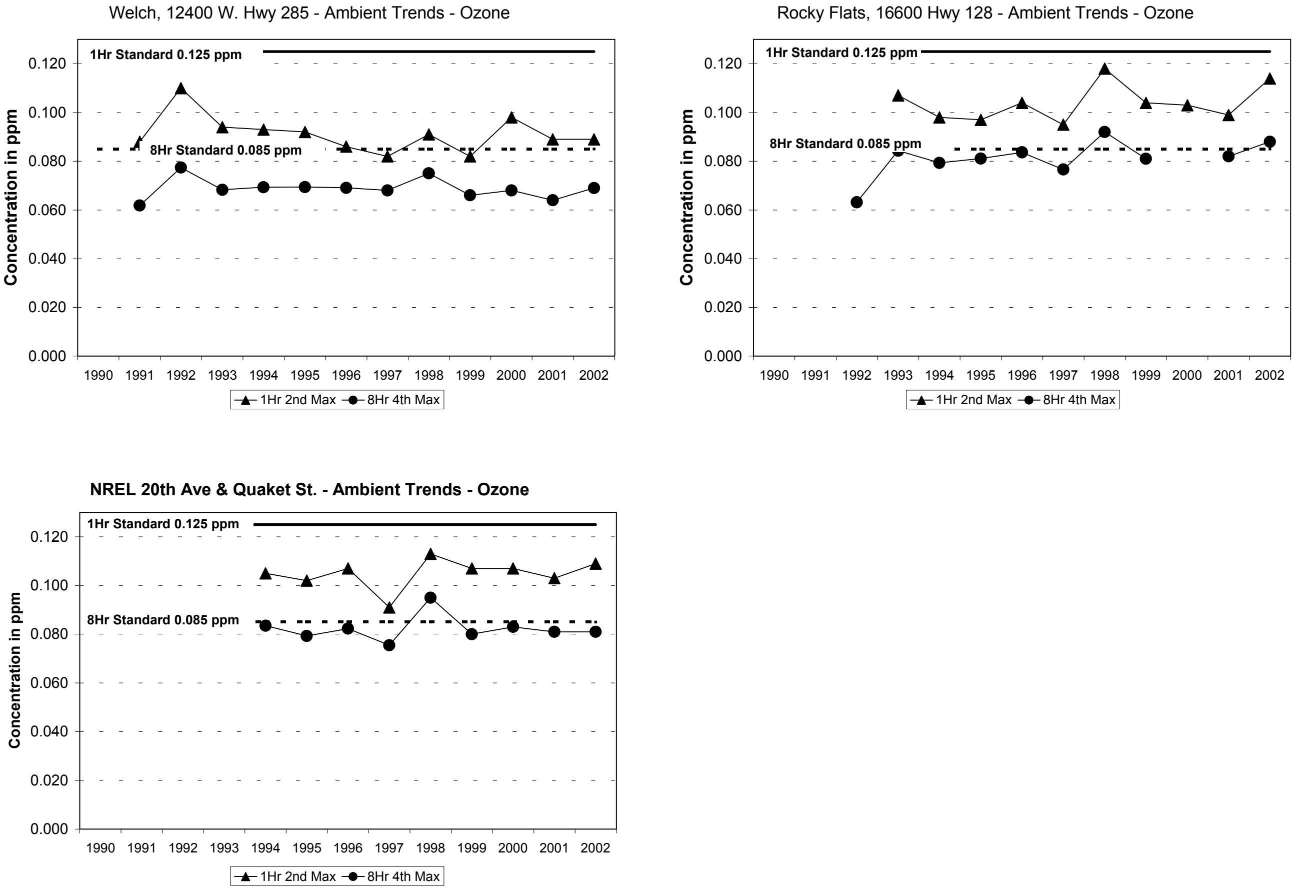


Highlands Reservoir 8100 S University Blvd - Ambient Trends Ozone



Denver Carriage, 23rd Ave. & Julian St. - Ambient Trends - Ozone

Figure 2-2. Ambient ozone trends at sites in enhanced I/M program counties.



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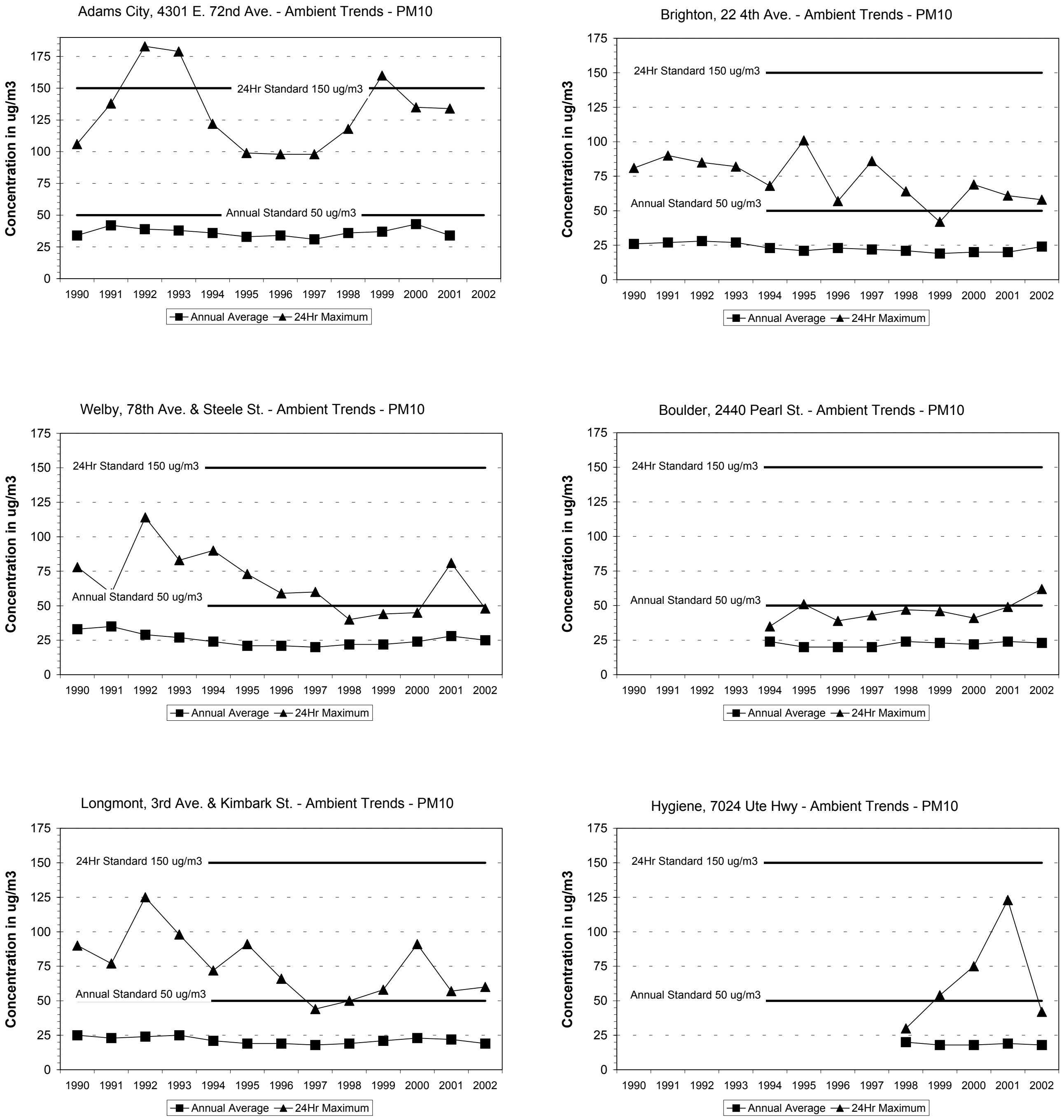


Adams City, 4301 E. 72nd Ave. - Ambient Trends - PM10

Brighton, 22 4th Ave. - Ambient Trends - PM10

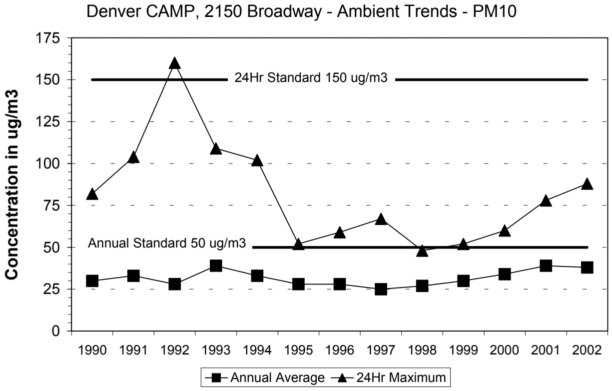
Welby, 78th Ave. & Steele St. - Ambient Trends - PM10

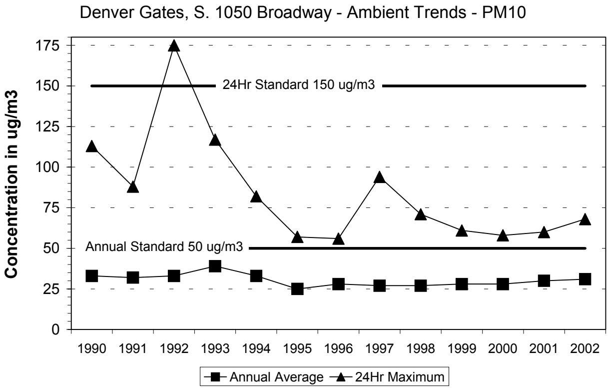
Boulder, 2440 Pearl St. - Ambient Trends - PM10

Longmont, 3rd Ave. & Kimbark St. - Ambient Trends - PM10

Hygiene, 7024 Ute Hwy - Ambient Trends - PM10

Figure 2-3. Ambient PM10 trends at sites in enhanced I/M program counties.





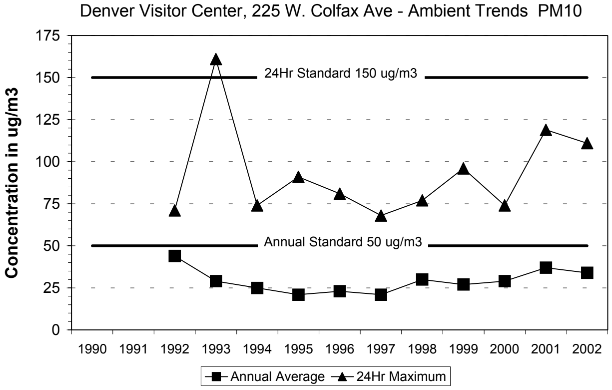


Figure 2-3. concluded.

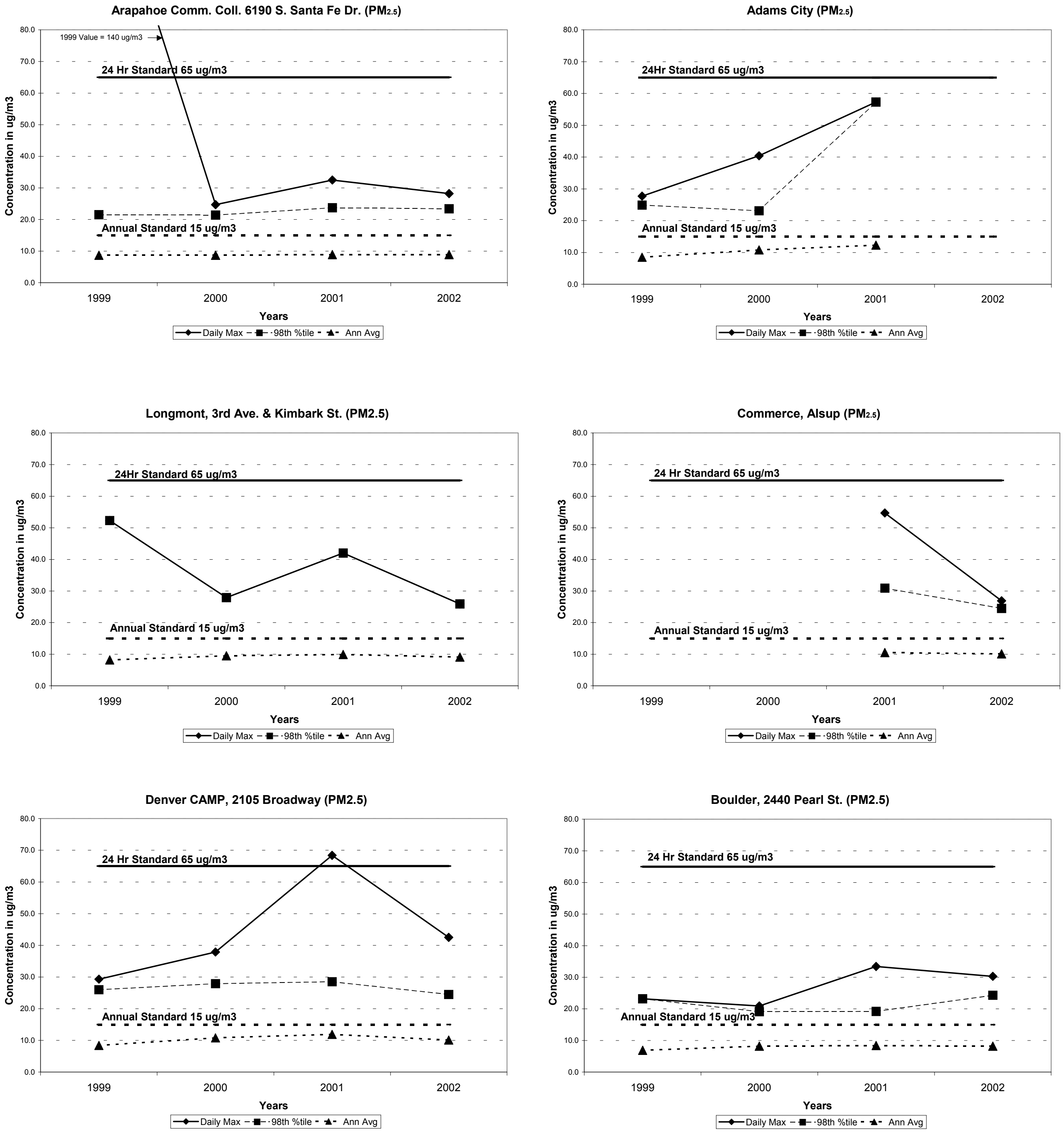


Figure 2-4. Ambient PM2.5 trends at sites in enhanced I/M program counties.

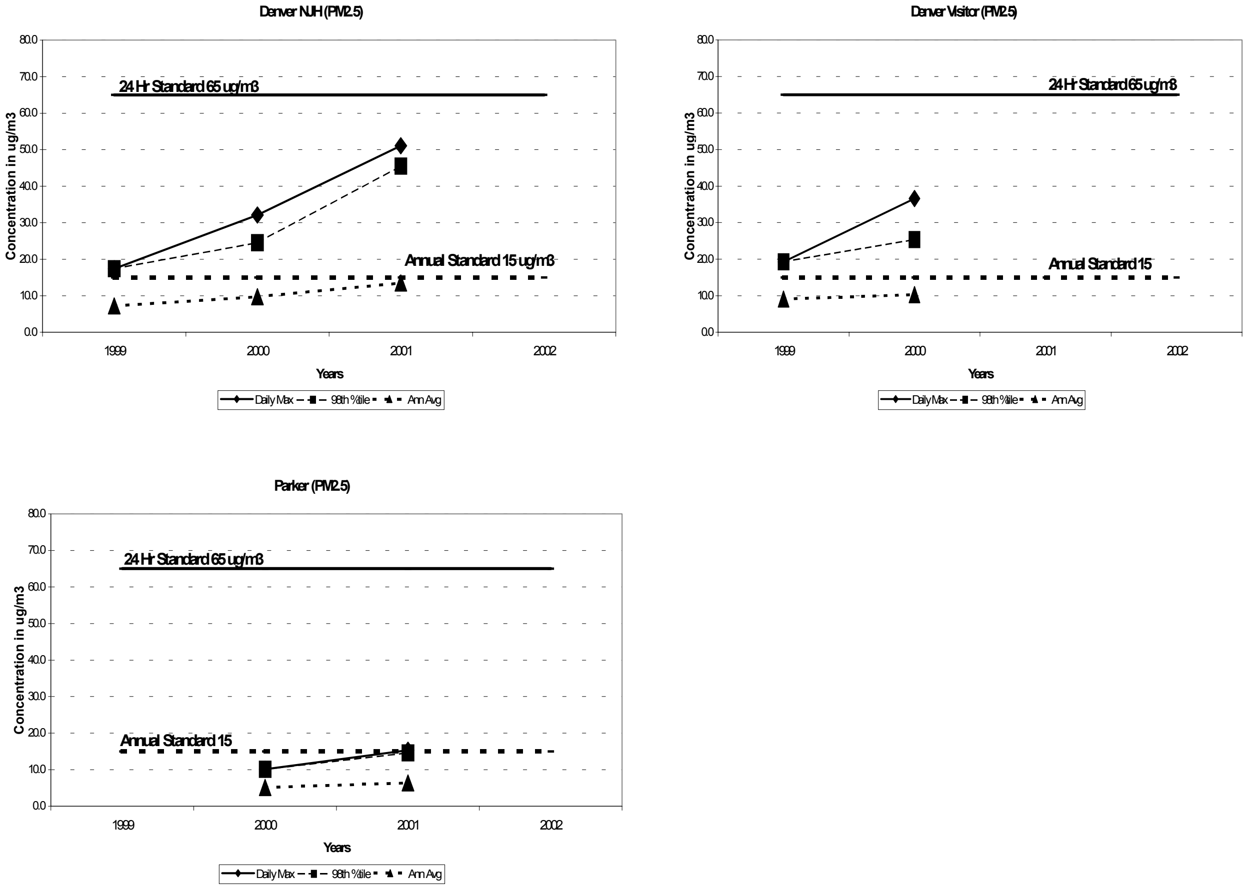


Figure 2-4. concluded.

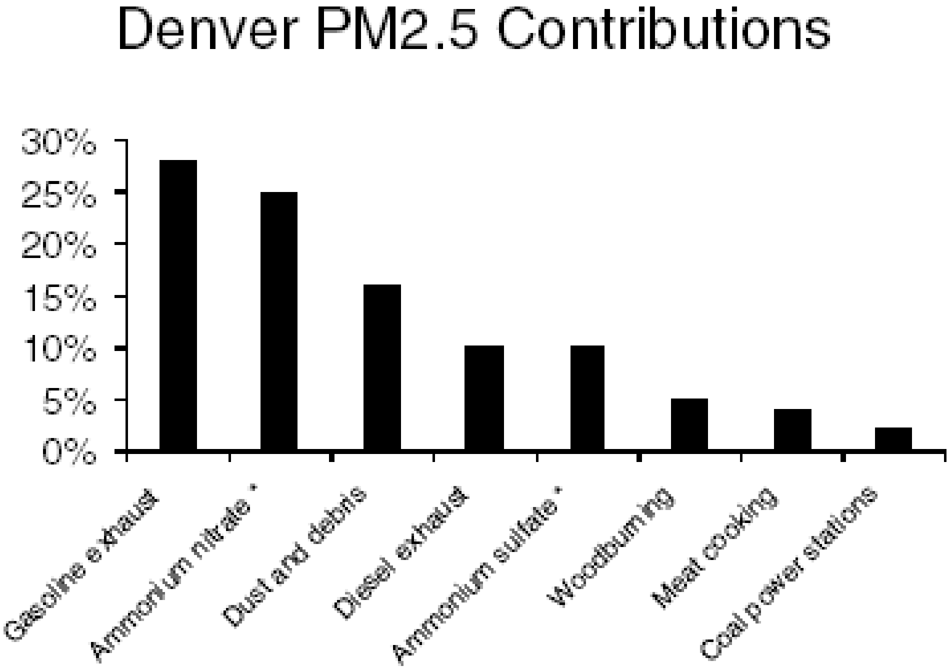


Figure 2-5. Relative contributions of particulate components to total PM2.5 (winter average) in Denver (source: Lawson and Smith, 1998).

3.0 DENVER VEHICLE FLEET CHARACTERISTICS

In this section we provide information on federal vehicle emissions standards and characteristics of the Denver vehicle fleet. This information is used in the benefits and cost estimates work described in later sections.

3.1 SUMMARY

Over the years, the Environmental Protection Agency (EPA) has implemented a series of progressively more stringent vehicle emissions standards and durability regulations. In addition, vehicle manufacturers have continually improved emissions performance and durability even during periods when the regulatory standards did not change. We found that with the continual tightening of these standards, and as older vehicles have been scrapped and replaced with newer vehicles, average vehicle emissions have declined substantially over time.

Using I/M test records and remote sensing measurements, we estimate that overall there are 1.74 million gasoline vehicles in the Denver area fleet. This includes 1.02 million light-duty gasoline cars, 0.66 million light-duty gasoline trucks, and 0.05 million heavy-duty gasoline trucks. Forty-five percent of these are 1994 or newer vehicles which have been equipped with more advanced emissions control systems. Approximately six percent are 1981 or older vehicles that have very limited, or in some cases no, emissions control systems.

3.2 VEHICLE EMISSION REGULATIONS AND CERTIFICATION STANDARDS

Vehicle emissions have been declining for many years, and will continue to decline. EPA has implemented a series of progressively more stringent vehicle emissions standards and durability regulations, and manufacturers have continually improved emissions performance and durability even during periods when the regulatory standards did not change. Congress first required emission controls on 1968 model year vehicles. The first catalytic converters appeared in the 1975 model year, and more sophisticated three-way catalytic converters (that reduce HC, CO, and NO_X emissions) with oxygen sensors were in most new cars beginning with the 1981 model year, in order to meet what are referred to as the “Tier 0” standards. Emission control requirements became significantly more stringent with the federal “Tier 1” standards beginning with 1994 model year vehicles, and the “Tier 2” standards required for 2004 and later model year vehicles. In addition to these standards, the automobile manufacturers agreed to a voluntary National Low Emission Vehicles (NLEV) program, which began in most of the country with model year 2001.

In addition to the emission standards, EPA also requires new vehicles to be equipped with on-board diagnostic (OBD) systems that monitor various components of vehicles’ engines and emission control systems. Second-generation OBD II systems were phased in beginning with the 1994 model year, and required in all 1996 and later model year vehicles.

3.3 DENVER FLEET CHARACTERISTICS

3.3.1 Vehicle Age Distributions, Mileage Accumulation Distributions, and Travel Fractions

The vehicle age distribution, also called the vehicle registration distribution, defines the fraction of vehicles in each vehicle class by model year. Vehicle age distributions are typically obtained from analysis of vehicle registration records. CDPHE provided vehicle registration distributions as part of the MOBILE6 input files. The registration distributions for calendar year 2000 are shown in Figure 3-1 for twenty five years as required input to the MOBILE6 model; 1976 refers to 1976 and older vehicles. The average age of a car is about 1½ years older than for light trucks.

The vehicle mileage accumulation distribution defines the average miles driven by age of vehicle for each vehicle class. The MOBILE6 model provides national defaults for mileage accumulation distributions, and these are used in most MOBILE6 modeling efforts. CDPHE uses these MOBILE6 defaults. Newer light trucks drive more miles per year than newer cars, but older light trucks drive fewer miles per year than older cars.

3.3.2 Travel Fractions

As older vehicles are retired, they are replaced by more recent models that start out cleaner and stay cleaner as they age. Vehicle emissions are estimated on a per mile basis, and typically newer vehicles are driven more miles per year than older vehicles. Total vehicle miles traveled by vehicle class, technology, and model year is therefore a key factor in estimating emissions. These so-called travel fractions were estimated by combining the CDPHE model year registration distributions and the MOBILE6 mileage accumulation rates for each vehicle class.

Figure 3-3 shows the calendar year 2000 travel fractions by vehicle class and model year. Newer vehicles have the largest travel fractions – there are both more of them and they are assumed to drive more miles per year than older vehicles. In this figure, 1976 refers to 1976 and older model years. This group represents an appreciable fraction of the total travel for all three vehicle classes. This is important because those generally have high emission rates.

Figure 3-4 shows the passenger car travel fractions by technology group for the years 1990 through 2015; Figures 3-5 and 3-6 show the travel fractions for light-duty trucks. What can be clearly seen is that over time a larger and larger fraction of vehicle miles traveled are from newer and newer technology cars.

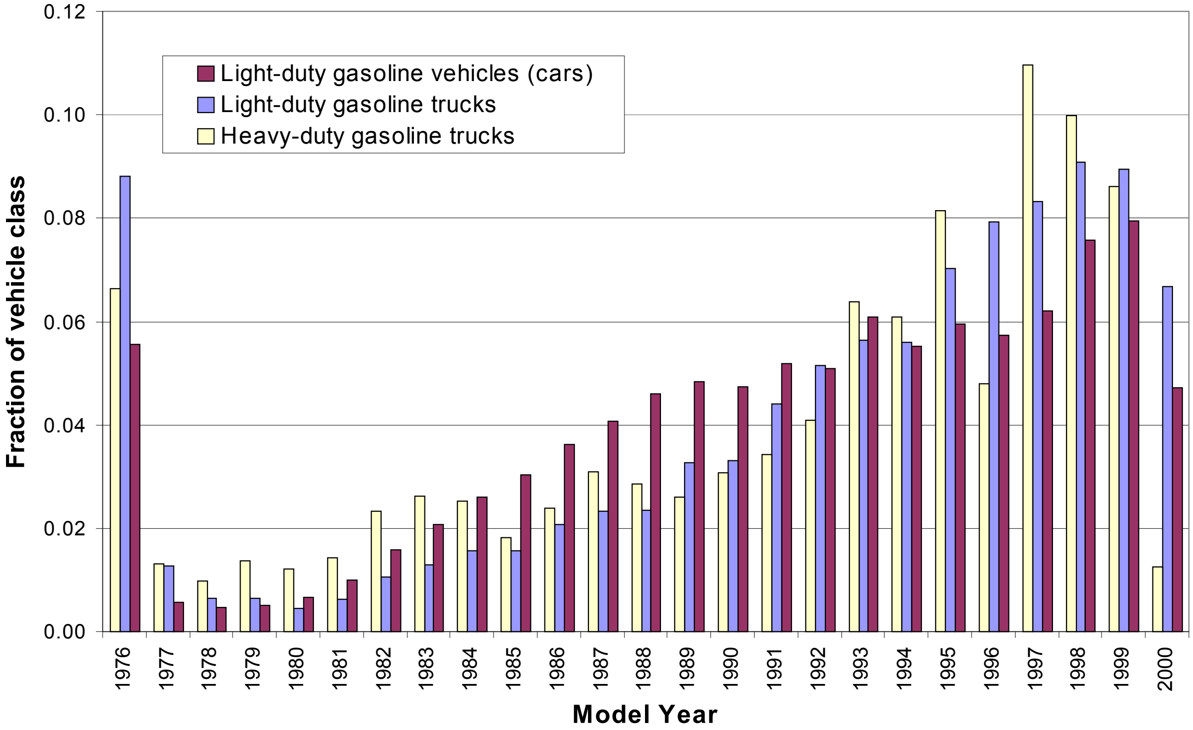


Figure 3-1. Vehicle registration distributions for calendar year 2000. (Source: CDPHE)

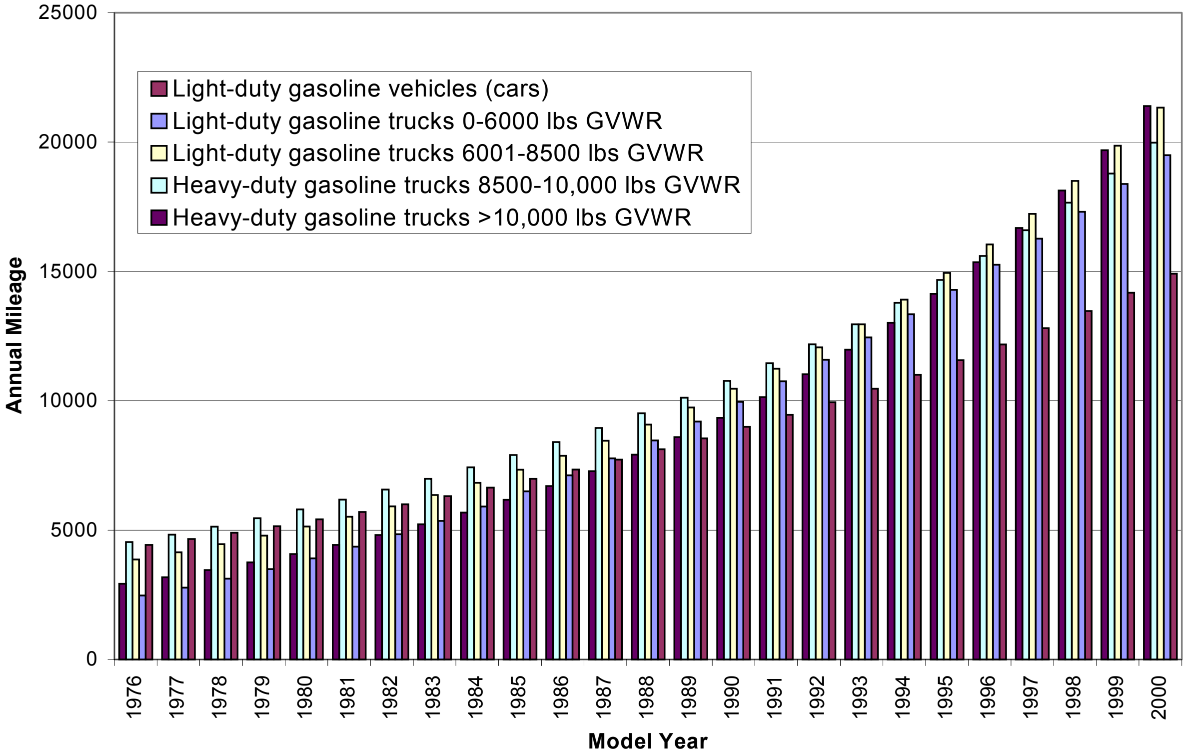


Figure 3-2. Vehicle mileage accumulation distributions for calendar year 2000. (Source: MOBILE6)

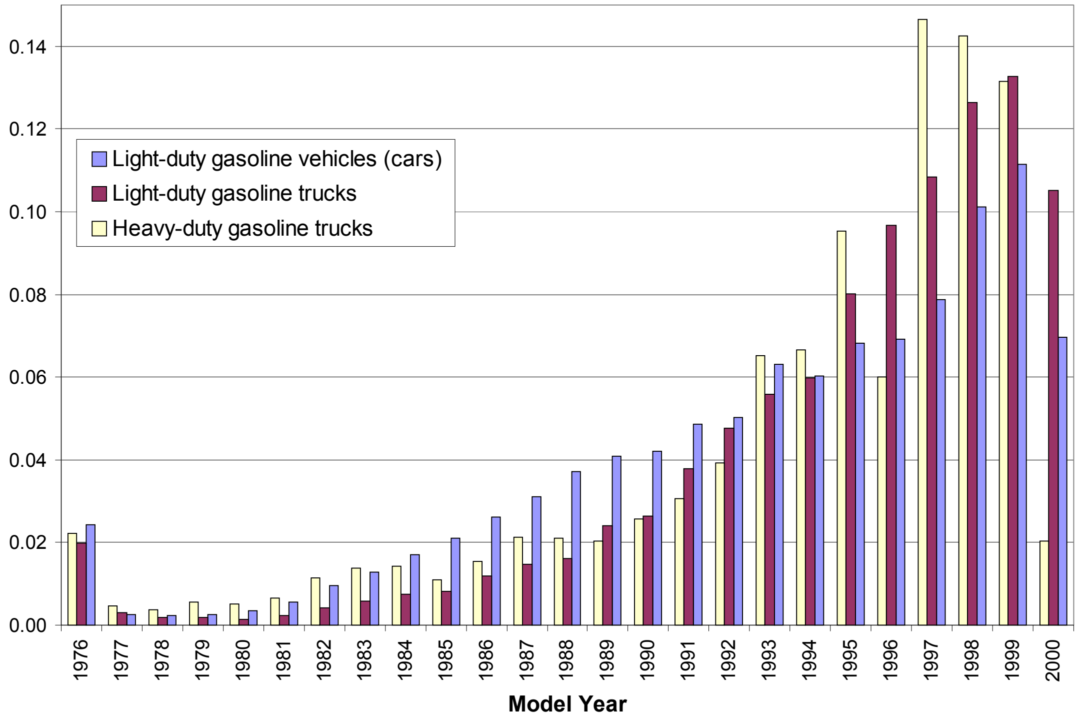


Figure 3-3. Calendar year 2000 model year-specific travel fractions by vehicle class. (Source: Analysis of data from CDPHE and MOBILE6)

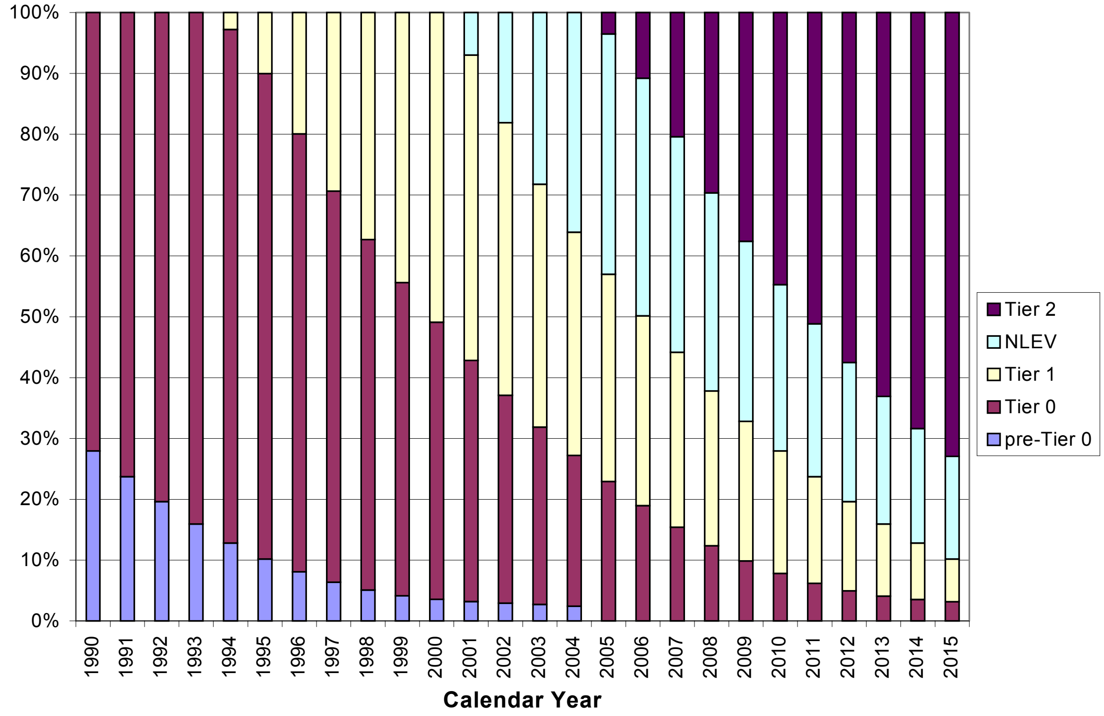


Figure 3-4. Trend in technology group-specific travel fractions for light-duty gasoline vehicles. (Source: Analysis of data from CDPHE and MOBILE6).

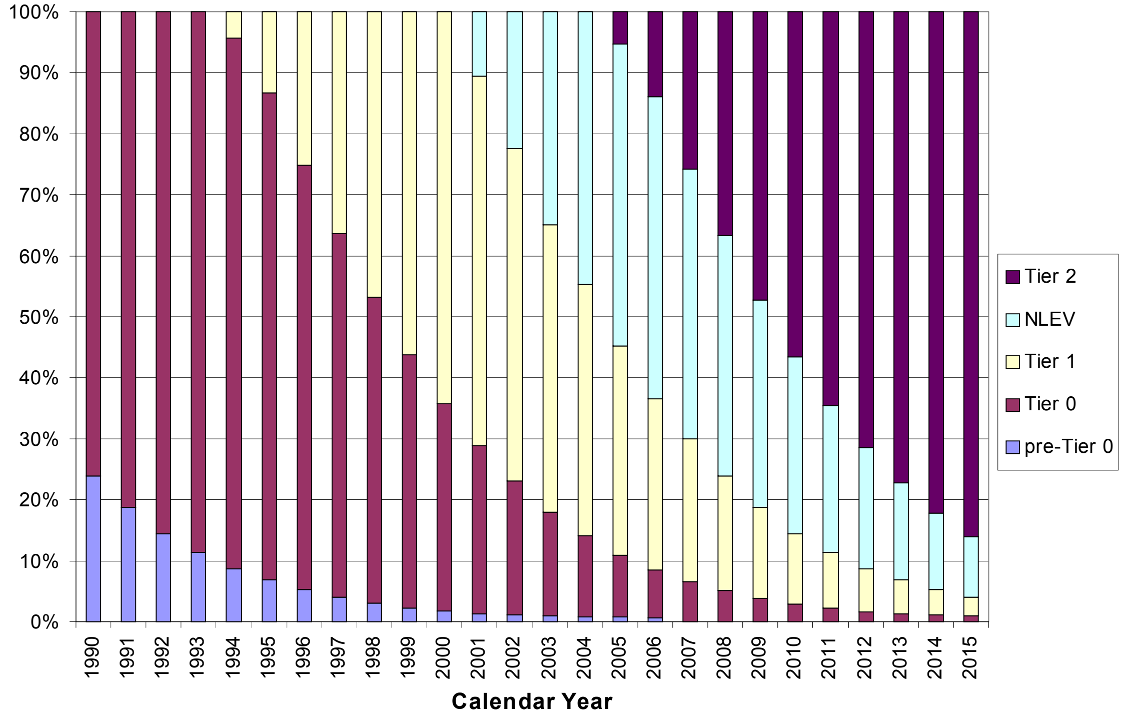


Figure 3-5. Trend in technology group-specific travel fractions for light-duty gas trucks <6000 lbs GVWR. (Source: Analysis of data from CDPHE and MOBILE6)

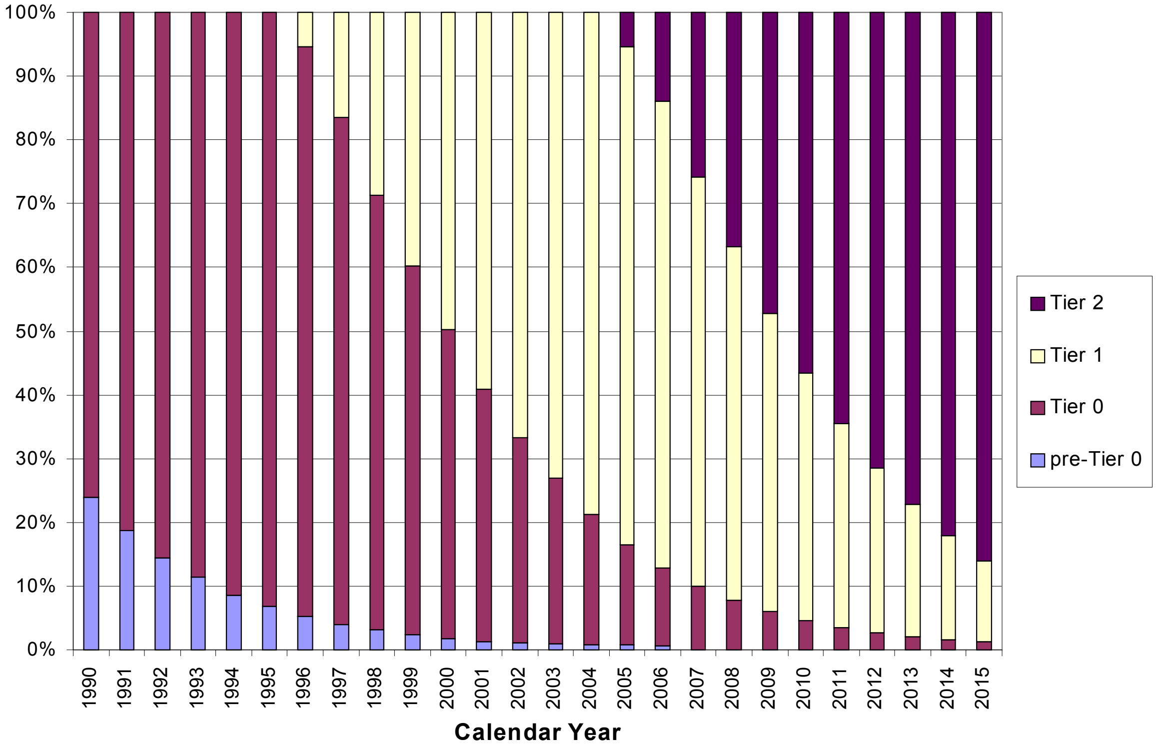


Figure 3-6. Trend in technology group-specific travel fractions for light-duty gas trucks >6000 lbs GVWR. (Source: Analysis of data from CDPHE and MOBILE6)

4.0 ESTIMATED EMISSION REDUCTION BENEFITS OF AIR PROGRAM

In this section we provide information on the estimated emission reduction benefits resulting from the AIR Program.

4.1 SUMMARY

In order to assess the benefit of the AIR Program, we used Program data and on-road emissions measurements to analyze the changes in emissions before and after vehicles were repaired or removed from the region from approximately June 2000 to June 2001. Specifically, we looked at:

- Vehicles that failed their initial inspection, were repaired, and then passed on retest; and
- Vehicles that failed their initial inspection, did not pass a retest, and were permanently removed from the region.

We estimated the emissions reduction for each vehicle and then projected this number out for the entire fleet of vehicles subject to the AIR Program. Overall, we found that the AIR Program has reduced carbon monoxide emissions by about 16 percent and hydrocarbons by about 18 percent. However, we found that, on average, repairs made resulted in increased nitrogen oxides emissions of about 0.5 percent. We also found that the Program has helped reduce fuel usage by 0.2 percent.

In general, carbon monoxide and hydrocarbon emissions benefits are similar for cars and light trucks; heavy trucks account for a very small portion of the carbon monoxide benefits, and a larger portion of the hydrocarbon benefits, particularly from older vehicles. The largest carbon monoxide and hydrocarbon benefits are for mid-1980s model year vehicles, which have less advanced emission control systems than more recent model years, and hence have higher base emissions. Specifically, we found that 1986 and older vehicles, which make up about 20 percent of the Denver area fleet, account for about 50 percent of the carbon monoxide and hydrocarbon benefits, and about 30 percent of the fuel savings. The oldest half of vehicles (1991 and older) account for about 85 percent of the carbon monoxide and hydrocarbon benefits, and 50 percent of the fuel savings. On the other hand, the newest 40 percent of vehicles tested (1994 and newer) account for only 10 percent of the carbon monoxide and hydrocarbon reduction benefits of the Program.

4.2 METHODOLOGY TO ESTIMATE EMISSION REDUCTION BENEFITS

The emissions reduction benefits of I/M programs accrue from three primary processes: lasting repairs and maintenance made to vehicles prior to initial I/M testing (pre-inspection maintenance); lasting repairs made to vehicles after they have failed I/M testing (post-failure repair); and permanent removal of failed vehicles from the I/M area (no-final-pass removal). Many I/M program evaluations are based on emission reductions immediately after vehicles pass their I/M cycle; however, an accurate evaluation must account for the durability of vehicle repairs, in order to estimate the emission benefit between I/M cycles. In addition, a simple "before" vs. "after" emissions comparison ignores the potentially large benefits from pre-inspection maintenance and no-final-pass removal that would not have occurred without the I/M program. We attempted to estimate the emissions reductions for each of these three components of the AIR program.

In addition, the full benefit of an I/M program is not merely the reduction in the emissions inventory as measured under the initial I/M test, but should include the reduction from how high emissions would have been if there had not been an I/M program. Finally, the benefit of a program should be measured over a period of time, such as a calendar year, rather than at a certain point in the I/M cycle, in order to capture the changes in emissions over time. Our estimate of the benefits of the AIR program includes the full benefit over a calendar year from one cycle of testing.

The estimation of the emissions impact of all three of the I/M processes, as well as emissions deterioration in the absence of the program, requires assumptions. Therefore we provide a best estimate of the emission reduction benefits of the Program, as well as a range of high and low benefit estimates, based on optimistic and conservative assumptions regarding repair durability and emissions deterioration. We present our best estimate in terms of average tons per day of each pollutant prevented by the program by vehicle model year, by vehicle type and by process.

We used a combination of I/M program test results and remote sensing measurements to estimate the effect of post-failure repair and no-final-pass removal. We also attempted to use remote sensing measurements to estimate the effect of pre-inspection maintenance; however, we were not able to discern a pre-inspection benefit using the relatively limited number of measurements available. Because there are no measurements of evaporative HC emissions, our estimate of the effect of the AIR Program is for exhaust emissions only; any reduction in evaporative HC emissions resulting from vehicle repair or replacement/removal from the AIR program is not estimated.

4.2.1 Description of Method and Data Used

We used a "bottom-up" approach to estimate the emission benefits of the AIR program from three processes: pre-inspection maintenance and repairs, post-failure repairs, and removal/replacement of no-final-pass vehicles. (Wenzel et al., 2000; Singer and Wenzel, 2003). For each process, emission reductions are estimated in terms of average grams per mile by vehicle type (heavy duty gasoline truck, light-duty gasoline truck, and light-duty gasoline passenger car) and model year (1971 to 2000, with all vehicles older than 1971 included in the 1971 model year). The gram per mile emission reduction is then multiplied by the number of vehicles tested, and multiplied by assumptions regarding annual mileage driven, obtained from EPA's MOBILE6 model[1], to obtain total grams of emission reduction. Grams

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[1] The model only includes annual mileage assumptions for vehicles 1 to 25 years of age; we extrapolated the polynomial curve fits from MOBILE6 out to 30 years to encompass model years 1971 through 2000. We averaged MOBILE6 annual mileage assumptions for LDGT1/2 and LDGT3/4 categories to obtain annual mileage assumptions for all light trucks, and HDGT2B/3 and HDGT4+ to obtain annual mileage assumptions for all heavy trucks.

are then converted to short tons, and divided by 365 days to obtain ton per day emission benefits.

For those 1981 and older vehicles tested in the annual idle program, the number of unique vehicles and average emission rates were calculated from all initial tests in 2000; for the biennial IM240 program, the number of unique vehicles and the year 1 emission rates were calculated from all initial tests in 2000, while the number of unique vehicles and year 2 emission rates were calculated from all initial tests in 1999. For vehicles tested in January of 1999 or 2000, our estimate of benefits is for the year January 2000 to January 2001. For vehicles tested in December of 1999 or 2000, our estimate of benefits is for the year December 2000 to December 2001. Because emissions increase as vehicles age, vehicles tested in December 2000 will have higher emissions than vehicles of the same model year tested in January 2000. Therefore, our estimate of benefits from the AIR program is for the average vehicle initially tested midway through the year 2000, and encompasses the year from roughly July 2000 to June 2001. We used the number of unique vehicles tested in each year, rather than the total number of initial tests in each year, to avoid double-counting vehicles that received an additional, change-of-ownership I/M cycle.

Figure 4-1 presents the number of unique vehicles tested in the Colorado AIR program, by vehicle type and model year. The figure indicates that a large number of model year 1997 and newer vehicles were tested in 1999 and 2000, even though they were exempted from the program until 2001. Vehicles from these exempted model years were tested either because they migrated from another state, and were required to be tested upon initial registration in Colorado, or they were sold and required to take a change-of-ownership I/M test. Very few heavy trucks are tested in the program. The number of heavy trucks tested increases from model year 1972 to 1978, but then decreases dramatically for model year 1979 and does not increase for newer model years.

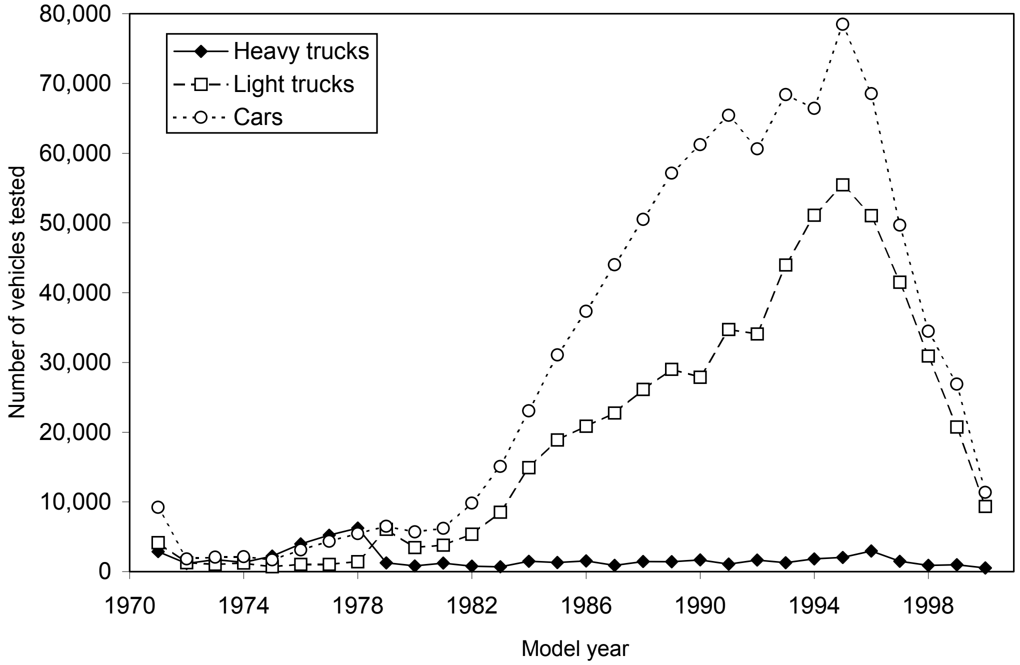

Figure 4-1. Number of gasoline vehicles tested in Colorado AIR Program (2000 for idle tests, 1999 and 2000 for IM240 tests).

Figure 4-2 shows the fraction of tested vehicles by model year and vehicle type. Starting with model year 1990 vehicles the fraction of light trucks steadily increases, from 31% of all 1990 vehicles to 44% of all model year 2000 vehicles. This increase in light trucks is accompanied by a corresponding decrease in cars tested, from 67% of all 1990 vehicles to only 54% of all 2000 vehicles. These trends reflect the exploding popularity of light-duty pickup trucks and SUVs in the 1990s. The heavy truck fraction of the I/M fleet decreases dramatically, from as much as half of the model year 1975 to 1978 fleet to under 10% of the 1979 fleet.

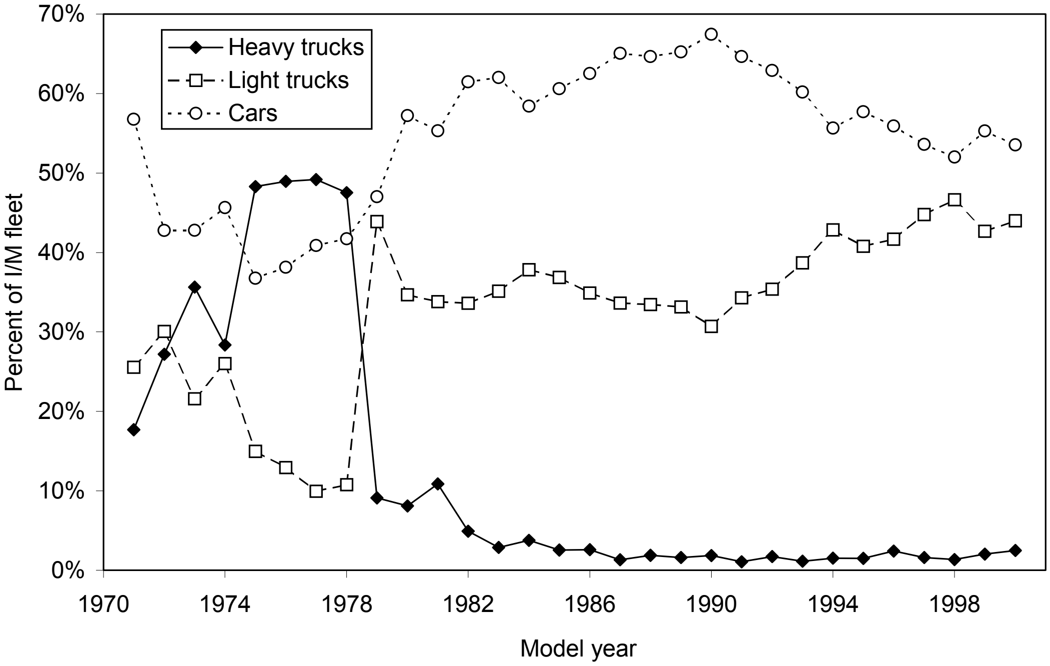

Figure 4-2. Distribution of I/M fleet by vehicle type and model year.

Figure 4-3 shows the MOBILE6 annual mileage assumptions, by vehicle type and model year. The figure indicates that the mileage assumptions vary dramatically by vehicle age, with the newest vehicles being driven several times the number of miles of older vehicles. The increase in annual miles by vehicle age is much large for trucks than cars: MOBILE6 assumes that a 2000 truck is driven over 20,000 miles, but a 1971 truck is driven only 2,100 miles. MOBILE6 assumes that 1971 cars are driven about 65% more annual miles than the average 1971 light truck, but that 2000 cars are driven 27% fewer annual miles than model year 2000 trucks. Clearly these assumptions regarding annual mileage by vehicle age are critical to accurately estimating emissions and emission benefits from the AIR program. We recommend that CDPHE use I/M test results (which record vehicle odometer readings), registration records, and remote sensing measurements to confirm that the MOBILE6 annual mileage assumptions reflect driving patterns in the Denver area.

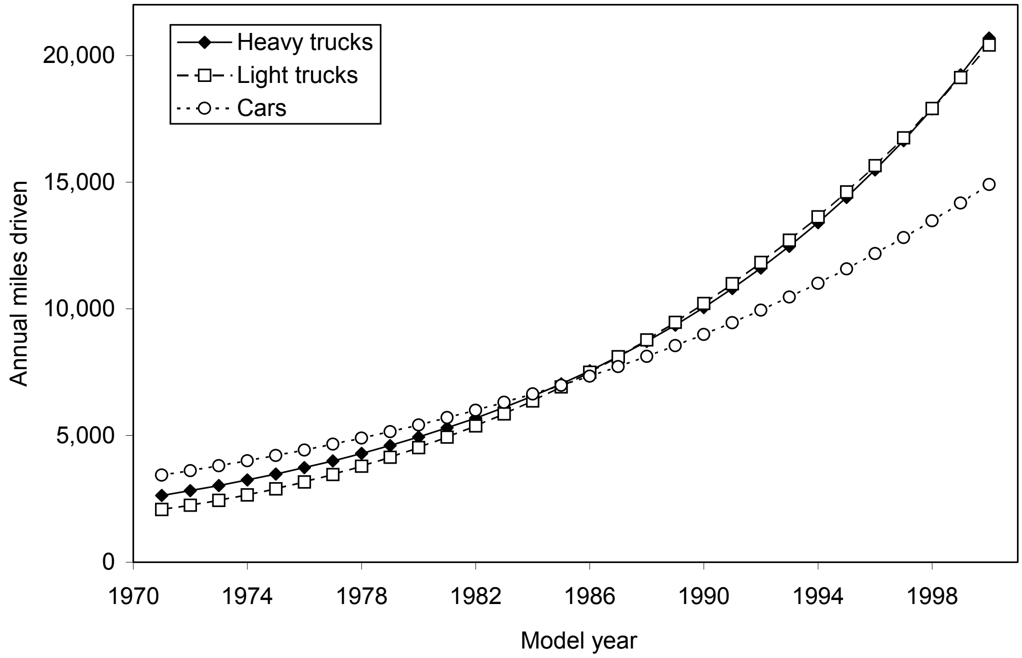

Figure 4-3. Annual mileage assumptions by vehicle type and model year (from MOBILE 6).

The IM240 test measures CO, HC, and NOx emissions in grams per mile, and fuel economy in miles per gallon; however, the two-speed idle test measures only CO and HC emissions, in percent and ppm concentrations. All estimates of idle emissions in this analysis were made using the 2500 rpm portion of the two-speed idle test. In order to calculate mass emissions and emission reductions of vehicles given the idle test, we needed to convert the idle CO and HC emission concentrations to rough IM240 equivalents. In previous analyses, including the previous audit of the AIR program, researchers have converted idle emissions to IM240 or FTP equivalents based on correlation coefficients for a small number of vehicles tested on both types of tests (Sierra research, 1997; DeFries et al., 1999; AIR, 1999). There are several limitations with this approach, including the lack of data on a sample of Colorado vehicles tested on both types of test. Therefore, we compared the IM240 and idle test emissions trends by vehicle type and model year, and developed conversion factors that best “link” the trends of the two emission tests over model year 1971 to 2000 vehicles. We developed six conversion factors. for the combination of three vehicle types and two pollutants; each factor was applied to all idle emission rates for that pollutant and vehicle type, regardless of model year or I/M result. Because no heavy-duty vehicles are given an IM240 test, we used the light-duty truck conversion factors for heavy-duty trucks. More details on how we derived these conversion factors can be found in Appendix 4A. Because the idle test does not measure NOx emissions, or emissions in terms of mass, we could not estimate changes in NOx emissions or fuel consumption for light-duty vehicles older than model year 1982, and all heavy-duty vehicles.

Clean vehicles can be passed after only 30 seconds of testing on the IM240. ESP has developed software to project what the emission rates of “fast-pass” vehicles would be if they were tested over a full IM240 test. The fast-pass feature was disabled for all vehicle tests conducted for a period of several months in early 1996. We compared the measured full-test emissions of these vehicles with the projected full-test emissions of fast-pass vehicles, by vehicle type and model year, to assess the accuracy of the ESP projection. We found that the projected emissions consistently overstated car CO across all model years (ranging from 5% to 20%, for individual model years), overstated CO for older light trucks (by as much as 30%, and understated CO for newer light trucks (by as much as 20%). The projected emissions tended to understate HC and NOx emissions for both car and light trucks. Given the time and resource constraints for this study, and the lack of a more recent random sample of vehicles given a full IM240 test, we used ESP's projection of full IM240 emission results in our estimation of program benefits. Details on the accuracy of the ESP projection can be found in Appendix 4B.

Finally, we attempted to use remote sensing measurements to estimate the effect of pre-inspection maintenance on vehicle emissions. There currently are two major sources of remote sensing measurements in the Denver area: several years of measurements made by the University of Denver at two sites, and several years of measurements made by the I/M program contractor, ESP, at multiple sites in the Denver area. The ESP measurements were requested by CDPHE to fulfill EPA's requirement that 0.5% of the Enhanced I/M on-road fleet be measured every year, and used to evaluate the effectiveness of the I/M program in reducing on-road emissions. We originally hoped to combine these datasets to obtain remote sensing measurements of enough vehicles to discern an impact of pre-inspection maintenance in the few weeks before a scheduled I/M test on on-road emissions. However, a comparison of remote sensing emissions from these two sources revealed substantial differences, indicating that the data could not be combined without adjustments. Therefore we focused our analysis of in-use emissions on the ESP measurements, simply because there were more of them available. Details on the comparison of ESP and DU remote sensing measurements can be found in Appendix 4C.

4.2.2 Emission Reductions from Pre-inspection Maintenance/Repair of All Vehicles

Previous analyses in Phoenix, Arizona and California indicate that pre-inspection maintenance can result in as much, or more, emission reduction as post-failure repair. However, estimation of emission reductions from pre-inspection maintenance is extremely difficult. Two methods have been used to date: unscheduled I/M testing of vehicles at roadside (preferably made soon before their scheduled I/M test; see Wenzel et al., 2000), and analysis of a large number of remote sensing measurements of vehicles made less than one month prior to their scheduled I/M test (see Wenzel, 2001). Roadside IM240 tests of Colorado vehicles are not available. Analysis of a large number of remote sensing measurements in Phoenix found a 12% reduction in on-road CO emissions roughly three weeks prior to initial I/M testing; this percent reduction was comparable to the reduction, also measured by remote sensing, from repairs of vehicles that failed their initial I/M test (Wenzel, 2001a).

As mentioned above, we originally hoped to combine remote sensing measurements made by UD and ESP to obtain enough measurements to discern an emissions reduction in the weeks before a scheduled I/M test, presumably from vehicle maintenance and repairs performed in anticipation of the inspection. However, we discovered that on-road emissions by vehicle type and model year from the two sources, although similar for CO were substantially different for HC and NOx, and could not be combined without careful adjustment. Therefore we analyzed the UD and ESP remote sensing emissions data separately.

We first had to make several adjustments to the remote sensing measurements, and filter out invalid measurements, according to protocols developed by the Coordinating Research Council E-23 project.[2] Then we matched the remote sensing measurements with the I/M test results of individual vehicles, by vehicle identification number (VIN). We analyzed remote sensing emissions of vehicles as a function of time before their I/M test. Figures 4-4 through 4-6 show the results of this analysis for CO, HC and NOx, respectively, using the ESP remote sensing measurements. The figures indicate that there is large variation, and statistical uncertainty, in average emissions by the number of weeks prior to the I/M test, and that there is no consistent increase in emissions in the months before, nor a consistent decrease in emissions in the weeks before, the I/M test. We found similar results using the UD remote sensing measurements, so combining the measurements from the two sources would not result in a consistent trend in emissions immediately before the I/M test. Therefore we assume that there is no benefit from pre-inspection maintenance in the AIR program.

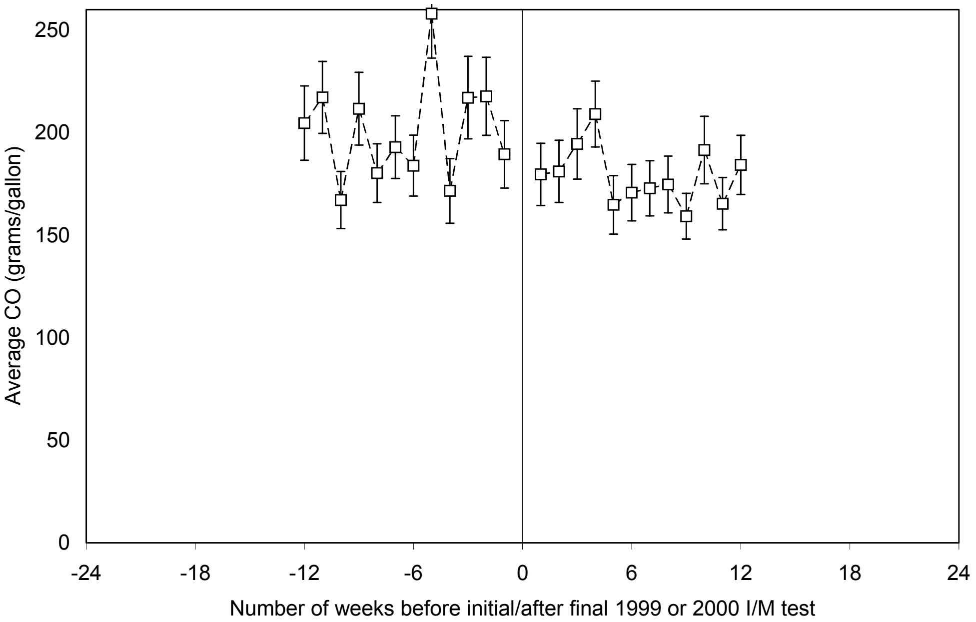

Figure 4-4. Average light-duty remote sensing CO emissions by number of weeks before initial or after final 1999 or 2000 I/M test.

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[2] We converted measured emissions concentrations into grams per gallon emission factors, using standard practice (Stedman and Bishop). We converted ESP HC emissions, which are reported as percent hexane, into percent propane, to make them comparable to the UD HC emission measurements; all HC emissions were then multiplied by a factor of two to account for the HC species in vehicle exhaust that are not detected by the spectrum of infrared light used in the remote sensor. We calculated vehicle specific power, a measure of the load on the engine at the time of measurement, using a standard equation in the literature (Pokharel et al., 2002). For the ESP data we identified invalid emissions measurements based on their emissions values. We limited our analysis only to measurements where it was determined that the reading of the pollutant of interest and the speed measurement were valid, and where the vehicles was experiencing a specific power of between 5 and 25 kilowatts per metric ton.

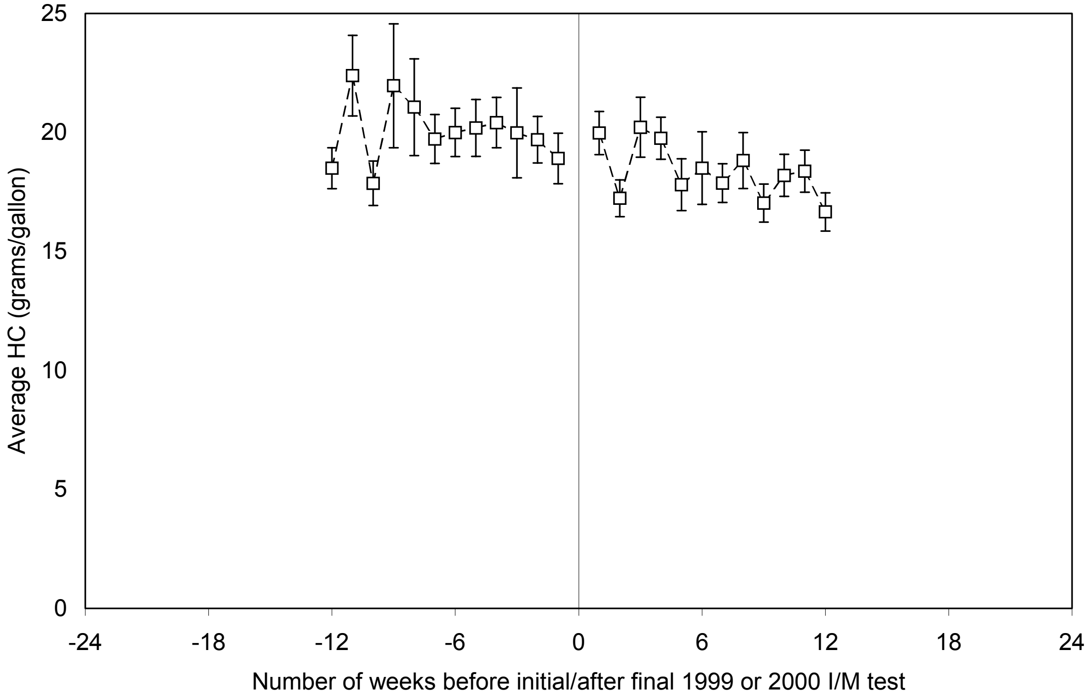

Figure 4-5. Average light-duty remote sensing HC emissions by number of weeks before initial or after final 1999 or 2000 I/M test.

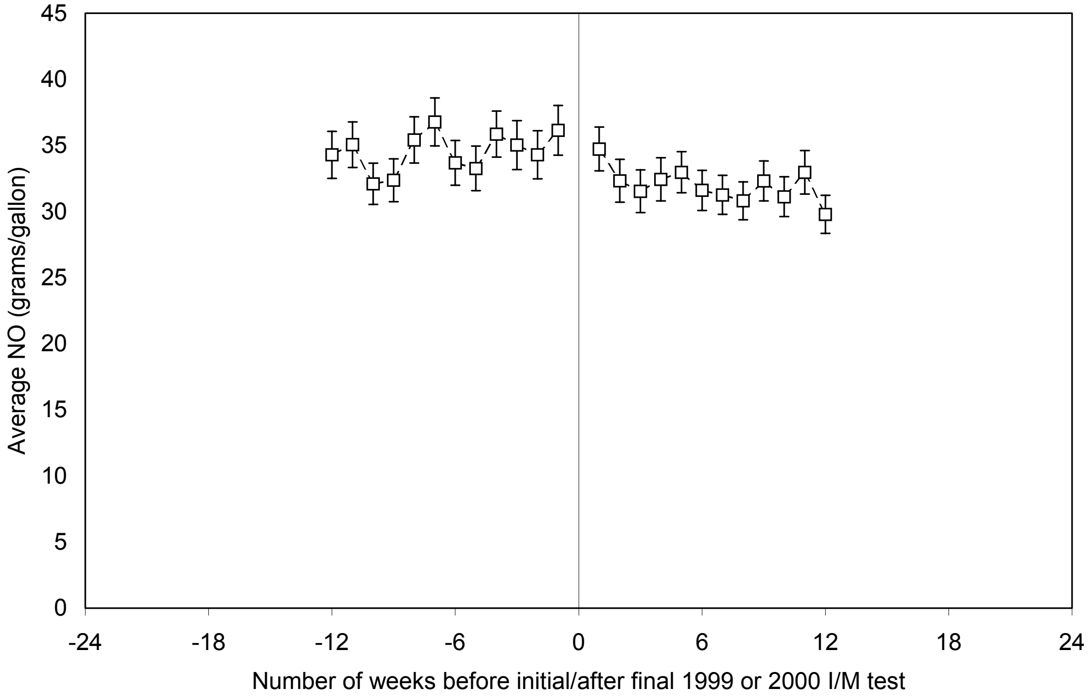

Figure 4-6. Average light-duty remote sensing NOx emissions, by number of weeks before initial or after final 1999 or 2000 I/M test.

We believe that, with a sufficient number of remote sensing measurements, such a benefit could be observed. For example, Figure 4-7 shows the number of ESP remote sensing measurements of light-duty vehicles by time relative to the I/M test: only 2,000 to 3,000 valid measurements per week were available from the ESP data. In contrast, 20,000 remote sensing measurements per week were available in the Phoenix area to detect the reduction in emissions three weeks prior to the I/M test. We recommend that in the future CDPHE utilize the measurements generated by the planned remote sensing clean screen program in the Denver area to estimate the effect of pre-inspection maintenance and repairs on on-road emissions.

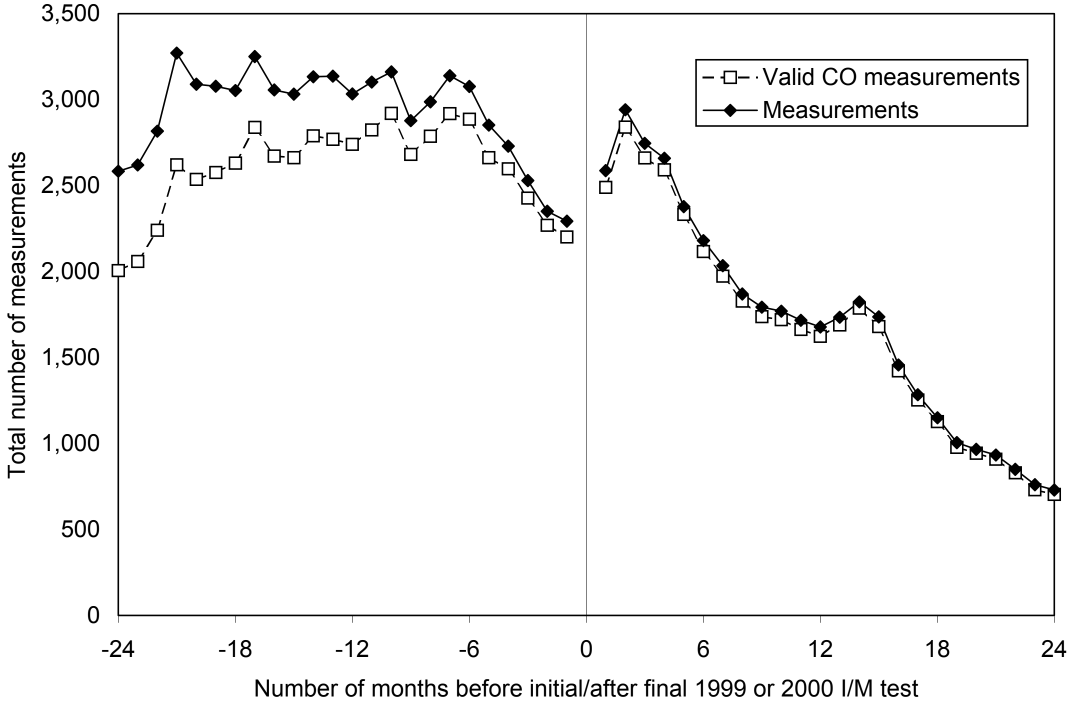

Figure 4-7. Number of remote sensing and valid CO measurements of light-duty vehicles, by number of weeks before initial or after final 1999 or 2000 I/M test.

4.2.3 Emission Reductions from Repair of Fail-Pass Vehicles

In a previous analysis we found that apparent repair of vehicles that failed their initial I/M test accounted for 50 to 65 percent of the emission benefits from the California Enhanced Smog Check program (Singer and Wenzel, 2003). We used I/M test results of vehicles that failed their initial I/M test, but passed a subsequent retest (or "fail-pass" vehicles) to estimate the benefits from vehicle repair in the AIR program. In order to estimate emission benefits from repairs, it is necessary to obtain information on the initial emission reduction from repair, as well as how quickly emissions increase (or "deteriorate") after repair. In addition, the analysis must include an estimate of how quickly emissions of these vehicles would have deteriorated in the absence of the AIR program. We originally proposed to use a subset of vehicles that received an off-cycle change-of-ownership test to estimate deterioration of emissions over the short term, and a subset of out-of-state vehicles to estimate how high emissions would have been if there was no AIR program.

4.2.3.1 Initial Emissions Reduction

We used the initial and final emission tests of fail-pass vehicles to estimate the emission reduction from vehicle repair. We followed CDPHE staff recommendations regarding which I/M test records to exclude from the analysis.[3] To identify the beginning and end of a specific I/M test cycle, we merged seven years of I/M test records of individual vehicles. We then sorted vehicles by their vehicle identification number (or VIN) and their test date and time, to determine the initial and final test in each I/M cycle for each vehicle. Each cycle was ended when the overall inspection result was a pass. Vehicles were categorized based on the outcome of each I/M cycle: *initial-pas*s if a vehicle passed its initial I/M test; *fail-pass* if it failed its initial test but passed a subsequent retest; and *no-final-pass* if it failed its initial test and never passed a subsequent retest. Vehicles that failed their initial test and received a repair waiver were grouped with the fail-pass vehicles, while vehicles that failed their initial test and were not retested were grouped with the no-final-pass vehicles. The determination of pass or fail was based on the overall test result, which includes the result of the visual inspection for missing or tampered emission controls, or whether the dashboard "check engine light" was illuminated.[4]

Figure 4-8 shows the fraction of vehicles that failed their initial I/M test, by vehicle type and model year. Failure rates by vehicle type are fairly constant for older vehicles up to model year 1985, with 13% of heavy trucks, 20% of cars, and 30% of light trucks failing their initial I/M test. However, starting with model year 1986, failure rates decline dramatically for newer vehicles, with less than 5% of the newest vehicles eligible for testing failing their initial test. Differences in failure rates by vehicle type and model year can reflect actual differences in emissions, but can also be the result of the different test methods used and the relative stringency of I/M cut points for a given vehicle. For example, the large increase in the overall failure rate of 1986 heavy trucks (from 14% to 21%) is mostly due to increased failures for HC emissions, as a result of a change in the HC cut point from 800 ppm HC for 1985 heavy trucks to 300 ppm for 1986 heavy trucks.

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[3] Tests coded as software evaluations, technician training tests, aborted tests, or voided tests, or occurring at technical centers run by CDPHE, were excluded from analysis. Vehicle types were determined based on the cut point applied at the time of the test, and not based on the vehicle type field in the test record.

[4] ESP records the test sequence in the test record of each vehicle; however, we noticed some discrepancies in this field, and determined the test sequence based on test date and time and result.

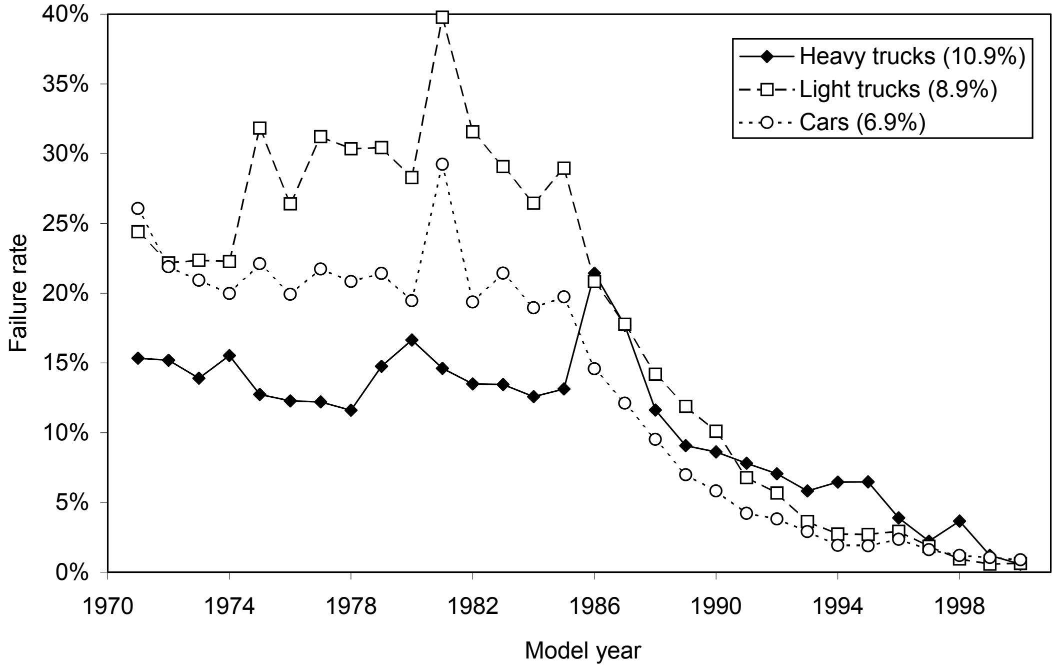

Figure 4-8. Percent of vehicles that fail initial I/M test, by vehicle type and model year.

In general, failure rates for light trucks are higher than for cars. Failure rates for heavy trucks are even lower than those for cars, with the exception of CO failure rates for 1993 and newer heavy trucks, and HC rates for 1986 and newer heavy trucks, which are several times those for light trucks. Because Colorado's program is focused on reducing CO emissions, CO cut points are relatively more stringent than the HC and NOx cut points, and the failure rates are much higher for CO than for HC and NOx. For example, the CO failure rate for 1982 light trucks is 26%, while the HC failure rate is 6%. Figure 4-9 shows the ratio of the CO failure rate to the HC failure rate, by vehicle type and model year. The figure indicates that the CO failure rates are less than twice that of the HC failure rates for all 1981 and older vehicles, and for all heavy trucks. The CO failure rates for 1982 to 1993 light-duty vehicles are two to four times those of the HC failure rates. The ratio of failure rates for 1997 and newer vehicles are not shown, as the rates for all pollutants in these model years are less than 1%. The NOx failure rates for all light-duty vehicles are extremely low, with less than 0.3% of the vehicles in any model year failing for NOx.

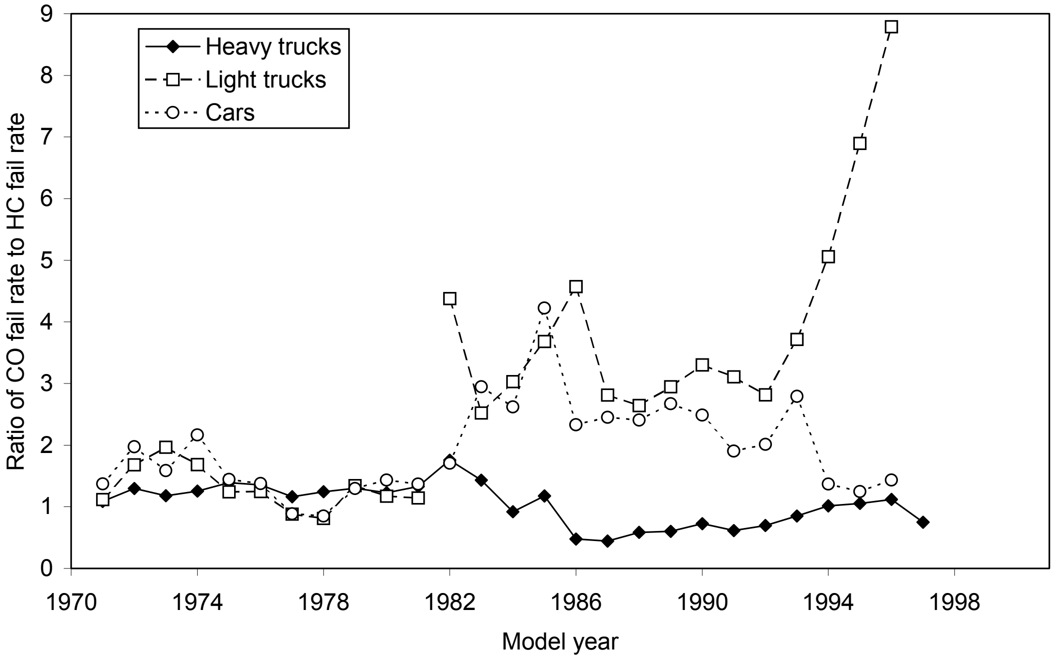

Figure 4-9. Ratio of CO failure rate to HC failure rate, by vehicle type and model year.

Figures 4-10 through 4-12 show the percent change in pollutants and fuel economy from the initial to the final test of the I/M cycle, by model year, for fail-pass cars, light trucks and heavy trucks, respectively. In Figure 4-8, HC and CO emissions are reduced by 60% and 70%, respectively, for model year 1982 to 1994 cars, while NOx emissions increase between 10% and 30% and fuel economy increases (or fuel use declines) about 20%. HC reductions are almost as high as CO reductions even though HC failure rates are much lower than CO failure rates, because many repairs to reduce CO emissions also result in reduced HC emissions. NOx emissions actually increase because the AIR program, which is focused primarily on reducing CO emissions, has very lenient (high) cut points for NOx emissions, and, consequently, a very low NOx failure rate. Vehicle engines can be tuned to reduce CO (and as a result HC) emissions in order to meet the relatively more stringent CO cut points; this engine tuning can lead to increased NOx emissions. This effect, dubbed a NOx "disbenefit", is expected in any I/M program that does not impose NOx cut points at least as stringent as CO or HC cut points, including programs that use an idle test that does not even measure NOx emissions.

For newer model years, which are mostly exempt from I/M testing (and tested because they are changing ownership or recently migrated to Colorado), HC and CO emission reductions fluctuate somewhat, while NOx emissions are unchanged or decrease (up to 50%), and fuel economy increases (up to 40%). These changes in the trends in NOx emissions and fuel economy changes are likely the result of the introduction of technologies to meet Tier 2 emission certification standards, and the required use of on-board diagnostic computers to monitor emissions controls and turn on a dashboard "malfunction indicator light" when a problem affecting emissions is noted.[5]

Emission changes in older model years are based on the idle test results, which have been converted to IM240 equivalents using a simple conversion method, mentioned earlier and discussed in Appendix 4B. Because this conversion involves applying the same factor to all model years of a given vehicle type, the conversion affects the absolute emissions level but does not affect the percent change in emissions from initial to final testing, as measured by the idle test. The percent HC reductions for the older vehicles are slightly less than those for 1982 through 1994 cars, while the percent CO reductions are less than half that of the 1982 through 1994 cars.

The trends in percent change by model year for light trucks are similar to those for cars. However, there is no clear distinction in the percent reductions for heavy trucks, with the percentages increasing from 50% for HC and 20% for CO for the oldest trucks, to 75% for HC and CO for model year 1993 trucks. Percent reductions in HC and CO fluctuate somewhat for the newer heavy trucks.

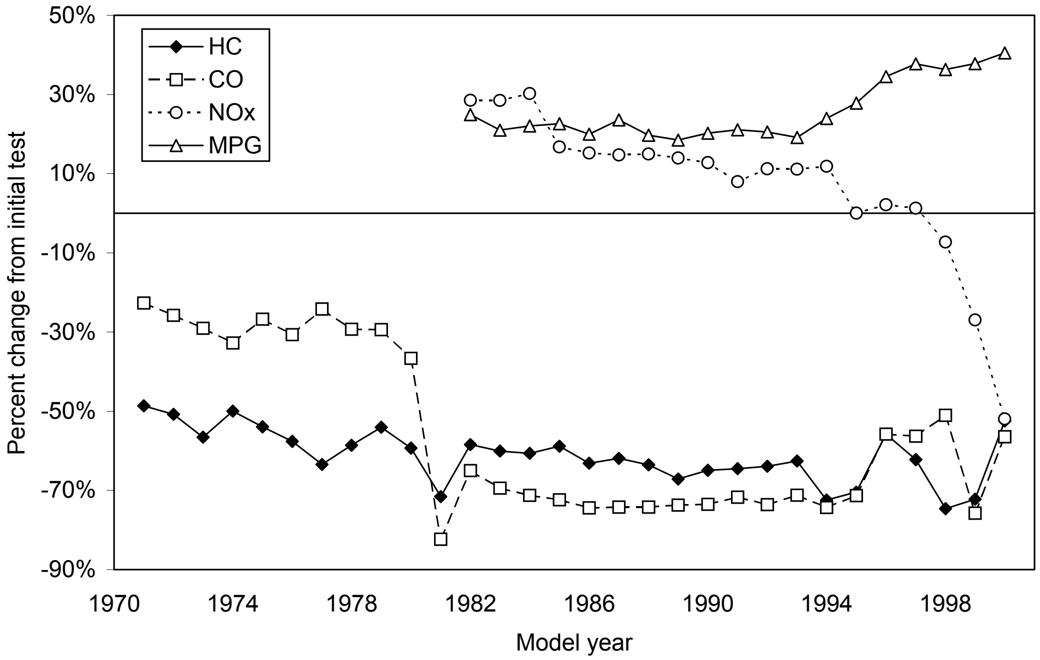

Figure 4-10. Percent change from initial to final I/M test, 2000 fail-pass passenger cars.

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[5] The on-board diagnostic, or OBD, regulations require much more sophisticated monitoring and diagnostic capability than the earlier check engine lights many manufacturers voluntarily installed on their vehicles.

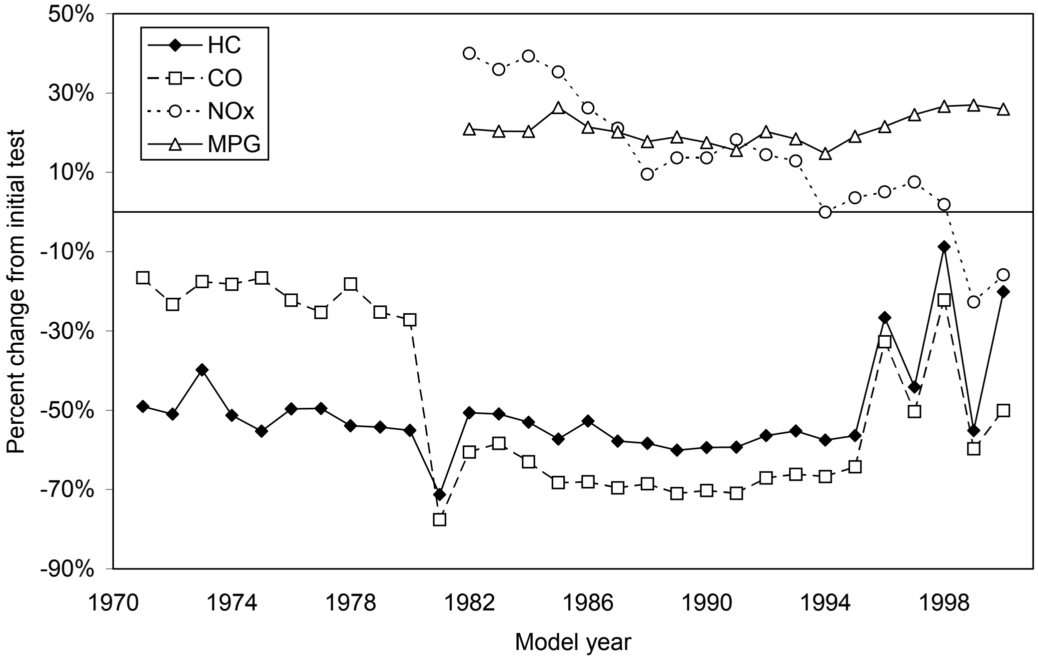

Figure 4-11. Percent change from initial to final I/M test, 2000 fail-pass light trucks.

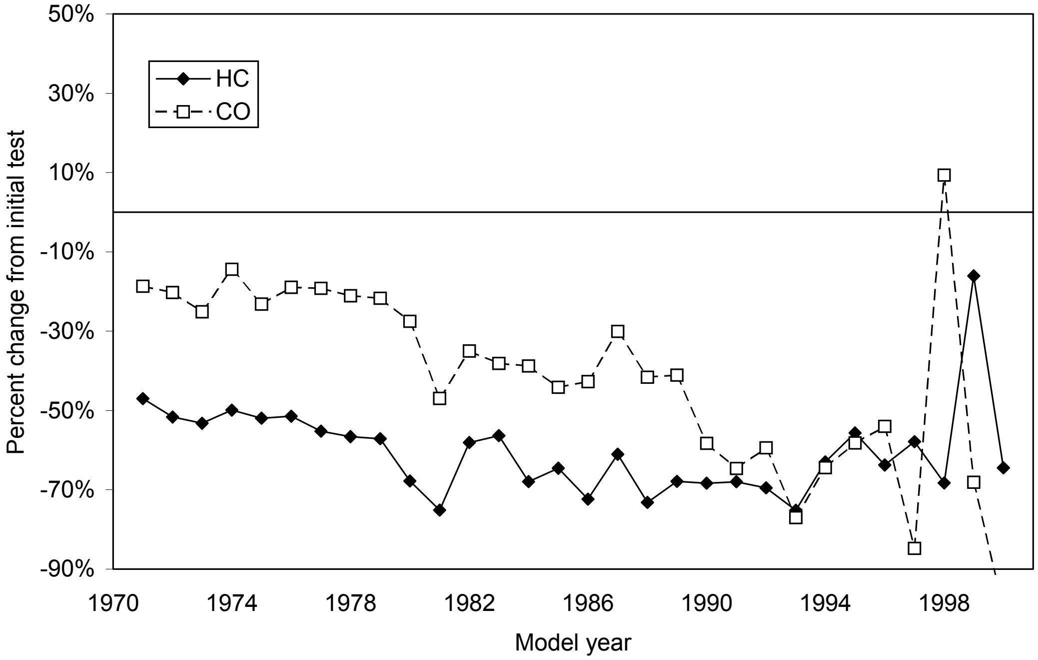

Figure 4-12. Percent change from initial to final I/M test, 2000 fail-pass heavy trucks.

4.2.3.2 Emissions Deterioration Over the Short Term

As discussed above, Colorado requires that a vehicle pass an off-cycle I/M inspection prior to it being sold or otherwise changing owners. Once a vehicle passes its change-of-ownership inspection, its emissions "clock" is reset, and it does not need to be tested again for another two years (or one year, if it is only required to get an idle test). Because change-of-ownership testing is required in Colorado, there are a large number of vehicles that have a second I/M cycle at varying times after passing their previous I/M cycle. We analyzed the emissions of these vehicles at different times since their previous cycle to better understand how quickly emissions deteriorate after a vehicle passes its I/M test. Because the emissions clock resets after every change-of-ownership inspection, all initial tests less than roughly two years (or one less than one year for vehicles in the annual program) after a previous inspection are change-of-ownership tests (and the previous inspection was a regular biennial or annual inspection). The analysis of change-of-ownership tests was limited to light-duty 1982 and newer vehicles required to be tested on the IM240.

Figure 4-13 shows the number of light-duty vehicles given a change-of-ownership I/M test, as a function of time since their last passing I/M test. The figure indicates that about 8,000 light-duty vehicles are tested in each month after passing their last I/M inspection. The number decreases to about 6,000 vehicles roughly 22 months after passing their last I/M inspection. The number of change-of-ownership tests peaks at over 11,000 vehicles roughly one year after passing their last I/M inspection; presumably 2,000 of these are vehicles were not tested because of a potential change in ownership, but because the owner mistakenly reported for (or was erroneously instructed to report for) an annual I/M inspection.

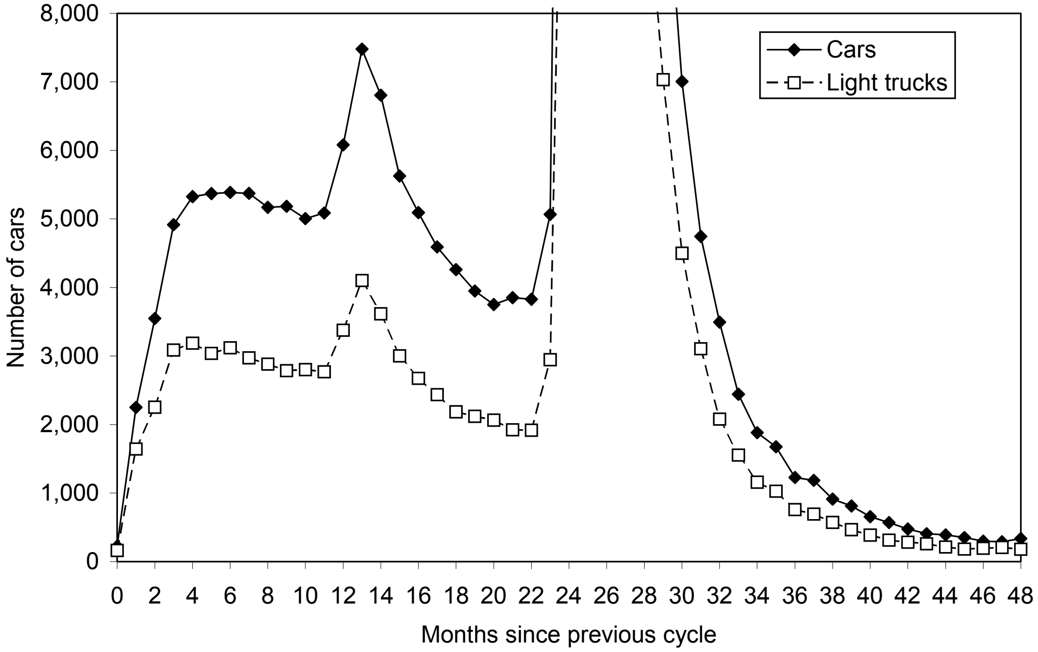

Figure 4-13. Number of light-duty vehicles given a change-of-ownership test in 2000, by vehicle type and time (months) since last inspection cycle.

Overall about 12% of the I/M fleet tested in 1999 and 2000 received a change-of-ownership test in addition to their regular biennial inspection. Figure 4-14 shows the fraction of vehicles that received a change-of-ownership test, by vehicle type and model year. About 4% of all tests of 1981 and older vehicles of each type are change-of-ownership tests. The same fraction of newer heavy trucks also are change-of-ownership tests. However, the percent of tests that are change-of-ownership tests increases for the newer light-duty vehicles, with cars ranging from 11% to 18% change-of-ownership tests, and light trucks ranging from 10% to 14% change-of-ownership tests. The consistent fluctuation in the fraction of change-of-ownership tests by model year is a result of the original even/odd model year test cycle.

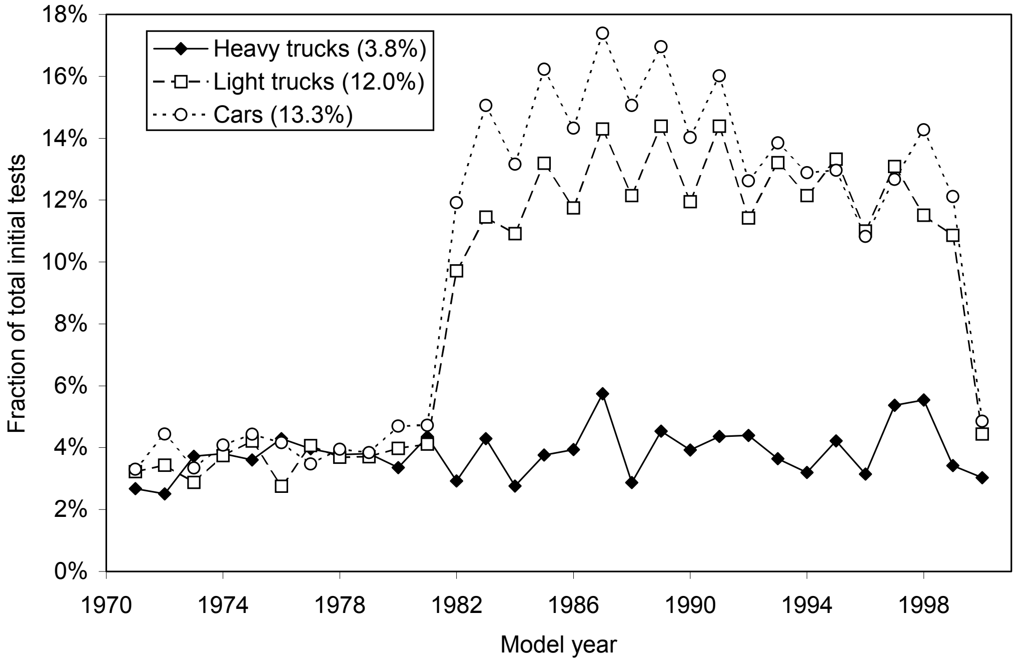

Figure 4-14. Fraction of all tests that are change-of-ownership tests, by vehicle type and model year.

Remember that a different group of vehicles is measured in each time period; care must be taken to ensure that the differences in emissions by time period do not reflect other differences between each group of vehicles, such as average age, that could also explain changes in emissions as a function of time. Figure 4-15 shows that the change-of-ownership vehicles are slightly older than the vehicles receiving a biennial test. In order to compare emissions of change-of-ownership vehicles measured at different times after their last I/M inspection, and to compare emissions of change-of-ownership vehicles with vehicles given a biennial inspection, we adjusted all average emissions by a common model year distribution of vehicles, that of the vehicles given a biennial I/M test.

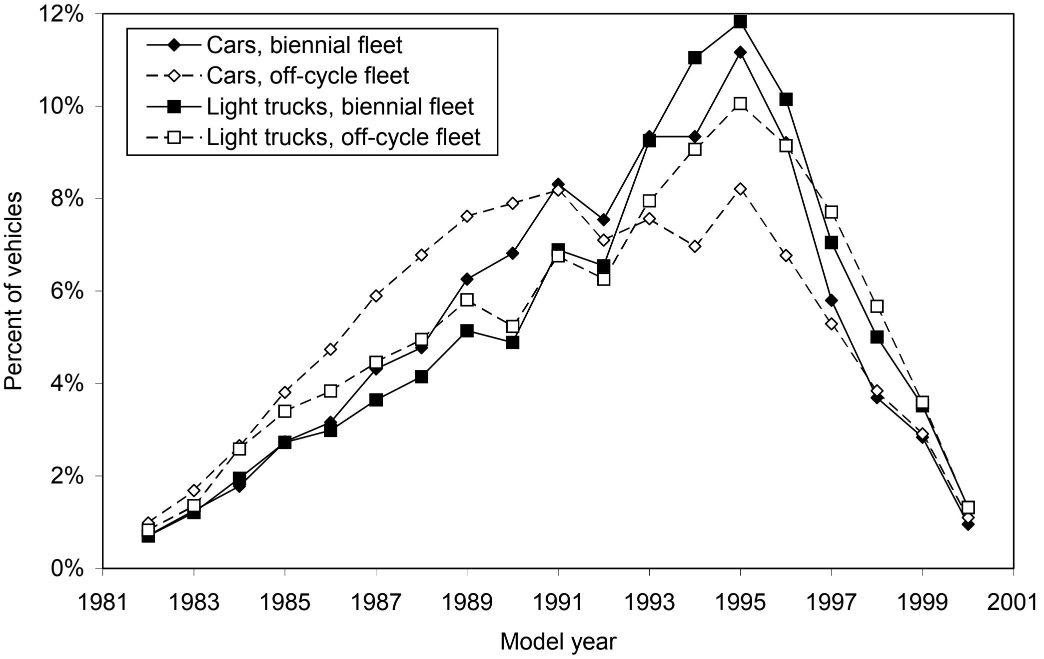

Figure 4-15. Model year distribution by vehicle fleet, type and model year.

Figures 4-16 through 4-18 show the average emissions of cars given a change-of-ownership test, as a function of time since they passed their previous I/M inspection. The filled symbols in Figures 4-16 through 4-18 by time since last inspection, of fail-pass (diamonds) and initial-pass (squares) cars in their previous cycle. The open symbols show the average emissions after adjustment to a common model year distribution, that of the cars given a biennial I/M test; this adjustment reduces the increase in emissions as a function of time since the last inspection. Note that in Figure 4-16 CO emissions gradually increase so that about 17 months after the previous inspection CO emissions of fail-pass and initial-pass cars are about 15% higher than at the time of their last passing test. These results are quite similar to results obtained from analyzing change-of-ownership tests in the California and Phoenix I/M programs (Wenzel et al., 2000; Wenzel et al., 2003). However, emissions begin to decrease about 20 months after the previous cycle, and around 26 months after the previous cycle they are only about 2% higher than at the time of the last passing test. (Results are similar for HC and NOx emissions in Figures 4-17 and 4-18). This decrease in emissions around 24 months after the last passing test suggests that the change-of-ownership vehicles exhibit greater emissions deterioration than the fleet of vehicles tested biennially. This suggests in turn that the change-of-ownership vehicles are not representative of the overall fleet; one can imagine that a portion of these vehicles are being sold (and tested off-cycle) precisely because they have problems that have resulted in increased emissions. Another possible explanation, however, is that vehicle owners may be less likely to pay for pre-inspection maintenance or repairs prior to a change-of-ownership inspection of a vehicle they hope to soon sell, than owners who are having their vehicle tested as part of a biennial inspection.

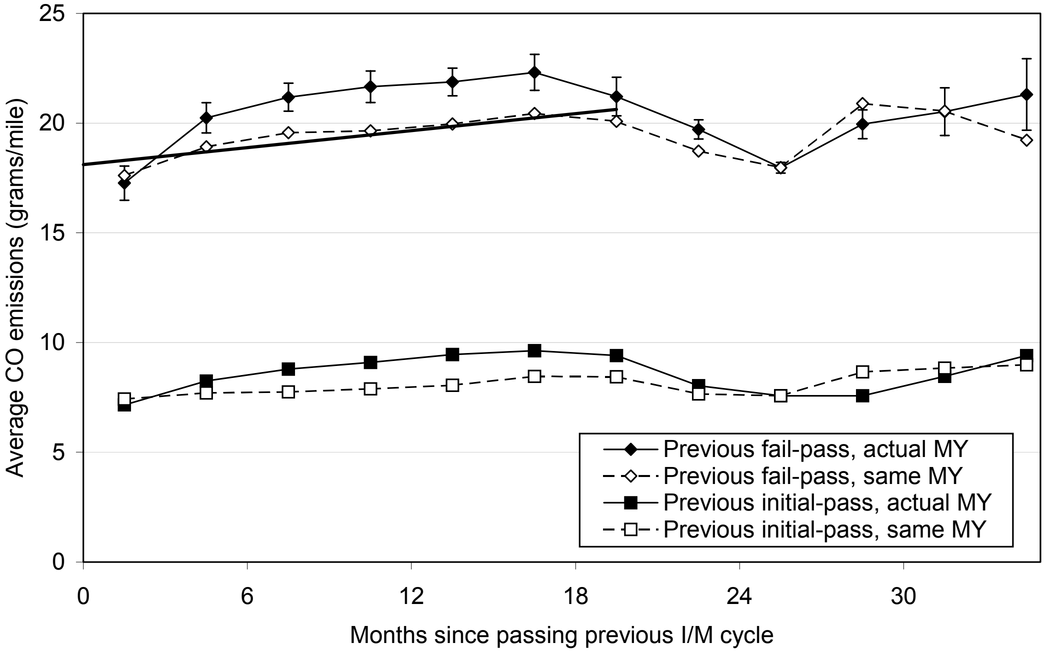

Figure 4-16. Average passenger car CO emissions by time since previous I/M cycle.

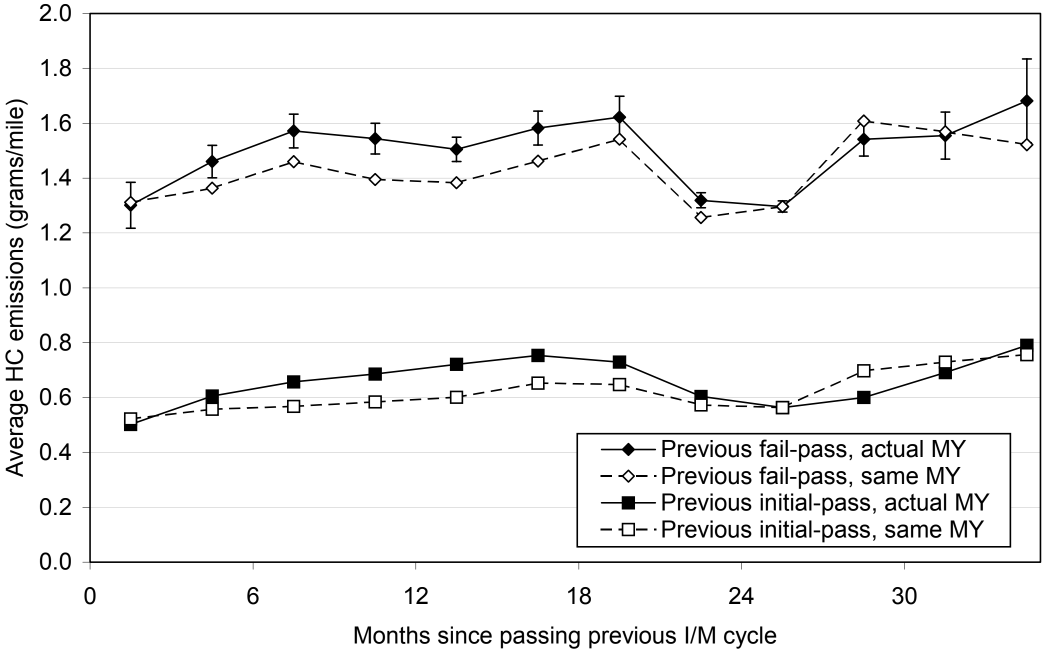

Figure 4-17. Average passenger car HC emissions by time since previous I/M cycle.

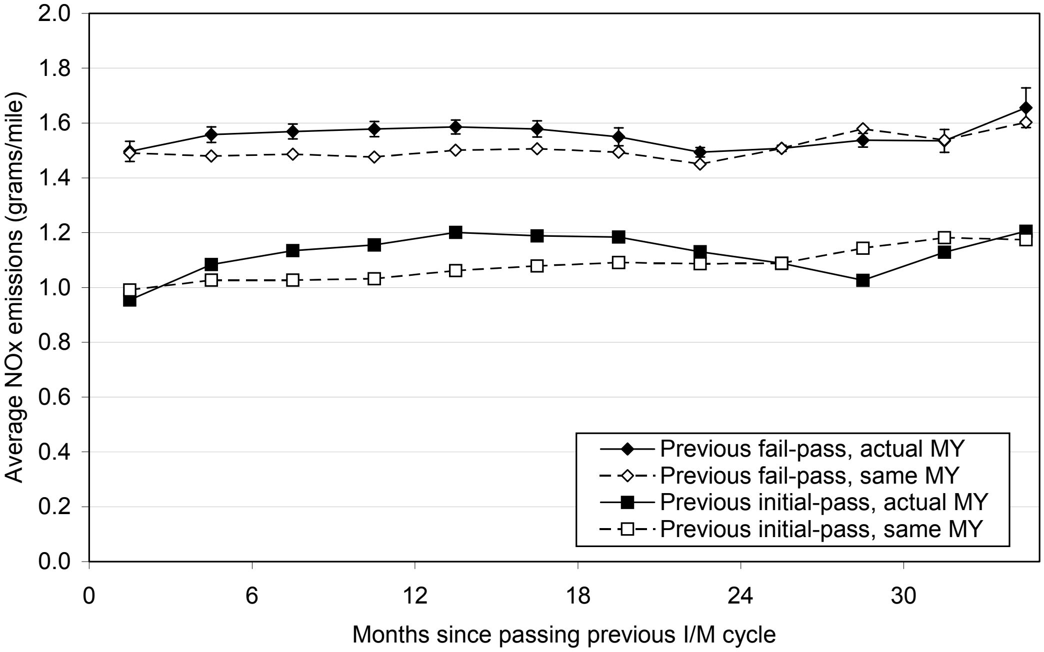

Figure 4-18. Average passenger car NOx emissions by time since previous I/M cycle.

Another test of whether the change-of-ownership vehicles are representative of the overall fleet is to compare the initial test emissions of initial-pass cars from the previous I/M inspection that received a change-of-ownership test with those of cars that were tested roughly two years after their previous I/M inspection, by model year. Figures 4-19 through 4-21 show that the CO emissions of the change-of-ownership initial-pass cars are only slightly higher (5% on average) on the initial test of the previous cycle than those of the biennially tested initial-pass cars; the change-of-ownership cars have substantially higher previous cycle initial test HC (11% on average) and NOx (6% on average) emissions than the cars tested biennially.

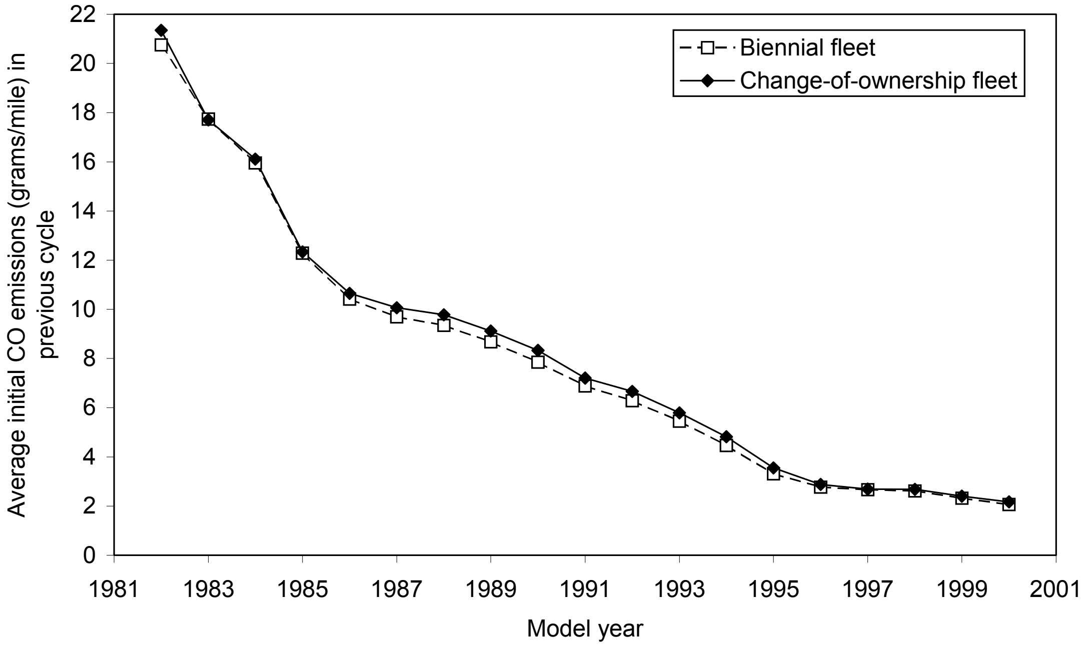

Figure 4-19. Average previous cycle initial test CO emissions of cars that initially-pass previous I/M cycle, by I/M fleet and model year.

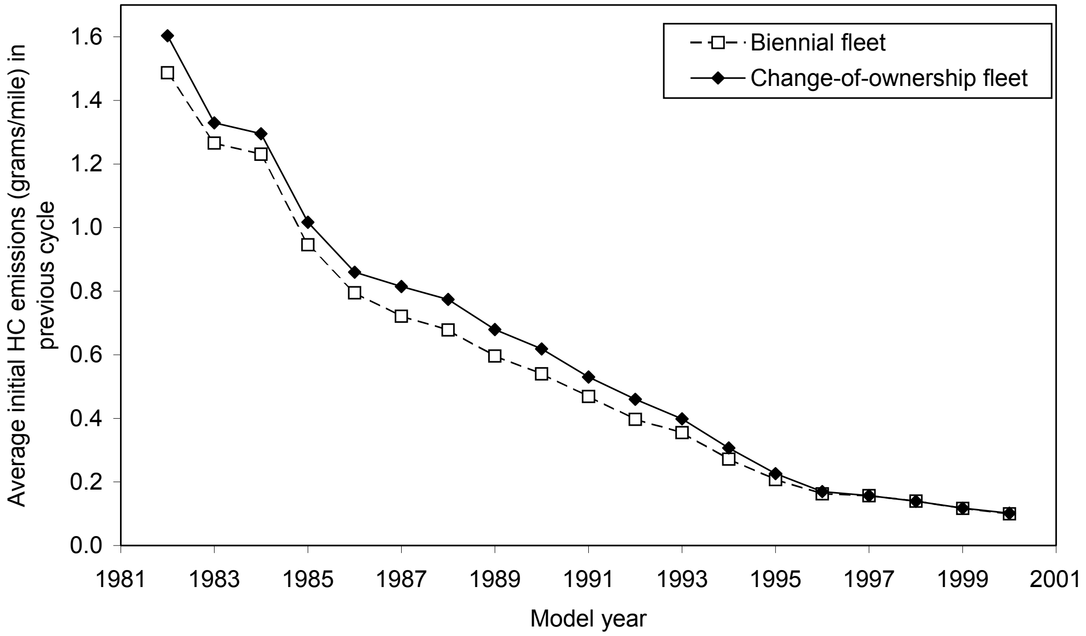

Figure 4-20. Average previous cycle initial test HC emissions of cars that initially-pass previous I/M cycle, by I/M fleet and model year.

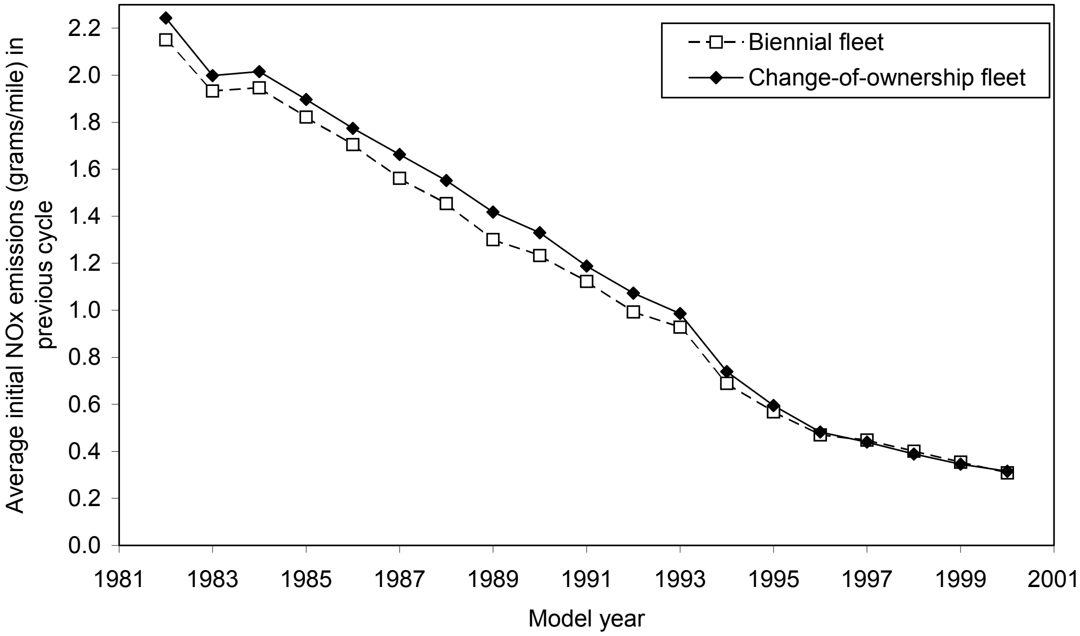

Figure 4-21. Average previous cycle initial test NOx emissions of cars that initially-pass previous I/M cycle, by I/M fleet and model year.

Figure 4-22 compares the emissions of two separate fleets of cars; those receiving a change-of-ownership test up to 21 months after their previous I/M inspection (open squares in the figure); and those receiving a biennial test roughly 24 months after their previous inspection (filled diamonds). All emission measurements are adjusted to a common model year distribution. The figure indicates that the change-of-ownership fleet has slightly higher initial and final emissions in the previous cycle than the biennial fleet, and that emissions on their next initial test also are slightly higher than those for the biennial fleet. Figure 4-22 also includes the emissions of all cars as a function of time since their previous I/M cycle (open circles; from Figures 4-16 through 4-18). The figure indicates that the emissions of change-of-ownership cars deteriorate dramatically almost immediately after their previous I/M cycle, up to the level of the biennial cars tested roughly two years later. This suggests that, if the change-of-ownership fleet is representative of the biennial fleet, almost all of the emissions deterioration observed over two tests of the biennial fleet roughly two years apart actually occurs almost immediately after they pass their previous I/M inspection. A critical question, therefore, is how representative of the biennial fleet is the change-of-ownership fleet?

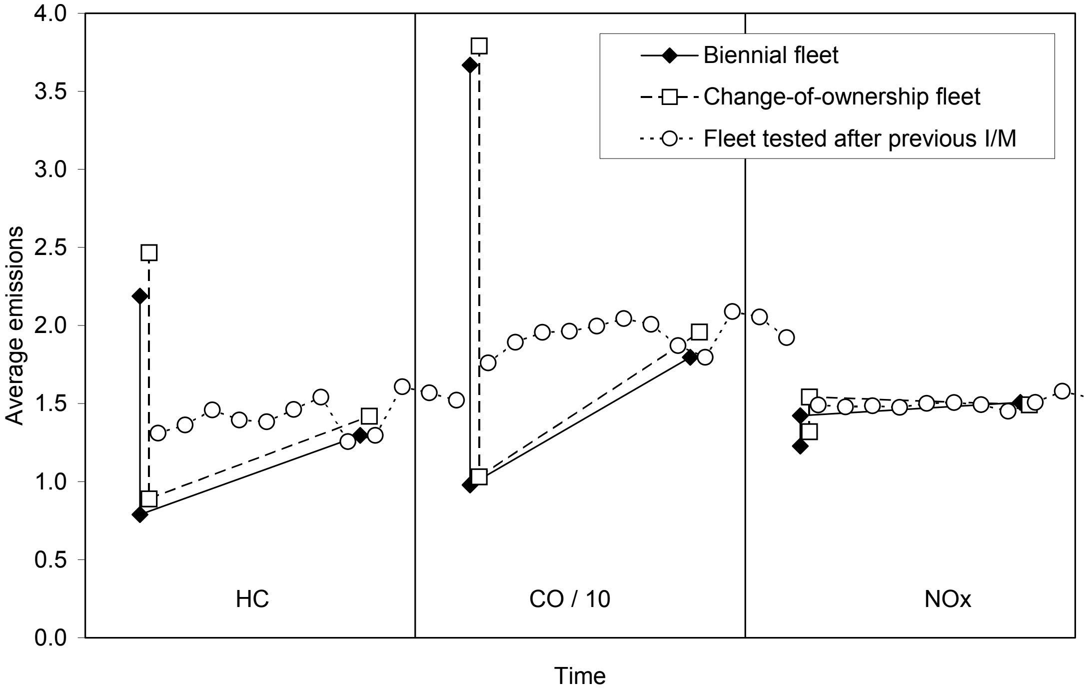

Figure 4-22. Emissions of fail-pass cars over a biennial I/M cycle, by fleet.

We also analyzed ESP remote sensing measurements of vehicles as a function of time since their last I/M test, to better understand short-term deterioration of emissions after repair. Figures 4-23 through 4-25 compare the remote sensing emissions of 1982 and newer fail-pass (filled diamonds) and initial-pass (open squares) light-duty vehicles with the IM240 emissions of similar vehicles given a biennial test (open diamonds, dashed line), by the number of months before the initial or after the final I/M test. The remote sensing emissions are shown on the left-hand scale, while the IM240 emissions are shown on the right-hand scale. The IM240 emissions are scaled so that the emissions rate at the initial test approximately equals the remote sensing emissions immediately prior to the I/M test. The IM240 tests indicate percent CO and HC emission reductions roughly two times those suggested by the remote sensing measurements; however, by the time of the next I/M inspection roughly two years later, the IM240 emission rates are comparable to those measured by remote sensing. The remote sensing data, therefore, appear to confirm the finding from the change-of-ownership I/M tests; that most, if not all, of the emissions deterioration observed in the biennial I/M fleet appears to occur almost immediately after the vehicles pass their previous I/M cycle.

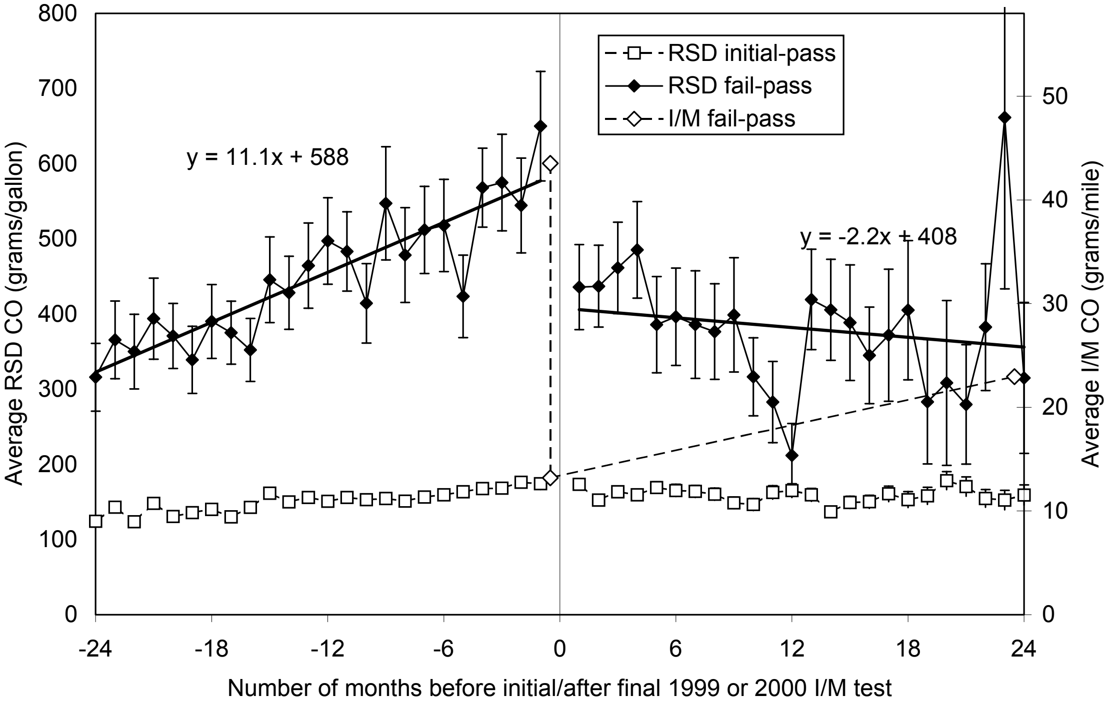

Figure 4-23. Comparison of remote sensing and I/M CO emissions of fail-pass light-duty vehicles before initial and after final I/M test.

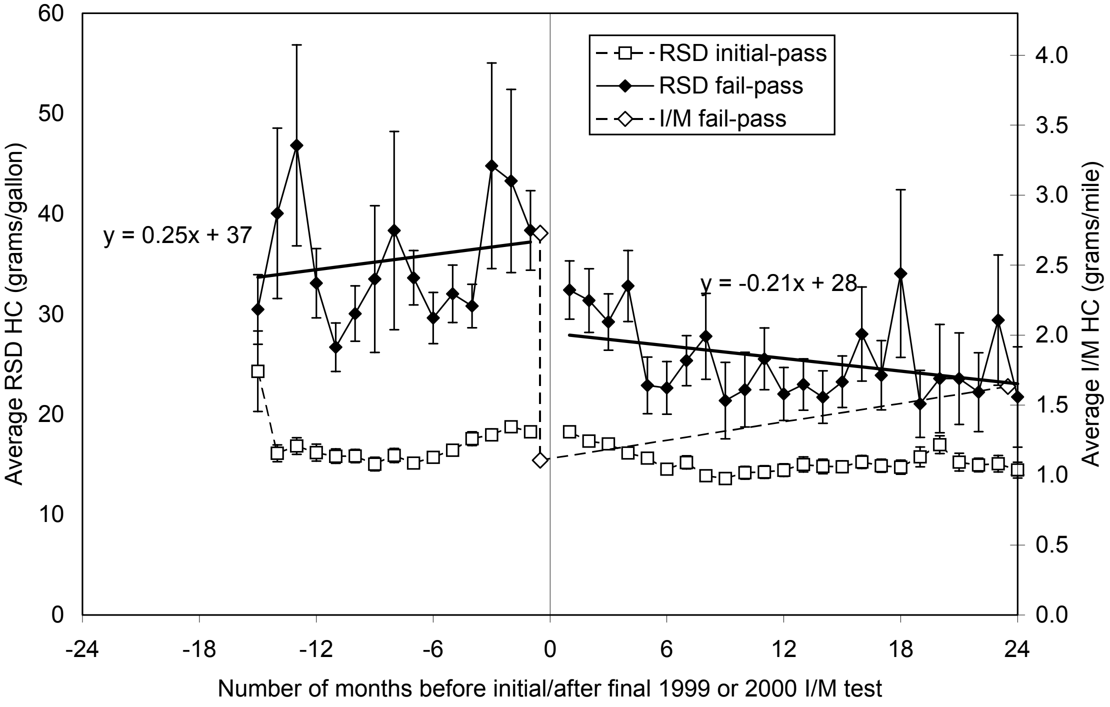

Figure 4-24. Comparison of remote sensing and I/M HC emissions of fail-pass light-duty vehicles before initial and after final I/M test.

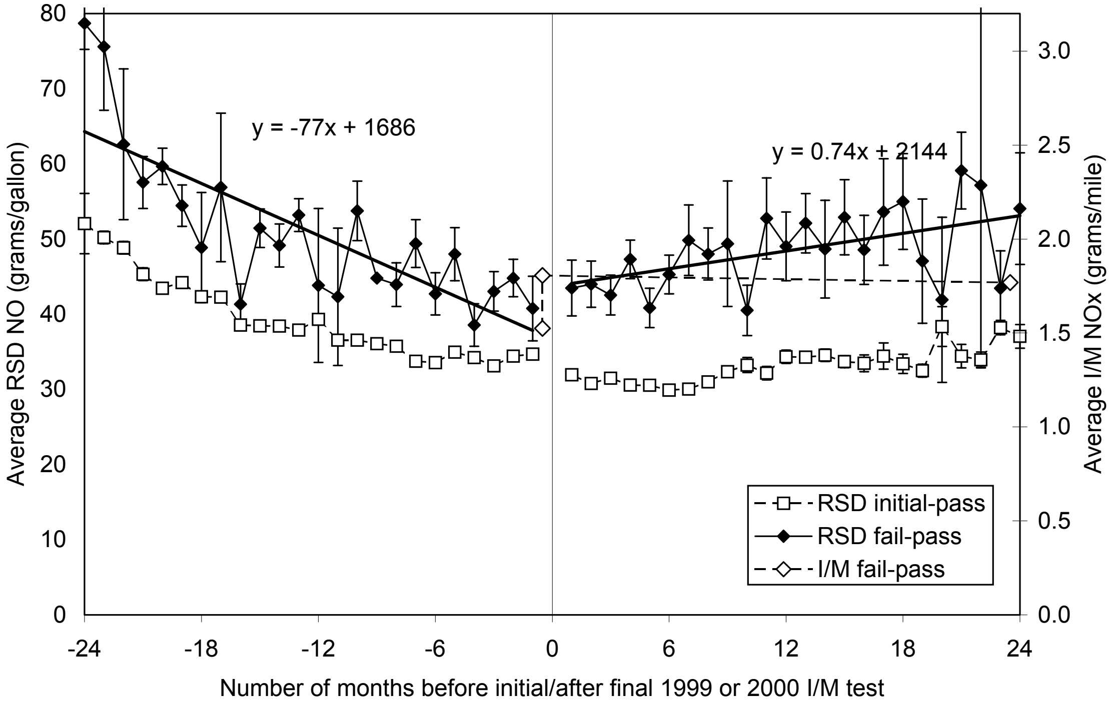

Figure 4-25. Comparison of remote sensing and I/M NOx emissions of fail-pass light-duty vehicles before initial and after final I/M test.

Note that the remote sensing emissions after the final I/M test appear to decrease for CO and HC, but increase for NOx. Figure 4-26 shows the average model year of the vehicles measured by remote sensing, and the fraction that are passenger cars, as a function of time relative to the I/M test. The average model year of fail-pass vehicles measured by remote sensing does not change over time; however, the fraction observed that are cars decreases over time after the I/M test. These trends suggest that the average remote sensing emissions of vehicles should increase as a function of time after the I/M test; however, we only observe such an increase in NOx emissions. We have no explanation for the decreases in CO and HC emissions after the I/M test. (Figure 4-26 indicates that the initial-pass vehicles measured on-road tend to be younger over time; this change in the average age of the initial-pass vehicles measured on-road may explain why there is little or no emissions increase over time for initial-pass vehicles after the I/M test.)

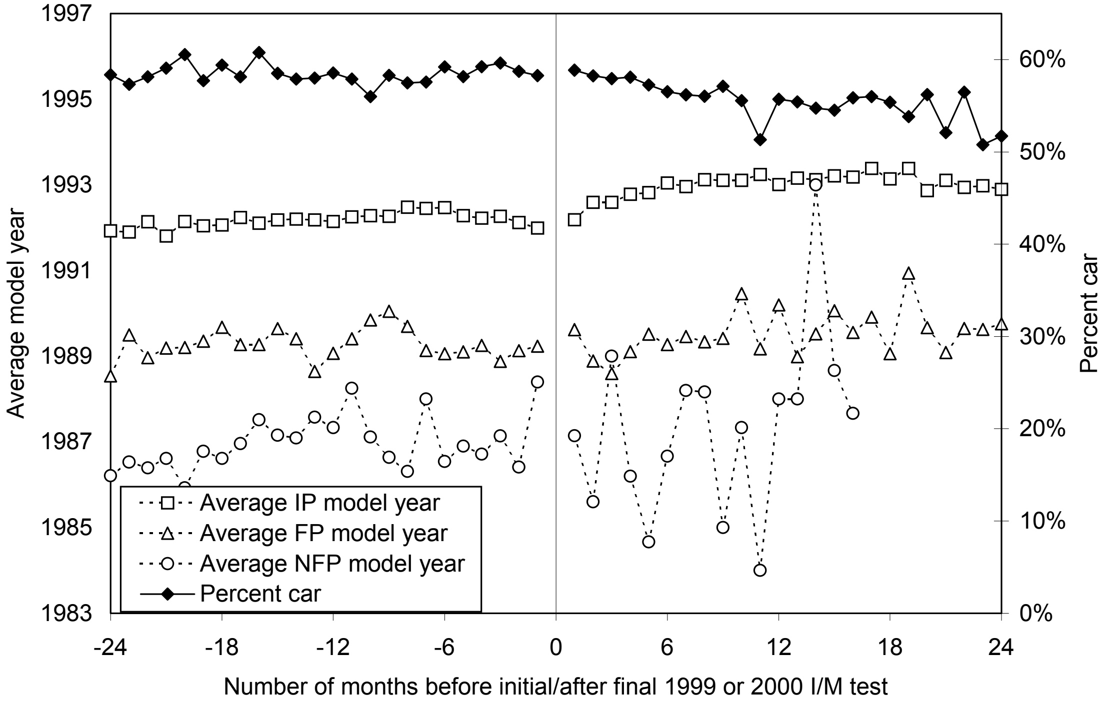

Figure 4-26. Average age of light-duty vehicles, by I/M result, and percent cars measured by remote sensing before initial and after final I/M test.

There are several possible explanations for why vehicle emissions would deteriorate so rapidly after passing an I/M inspection: the vehicle was not properly warmed up prior to the failing test in either the first or second cycles; the vehicle passed the initial cycle because a legitimate repair temporarily lowered emissions; the second cycle failure was due to an emissions problem unrelated to the problem identified and repaired in the initial cycle; the mechanic fraudulently passed the vehicle in the initial cycle, but not on the initial test in the next I/M cycle; the vehicle owner or his/her mechanic knows how to adjust, or alter the fuel chemistry of, the vehicle to pass a test, and then readjusts the vehicle after it passes; or the vehicle has an intermittent problem with its emission controls, which causes it to fail one test and pass a subsequent test, without any repairs being made. The rapid increase in emissions so soon after passing an I/M test are likely due to a combination of these causes. However, we suspect that a relatively large number of vehicles with intermittent malfunctions, and highly variable emissions, are causing this effect. The result is that much of the apparent emission reduction from the I/M program, as observed in the initial and final I/M test results, may not be real or lasting.

For our high estimate of the emission benefits of vehicle repair, we use the initial and final I/M emissions of fail-pass vehicles, and assume that emissions would deteriorate linearly to the level observed for the biennial fleet tested roughly two years later. We base our low estimate of the benefits from repair on the analysis of the short-term emissions deterioration using the change-in-ownership vehicles and remote sensing data. The low estimate assumes that emissions of fail-pass vehicles would immediately deteriorate to the level observed two years later in the I/M test records, and would remain constant over the following two years. Our best estimate is simply the average of our low and high estimates.

4.2.3.3 Emissions Deterioration without I/M

Our estimate of the benefits of post-failure repair also requires an assumption regarding whether, and how quickly, emissions of fail-pass vehicles would increase if there were no I/M program. We used the observed emission rates of no-final-pass vehicles in the I/M test records for our assumptions regarding the emissions of fail-pass vehicles in the absence of I/M. For our high estimate we assumed that emissions of fail-pass vehicles would deteriorate to the level of no-final-pass vehicles one year later, and then would remain constant for the next year. Under our low estimate we assumed that emissions would not deteriorate at all over the next two years. Our best estimate assumes that emissions would deteriorate to the level of no-final-pass vehicles, but over two years, rather than the one year assumed in the high estimate.

We examined the potential of using out-of-state vehicles receiving their first Colorado I/M test as a proxy for vehicles that had never been given an I/M test. However, we rejected this approach, as the vehicles that migrate into Colorado from other states likely are better maintained, and therefore have lower average emissions, than vehicles that have never been subjected to an I/M program. Instead, we used the emission rates of no-final-pass vehicles, as discussed above.

4.2.3.4 Summary of Assumptions Regarding Post-failure Repair

Figure 4-27 shows the assumptions used in estimating CO benefits of post-failure repair of model year 1985 cars; on average these cars have CO emissions of 45 grams/mile after their initial I/M test. The CO cut point for 1985 cars is 20 grams per mile. The assumptions shown include the rate at which emissions deteriorate after fail-pass vehicles pass their I/M retest, and what emissions would have been if there was no I/M program. The sum of areas A and B in the figure, and identified by solid lines, is our lower bound estimate of the emissions reductions from the AIR program. The lower bound estimate assumes that emissions of fail-pass vehicles will essentially deteriorate to the level observed on the initial test of their next I/M cycle (27 grams/mile) immediately after passing their initial I/M cycle. Under the lower bound estimate, emissions would not deteriorate at all if there was no I/M program, and would remain at the level of their initial test (45 grams/mile) over the next two years. The upper bound estimate of the program benefits is shown by the dotted line. The upper bound estimate takes the observed emissions of the fail-pass cars at the time they pass their retest (12 grams/mile), and assumes that emissions deteriorate linearly to the level observed on the initial test of their next I/M cycle (27 grams/mile). Without the I/M program, the upper bound estimate assumes that emissions would have deteriorated to the observed level of no-final-pass vehicles (64 grams/mile) by the end of the first year. Finally, our best estimate of program benefits is the lower bound estimate (A + B) plus areas C, D, E and F, shown in large dashed lines in the figure. The best estimate assumes that emissions after passing the retest immediately deteriorate to midway between the observed final test and the initial test in the next I/M cycle (20 grams/mile), and then deteriorate linearly to the level of the initial test in the next cycle (27 grams/mile). The best estimate assumes that, without the AIR program, emissions would have deteriorated to the level of no-final-pass vehicles (64 grams/mile) by the end of two years after the initial test. The changes in emission rates due to vehicle repair are multiplied by the number of unique fail-pass vehicles tested in 1999 and 2000.

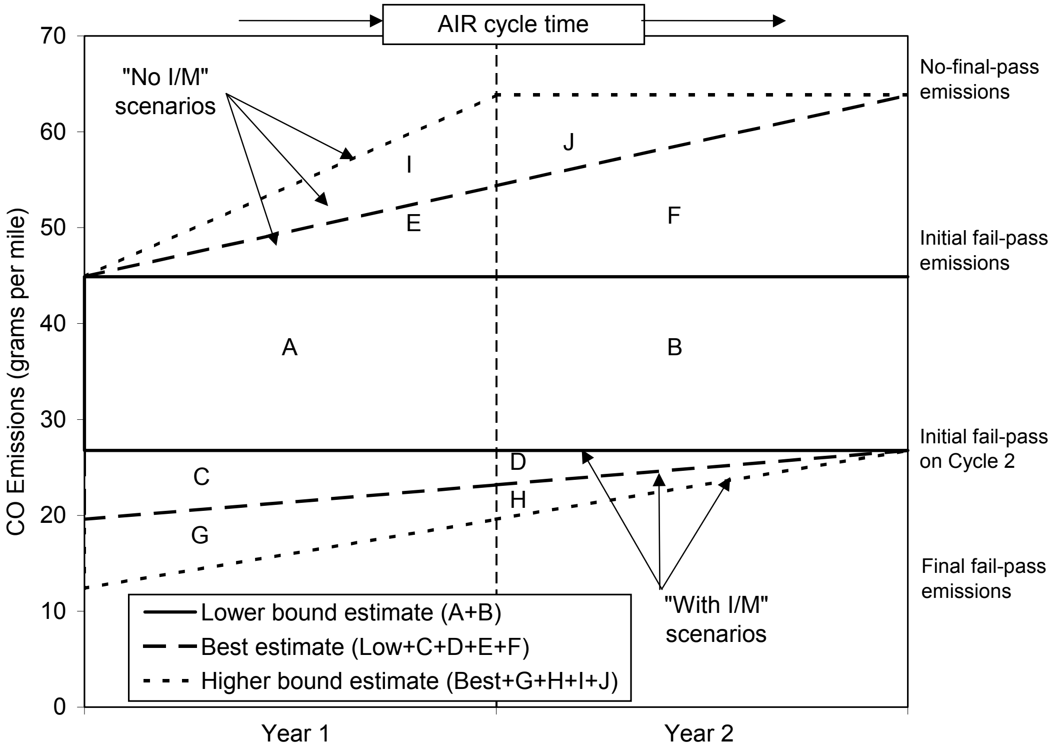

Figure 4-27. Example of assumptions used to estimate CO emissions reductions from the repair of 1985 passenger cars.

For IM240 vehicles tested in 1999, only the benefits in year 2 are used (i.e. B for lower bound estimate, B + D + F for the best estimate, and B + D + F + H + J for the higher bound estimate). Similarly, only the benefits in year 1 are used for the vehicles tested in 2000 (i.e. A for lower bound estimate, A + C + E for the best estimate, and A + C + E + G + I for the higher bound estimate).

4.2.4 Emission Reductions Permanent Removal/Replacement of No-Final-Pass Vehicles

The third component of I/M effectiveness is the benefit from permanent removal of vehicles that failed their initial test and did not pass a subsequent retest, what we call “no-final-pass” vehicles. These vehicles include vehicles that failed a subsequent retest, as well as those that never got a retest. 16% of cars, 14% of light trucks, and 10% of heavy trucks failed their initial test in 1999 or 2000 and did not pass a retest by December 2002. These percentages are lower than reported in the previous audit (23%), probably because we tracked these vehicles over a longer time period (two to four years). Figure 4-28 shows the number of no-final-pass vehicles, as a percent of all vehicles that failed their initial I/M test, by vehicle type and model year.

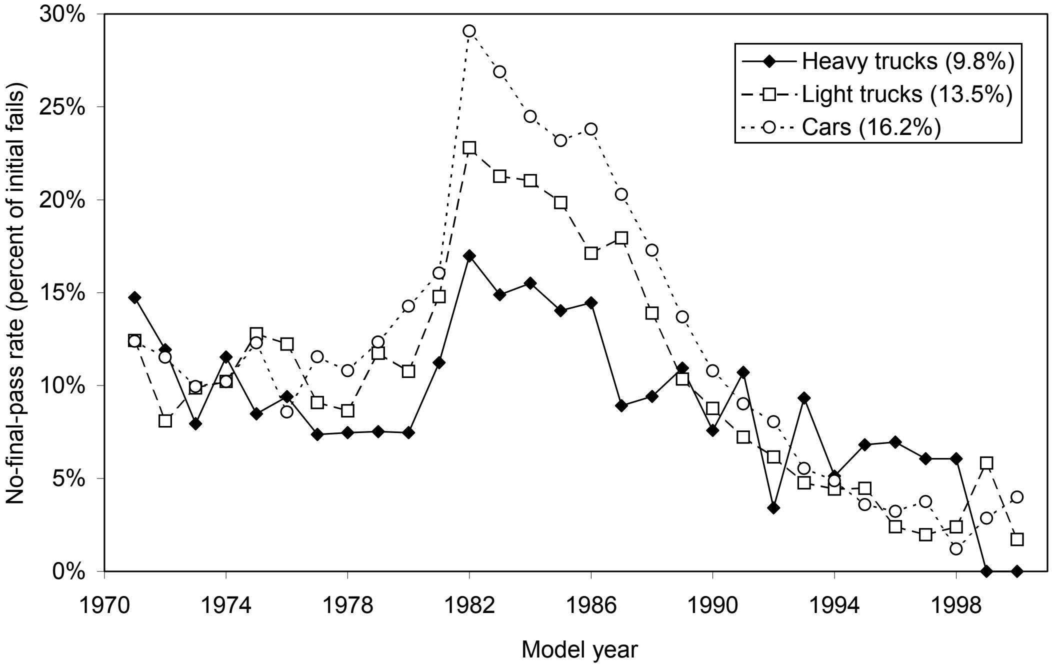

Figure 4-28. No-final-pass rate (percent of all initial fails that do not pass subsequent retest) by vehicle type and model year.

We used remote sensing measurements made by ESP in 1999 and 2000 to estimate the fraction of no-final-pass vehicles that continued to be driven in the Denver area as function of time since they failed their I/M test. We limited the analysis of remote sensing data to 1982 to 1995 light-duty vehicles. Figure 4-29 shows the fraction of I/M-tested vehicles that were observed on-road by the remote sensors as a function of time before their initial and after their final I/M test in 1999 or 2000. The figure shows the trend for three groups of vehicles: those that received a subsequent I/M cycle after 2000; those that eventually passed their test in 1999 or 2000 but did not receive a subsequent I/M cycle after 2000; and those that failed their initial test in 1999 or 2000 and did not pass a retest. The figure indicates that for each of the three fleets, the fraction of vehicles observed on-road declines over time. This has to do with the timing of the I/M tests and the remote sensing measurements available. However, the group that did receive a subsequent test can be thought of as a control group of vehicles that were known to be driven in the Denver area for at least two years after they passed their 1999 or 2000 I/M cycle. Note that less than one percent of the I/M-tested vehicles in each group were observed on-road in each time period; this is a result of the relatively small number of remote sensing measurements available (the measurements were intended to sample 0.5% of the I/M fleet).

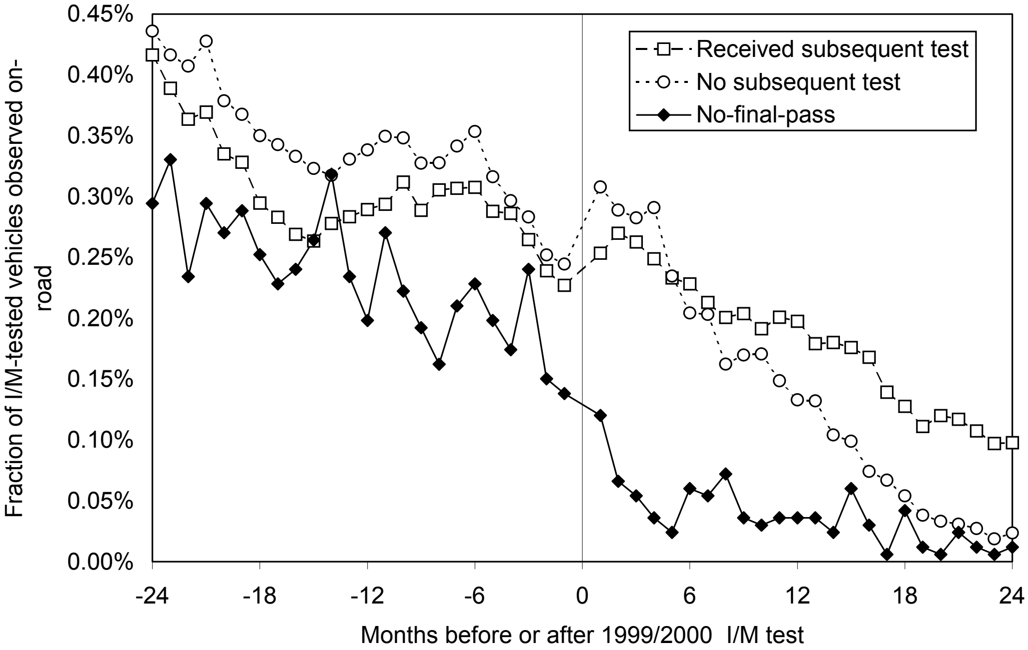

Figure 4-29. Fraction of the 1982 to 1995 light-duty I/M fleet observed on road in the Denver area by remote sensing, by I/M test result and time before initial and after final I/M test.

Figure 4-30 takes the ratio of the fraction of the "no subsequent test" vehicles, and the no-final-pass vehicles, to the fraction of the "received subsequent test" vehicles in Figure 4-29. We would expect the ratios of these two groups of vehicles to be close to 100% before their initial I/M test, and to decline over time after their final I/M test as more vehicles in each group are permanently removed from the Denver area. The ratio of the no subsequent test vehicles follows this pattern: the ratio is close to 100% for the two years prior to their initial I/M test, and then decreases dramatically for the two years after their final I/M test. By two years after their final I/M test only 20% of them are estimated to be driving in the Denver area (and perhaps avoiding program test requirements). The no-final-pass vehicles also follows this pattern, although it appears that these vehicles were less likely than the no subsequent test vehicles to be observed on road in the months before their initial I/M, with only about 70% likely to be observed on-road immediately prior to their initial I/M test. The fraction of no-final-pass vehicles likely to be observed on-road drops to 20% only two months after their final I/M test, and continues to gradually decline over the next two years. On average, 18% of the no-final-pass vehicles are likely to be observed on-road in the two years after they failed their I/M test.

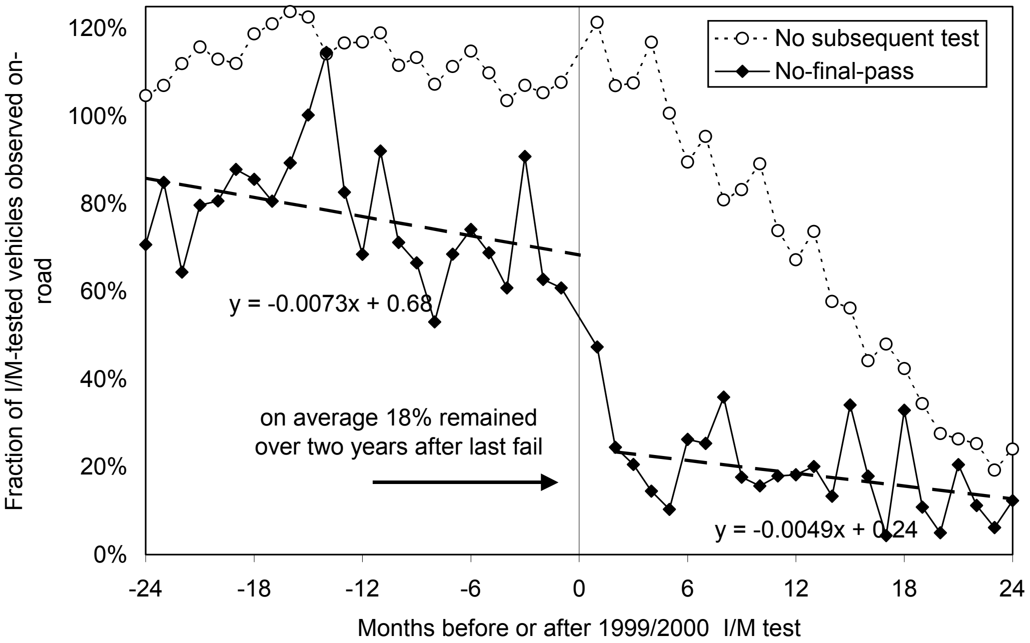

Figure 4-30. Ratio of the percent of no-subsequent-test and no-final-pass vehicles observed on-road to the percent of subsequently-tested vehicles observed on-road, by time before initial and after final I/M test.

We therefore assume that 82% of the no-final-pass vehicles are permanently removed from the I/M area as a result of the AIR program, at least in the first two years after they failed their test. It is possible that the fraction of no-final-pass vehicles permanently removed from the Denver area varies by model year, with older vehicles being removed at a higher rate than newer vehicles. However, there were not enough remote sensing measurements to analyze the removal rate by model year groups. Therefore we assumed the same fraction removed across all model years. There is some evidence in the remote sensing data to support this assumption. Figure 4-31 shows the average model year of the three vehicle groups, as a function of time before and after their I/M test. If older vehicles were being removed after their last I/M test at a faster rate than newer vehicles, the average model year of vehicles observed on-road should increase as a function of time after their last I/M test. The figure indicates that this is not the case for any of the three groups, including the no-final-pass vehicles (although there is great fluctuation in the average model year for individual time periods). This supports our assumption that all model years of no-final-pass vehicles are being removed from the Denver area after their last I/M test at about the same rate.

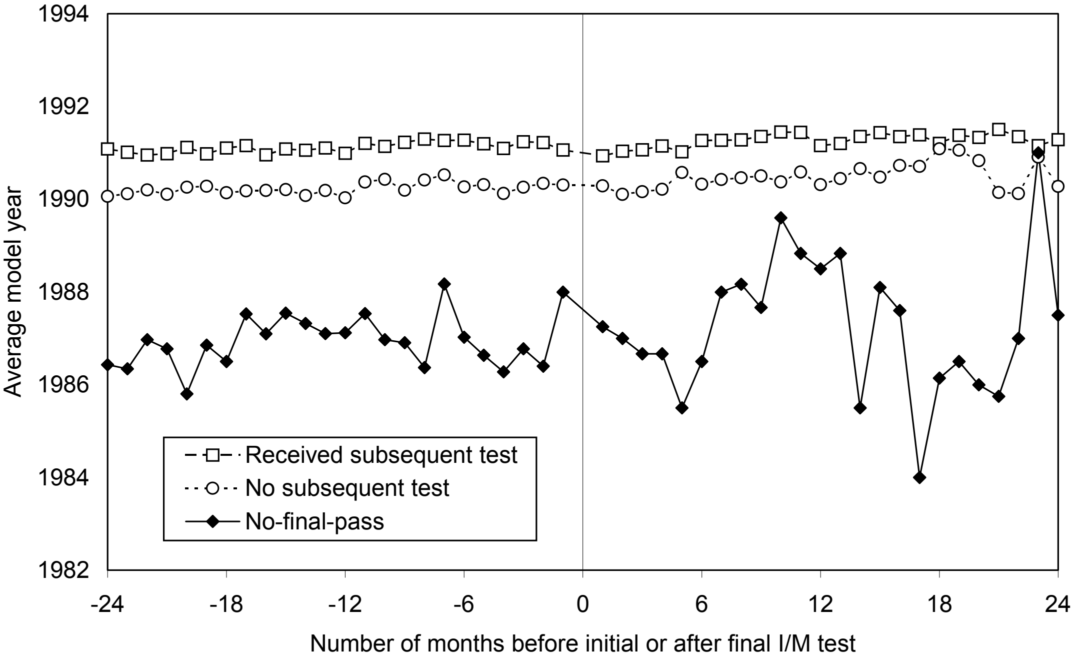

Figure 4-31. Average model year of the 1982 to 1995 light-duty I/M fleet observed on road in the Denver area by remote sensing, by I/M test result and time before initial and after final I/M test.

We attribute all of the emission reduction from vehicle removal to the AIR program, because the owners of these vehicles likely would not pay for an initial I/M inspection if they anticipated removing them from the I/M area. Our high estimate assumes that the no-final-pass vehicles are removed and not replaced. This assumption results in substantial emission reductions, as all of the emissions of these vehicles, and not just the emissions in excess of I/M cut points, are removed from the area's emission inventory. For our low estimate we assume that the removed vehicles are replaced by the average initial-pass vehicle of the same age, with lower emissions than the no-final-pass vehicles. For our best estimate we assume that they are replaced by the average initial-pass vehicle five years newer, with even lower emissions than the initial emissions of the no-final-pass vehicles. In addition, we assume that the newer vehicles would be driven more annual miles than the older no-final-pass vehicles they replaced (under the assumption that the vehicle owner will drive a better performing vehicle more miles than he or she would have driven the poorer performing vehicle).

4.3 ESTIMATES OF EMISSION REDUCTION BENEFITS

Table 4-1 shows the emission reductions in tons per day, and fuel savings in gallons per day, by vehicle type. Our best estimates of program benefits are shown in bold type; the range in each estimate is shown in parentheses. We estimate that the Colorado AIR program reduced HC and CO emissions by 8.0 and 92.1 tons per day, respectively, and reduced fuel use by 5,800 gallons per day. As a result of the program, NOx emissions increase less than 1.0 ton per day. Because the idle test does not measure NOx or fuel economy, we could not estimate the changes in NOx emissions or fuel use in heavy trucks. The HC and CO reductions were about evenly split between cars and light trucks, with heavy trucks accounting for another 12% of HC reductions. However, most of the NOx increase, and fuel savings, came from light trucks as opposed to cars.

Table 4-1. Emission reductions and fuel savings by vehicle type.

Vehicle type	**Emissions reduced (tons per day)**			**Fuel savings (gallons per day)**
	HC	**CO**	**NOx**	
Heavy trucks	**1** (1-1)	**2** (2-3)	0.0	0
Light trucks	**3** (2-4)	**45** (32-54)	**-0.2** (–0.4 – 0.0)	**3,700** (1,800-11,900)
Cars	**4** (2-5)	**45** (33-53)	**-0.1** (-0.2-0.1)	**2,100** (400-10,800)
Total	**8.0** (5-10)	**92** (67-110)	**-0.3** (-0.6-0.2)	**5,800** (2,300-22,700)
Distribution				
Heavy trucks	12%	2%	0%	0%
Light trucks	41%	49%	74%	64%
Cars	47%	48%	26%	36%
Total	100%	100%	100%	100%

Table 4-2 shows the estimates of program benefits by process. As noted above, we only estimated benefits from two of the three processes in which I/M programs reduce emissions: repair of vehicles that fail an I/M test, and permanent removal from the I/M area of vehicles that fail their initial test and do not pass a subsequent test (no-final-pass vehicles). Table 4-2 indicates that 80% of the HC and CO benefit came from repair of failing vehicles, with vehicle removal accounting for the remaining 20%. Although repairing failed vehicles increased NOx emissions somewhat, replacing no-final-pass vehicles with the average 5-year newer vehicle (in our best estimate) reduced NOx emissions; the net result is a slight increase in NOx emissions. Similarly, vehicle repair reduced fuel use, but replacement increased fuel use somewhat, with the net result a decrease in fuel use.

Table 4-2. Emission reductions and fuel savings by process.

Process	**Emissions reduced (tons per day)**			**Fuel savings (gallons per day)**
	HC	**CO**	**NOx**	
Repair	**6** (4-8)	**73** (50-87)	**-0.4** (–0.5 – -0.3)	**6,300** (2,200-10,200)
Replacement	**2** (1-2)	**19** (16-22)	**0.1** (-0.1-0.5)	**-500** (100-12,500)
Total	**8** (5-10)	**92** (67-109)	**-0.3** (-0.6-0.2)	**5,800** (2,300-22,700)
Distribution				
Repair	80%	79%	134%	109%
Replacement	20%	21%	-34%	-9%
Total	100%	100%	100%	100%

Figures 4-32 through 4-35 show the emission reductions under our best estimate for each pollutant and fuel by model year and process. Note that we assumed no benefit from pre-inspection maintenance and repairs, based on our analysis of remote sensing data, as described earlier. The figures indicate that model year 1985 vehicles account for more CO and HC emission reductions than any other model year. Benefits by model year decline as model year increases (or age decreases) for vehicles newer than 1985, presumably because of improved vehicle technology that reduces emissions deterioration. On the other hand, benefits by model year also decline as model year decreases (or age increases) for the vehicles older than 1985. This is likely due to the reduction in the number of vehicles tested, and assumed annual miles driven, as age increases for these older vehicles. Note that the emissions benefits for 1971 model year vehicles include the benefits for all vehicles older than 1971, all of which are subject to the AIR program. As a group, vehicles newer than 1985 account for more of the CO and HC reductions than vehicles older than 1985. 1997 and newer vehicles were exempt from the program in 2000, and 1996 vehicles were exempt in 1999; these and newer vehicles were tested in the AIR program either because they were being registered in Colorado from another state, or they were required to be tested before they were sold to a new owner. The newest model year required to be tested, 1995, accounts for the same portion, if not more, of the CO and HC reductions as model year 1994.

Figure 4-34 indicates that NOx emissions increase from post-failure repair of 1993 and older vehicles, as a result of the NOx disbenefit discussed earlier. The figure indicates that post-failure repairs actually reduce NOx in model year 1994 and newer vehicles. In contrast, there is a NOx benefit from replacement of no-final-pass vehicles with cleaner vehicles, in almost all model years.

Figure 4-35 shows fuel savings from vehicle repair, for all model years; however, there are small increases in fuel use from replacement of model year 1986 through 1994 no-final-pass vehicles. This is because in the I/M test results average fuel economy of initial-pass vehicles decreases (or per mile fuel use increases) as model year increases (or age decreases), and our best estimate of vehicle replacement uses newer vehicles to replace the no-final-pass vehicles. One explanation for why the I/M data suggest that fuel use increases with increasing model is that ESP does not adjust fuel economy for fast-pass vehicles to the full IM240 equivalent; some other aspect of how ESP calculates fuel economy may also explain this result. Figure 4-35 indicates that fuel savings are greatest for 1996 vehicles, even though fewer of these vehicles were tested in 1999 because they were exempted from the program at that time.

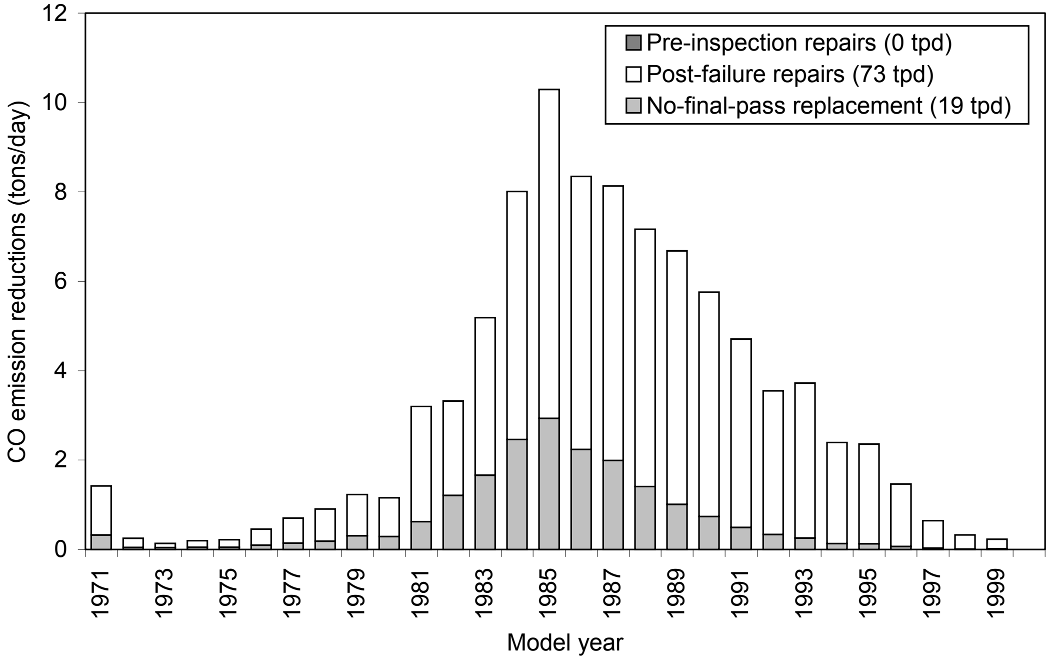

Figure 4-32. Best estimate of CO benefits (tons/day), by process and vehicle model year.

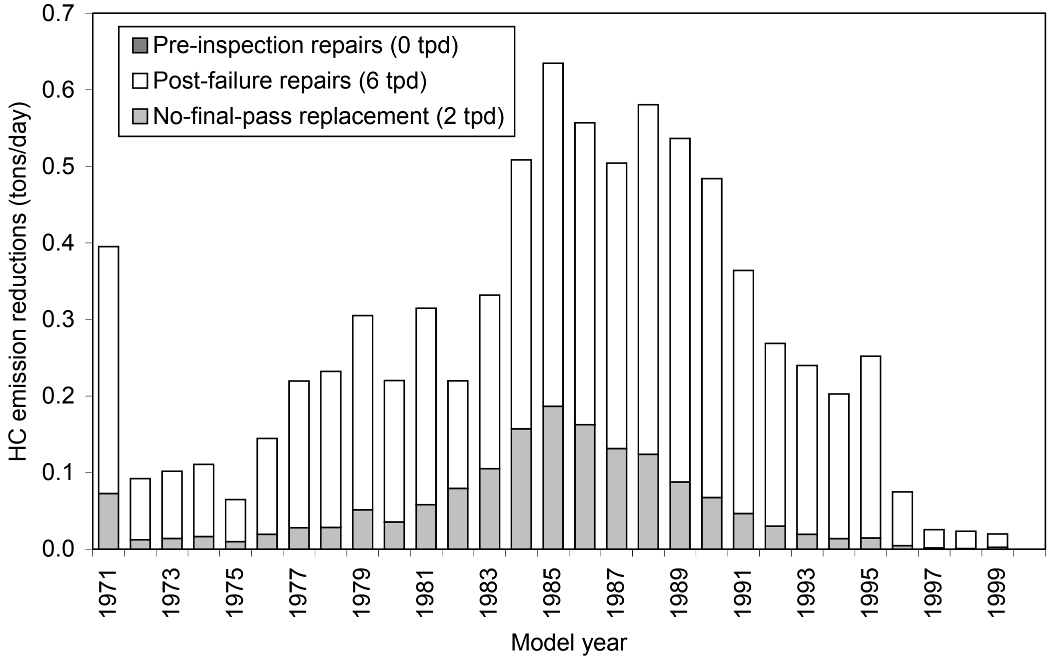

Figure 4-33. Best estimate of HC benefits (tons/day), by process and vehicle model year.

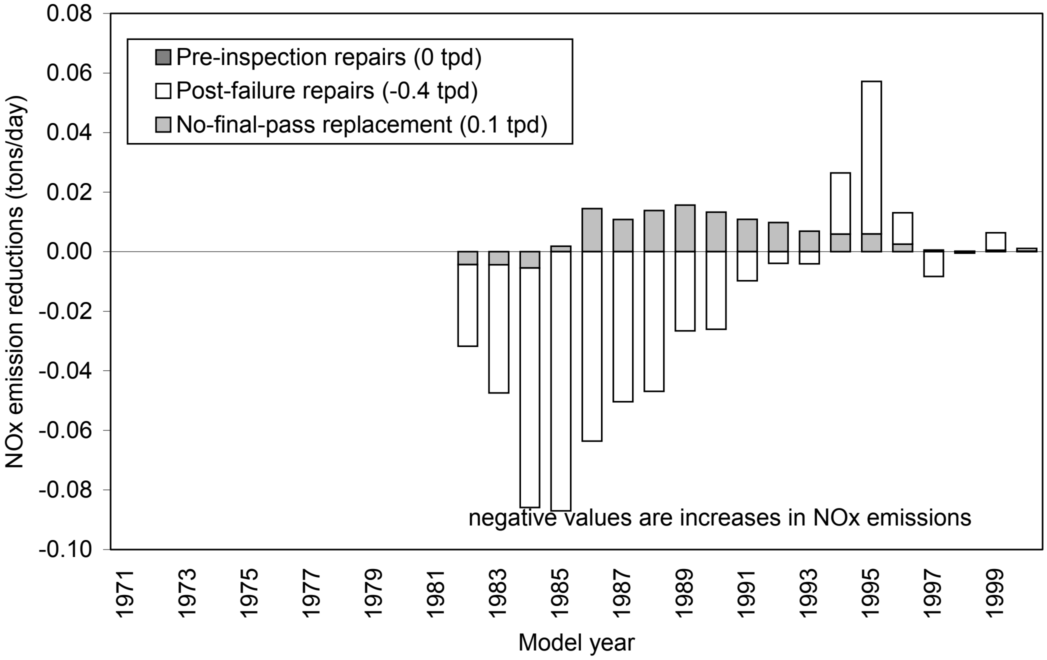

Figure 4-34. Best estimate of NOx benefits (tons/day), by process and vehicle model year.

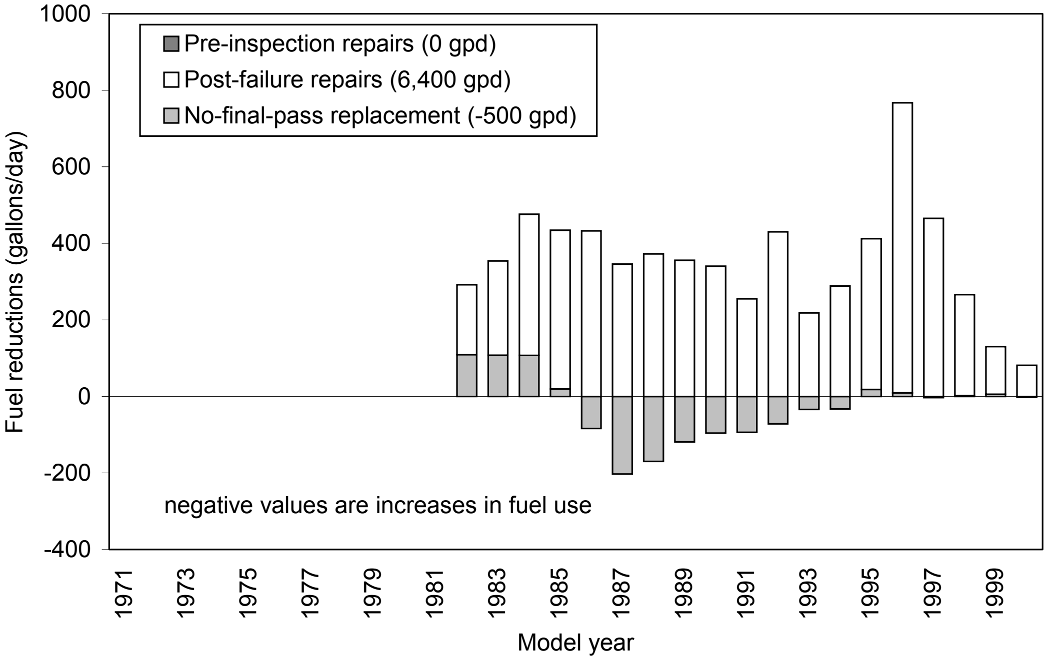

Figure 4-35. Best estimate of fuel benefits (gallons/day), by process and vehicle model year.

Figures 4-36 through 4-39 show the reductions by vehicle type and model year. In general CO and HC emissions benefits are similar for cars and light trucks; heavy trucks account for a very small portion of the CO benefits, and a larger portion of the HC benefits, particularly from older vehicles (heavy trucks account for half of the HC benefits from 1975 to 1978 vehicles; this is because the fraction of heavy trucks in the I/M fleet is highest for these model years, as shown in Figure 1). The changes in NOx and fuel use could not be estimate for heavy trucks, because NOx and CO_2 emissions are not measured on the idle test.

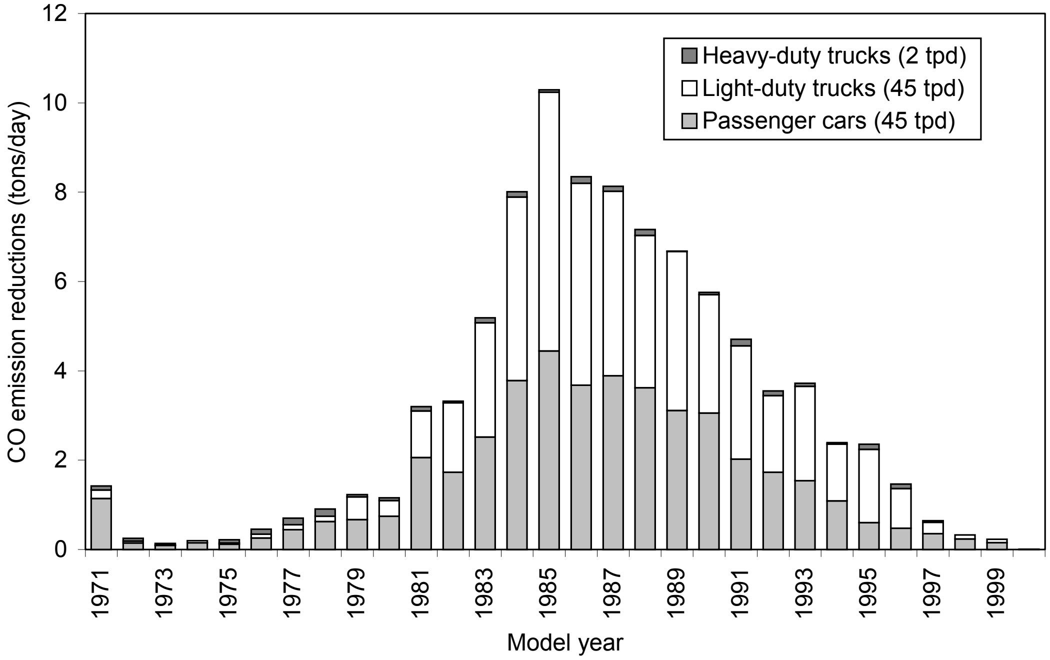

Figure 4-36. Best estimate of CO benefits (tons/day), by vehicle type and model year.

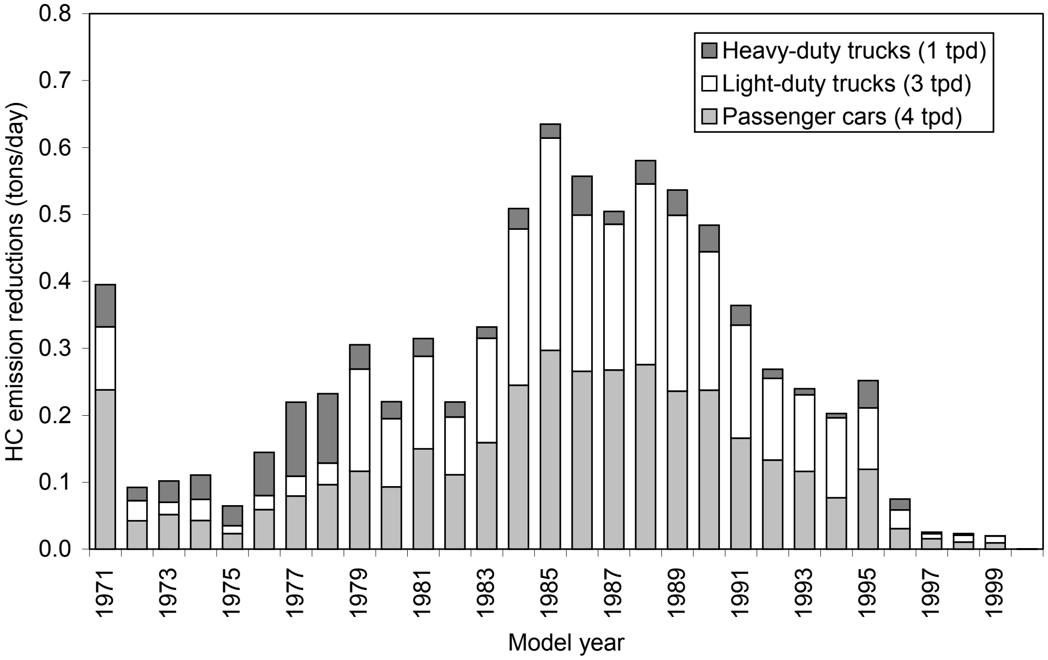

Figure 4-37. Best estimate of HC benefits (tons/day), by vehicle type and model year.

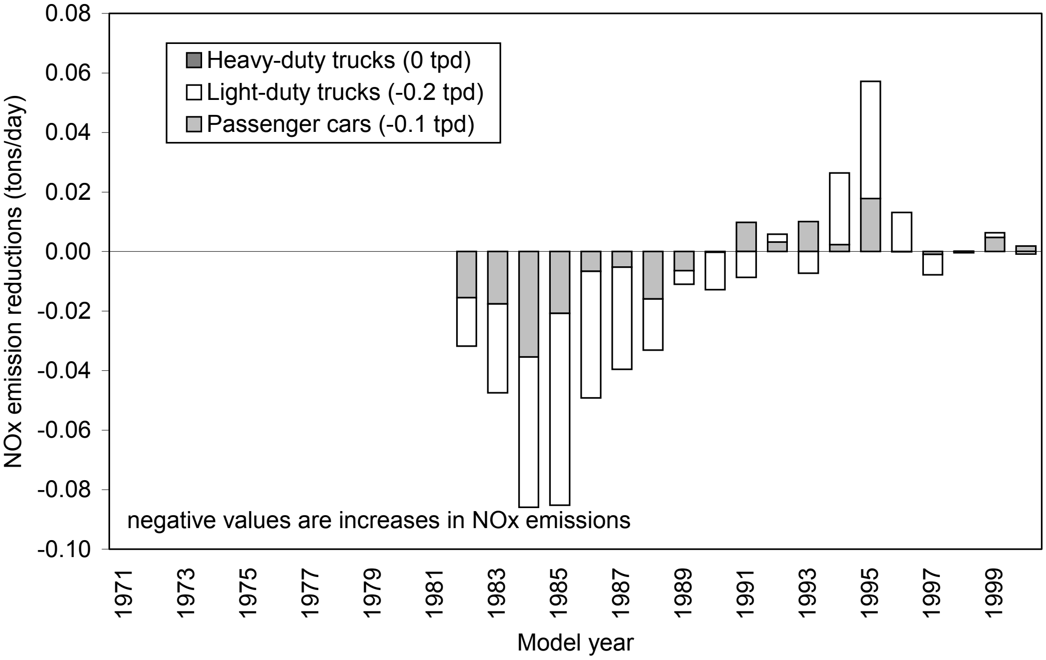

Figure 4-38. Best estimate of NOx benefits (tons/day), by vehicle type and model year.

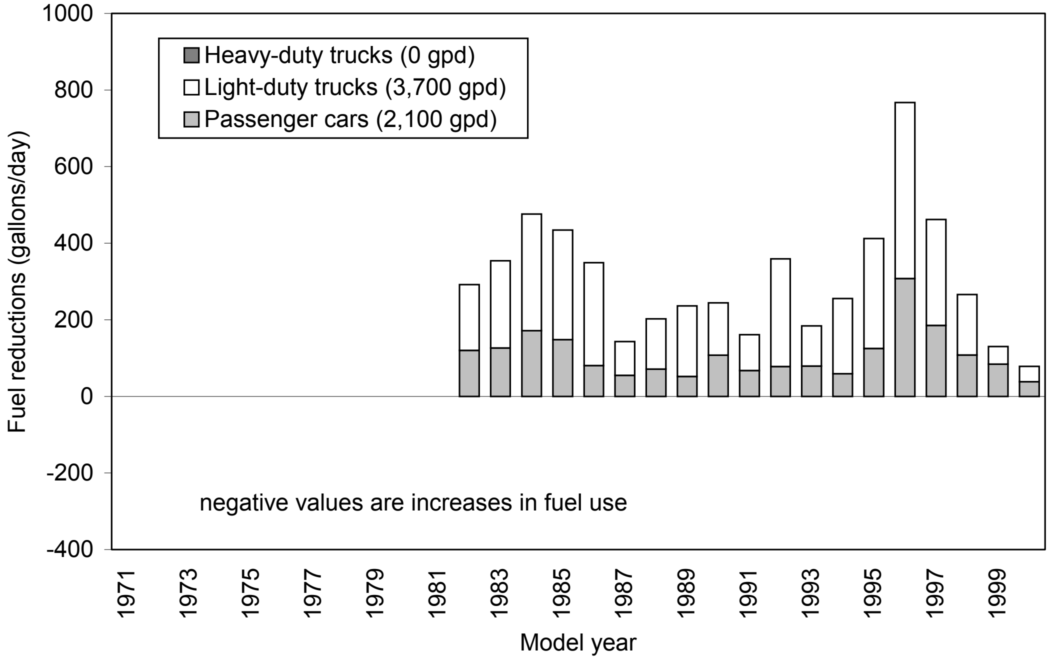

Figure 4-39. Best estimate of fuel benefits (gallons/day), by vehicle type and model year.

Figure 4-40 shows the cumulative distribution of program benefits, and vehicles tested, by model year, from the oldest to the newest vehicles. The figure indicates that the 20% oldest vehicles (1986 and older) account for about half of the CO and HC benefits, and 30% of the fuel savings. Similarly, the oldest half of vehicles (1991 and older) account for about 85% of the CO and HC benefits, and half of the fuel savings. Figure 4-41 shows the same data, but from the newest vehicles to the oldest vehicles. The newest 40% of vehicles tested (1994 and newer) account for only 10% of the CO and HC benefits.

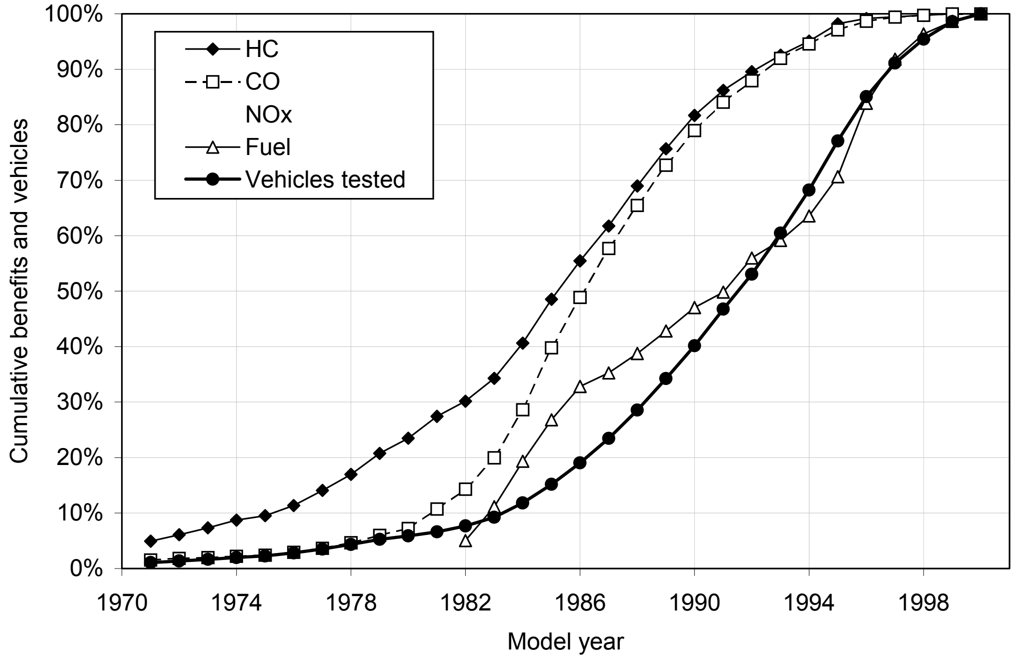

Figure 4-40. Cumulative fraction of vehicles tested and benefits, from oldest to newest vehicles.

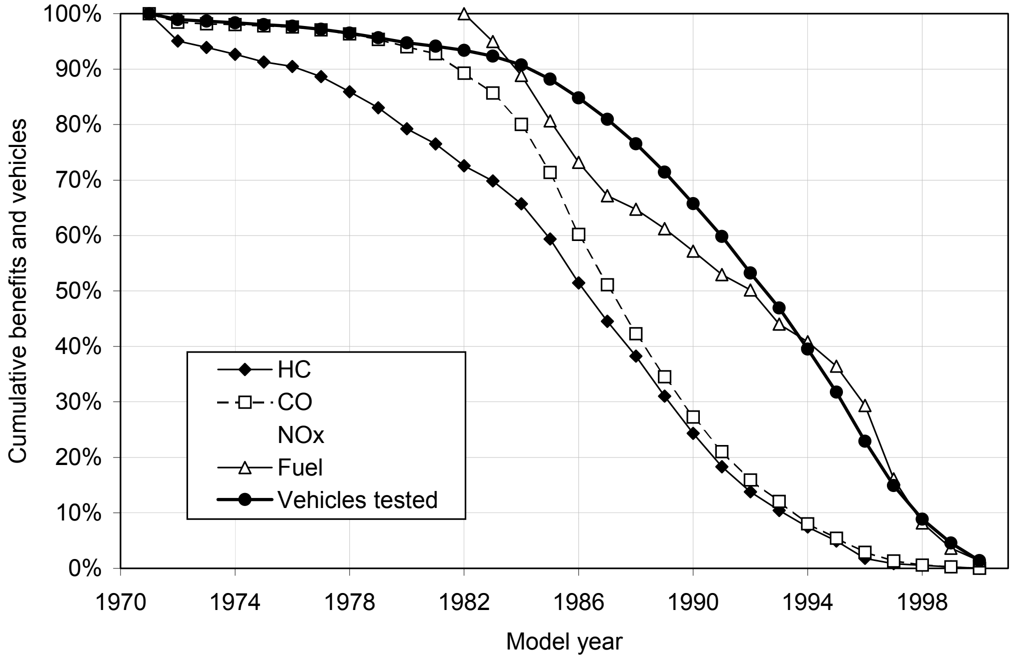

Figure 4-41. Cumulative fraction of vehicles tested and benefits, from newest to oldest vehicles.

Figure 4-42 shows the program benefits per 100,000 vehicles tested, by model year. Model years with high benefits per vehicle tested indicate where the AIR program is most efficiently obtaining emission reductions. The shape of the CO and HC curves in Figure 4-42 are quite similar, and suggest that the program is most efficient in reducing emissions from 1981 vehicles. The efficiency of the program steadily decreases with increasing model year for 1981 and newer vehicles; the emissions reductions per vehicle tested are the smallest for the newest vehicles, particularly 1996 and newer vehicles. Program efficiency drops off somewhat with decreasing model year for vehicles older than 1981, but then increases again for 1973 and older vehicles.

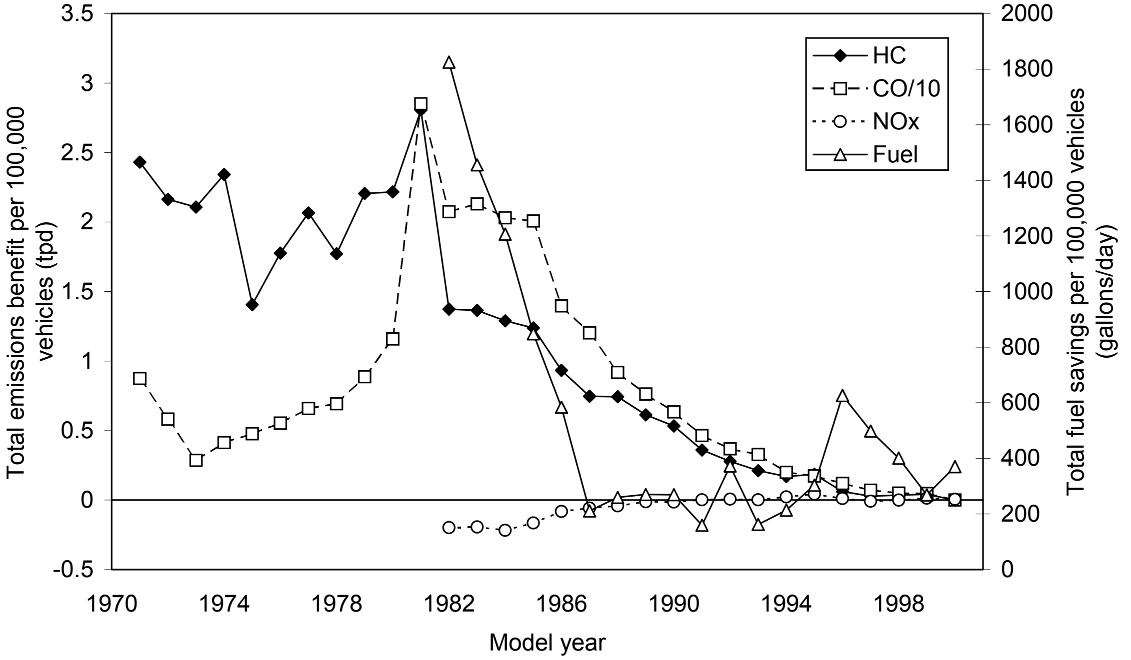

Figure 4-42. Total emissions and benefits per 100,000 vehicles tested, by model year.

In order to estimate the percentage reduction in emissions from the Colorado AIR program, we have to estimate what the emissions of the I/M fleet would have been without the program. To do this we simply combined the estimated emissions of the fail-pass, initial-pass, and no-final-pass vehicles. For the fail-pass vehicles, we used the three emissions estimates in the no-I/M case, described above. For the initial-pass vehicles we used the observed deterioration at their next test roughly two years later. We assumed that the emissions of no-final-pass vehicles would not have deteriorated in the absence of the AIR program.

Table 4-3 shows our estimate of the total emissions inventory of the I/M fleet, and the percent change in emissions and fuel use attributable to the AIR program. We estimate that the total I/M fleet accounts for 43 tons HC, 530 tons CO, 53 tons NOx, and 2.3 million gallons of gasoline per day (note that the fuel use in Table 4-3 is expressed in million gallons per day). The AIR program reduces the HC and CO emissions of the I/M fleet by about 18% from what they would have been without the program, and increases NOx emissions by less than one percent. In addition, the program saves less than one percent of the fuel used by the fleet reporting for I/M testing.

Table 4-3. I/M fleet baseline emissions and fuel use, and percent reduction from AIR program, by vehicle type.

Vehicle type	I/M fleet baseline emissions (tons per day)			Fuel use (million gallons per day)
	HC	**CO**	**NOx**	
Heavy trucks	**5** (4-5)	**30** (30-30)	NA	NA
Light trucks	**19** (18-20)	**237** (228-242)	**27** (27-27)	**1.2** (1.2-1.2)
Cars	**19** (18-20)	**263** (255-267)	**26** (26-26)	**1.1** (1.1-1.1)
Total	**43** (41-44)	**530** (513-539)	**53** (53-53)	**2.3** (2.3-2.3)
Percent change				
Heavy trucks	-21% (-16% to -24%)	-7% (-7% to –8%)		
Light trucks	-17% (-11% to –21%)	-19% (-14% to –23%)	1% (1% to 0%)	-0% (-0% to –0%)
Cars	-20 (-13% to –23%)%	-17% (-13% to –20%)	0% (1% to -1%)	-0% (0% to –1%)
Total	-19% (-12% to –22%)	-17% (-13% to –20%)	1% (1% to -0%)	-0% (-0% to –1%)

Figures 4-43 through 4-45 show the percent reductions from the baseline I/M fleet by vehicle type and model year.

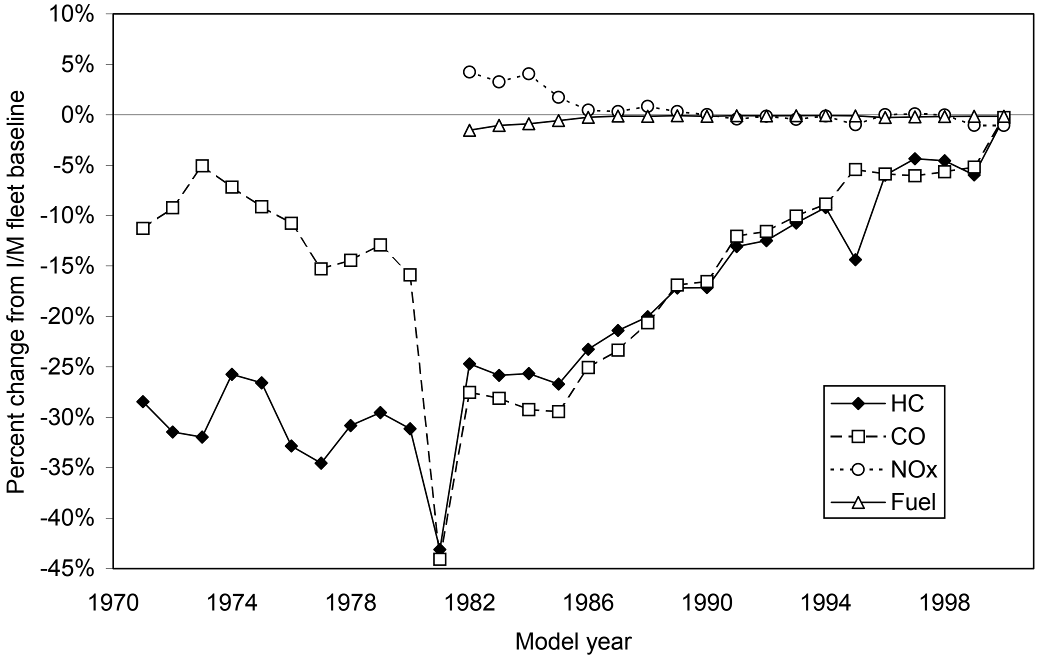

Figure 4-43. Percent change in passenger car I/M fleet baseline emissions and fuel use.

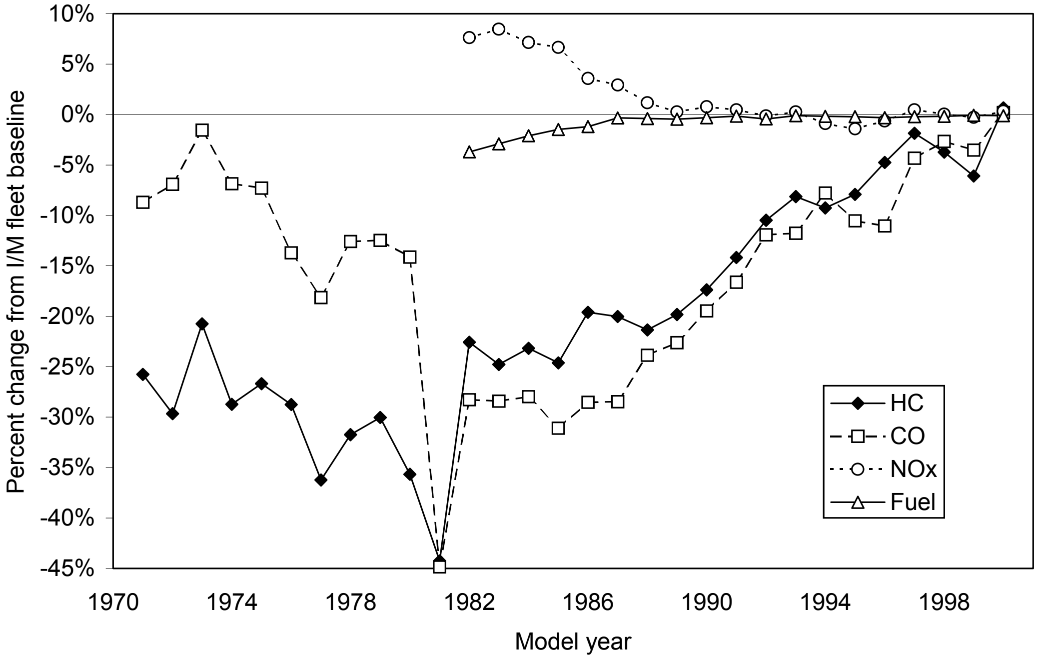

Figure 4-44. Percent change in light truck I/M fleet baseline emissions and fuel use.

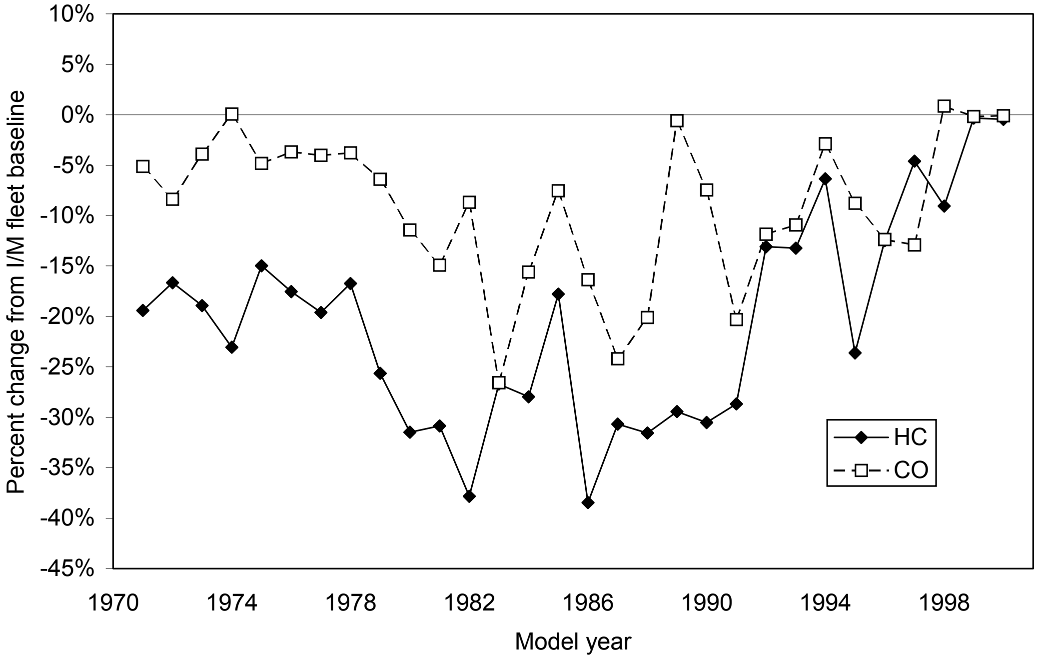

Figure 4-45. Percent change in heavy truck I/M fleet baseline emissions.

Finally, we estimated the percent reduction from the total on-road vehicle fleet, including vehicles not participating in the I/M program or exempt from I/M testing (because of their age). We used the ESP remote sensing measurements to estimate the fraction of vehicles in the on-road fleet that did not participate in the AIR program. Figure 4-46 indicates that this fraction is 9% for all model years: 2% for all model years eligible for the program, and much higher for new model years exempted from the program. This estimate probably overstates the fraction of the on-road fleet that is not tested in the I/M program, as many plates of vehicles reporting for I/M testing are coded with a number of "X"s followed by the last few digits in the VIN. These vehicles reporting for I/M tests therefore would not be matched with an on-road observation of the vehicle in the remote sensing data.

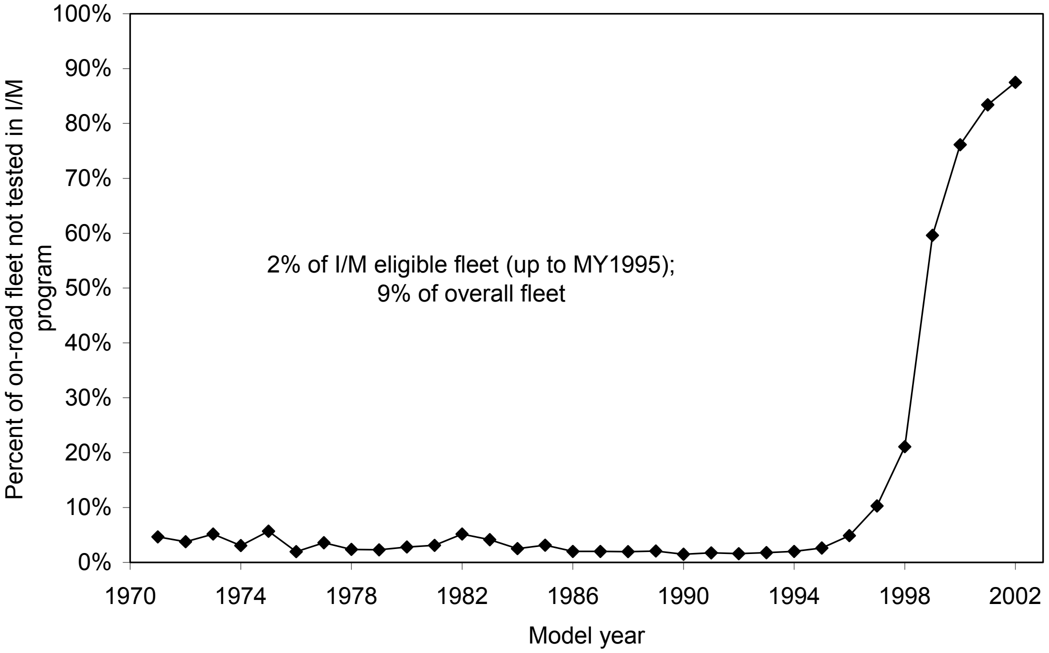

Figure 4-46. Percent of on-road fleet not tested in I/M program, based on ESP remote sensing measurements in 1999 and 2000.

We divided the number of untested vehicles observed on-road by the number of tested vehicles observed on-road, by model year, to obtain adjustment factors. We then used these factors to adjust the total emissions of the I/M fleet by model year to estimate the total emissions of the entire on-road fleet. Use of these adjustment factors to estimate emissions of the entire on-road fleet assumes that the on-road fleet has the same proportion of initial-pass, fail-pass, and no-final-pass vehicles by model year as observed in the I/M-tested fleet.

Table 4-4 shows our estimate of the total emissions inventory of the on-road fleet, and the percent change in emissions and fuel use attributable to the AIR program. The results in Table 4-4 are only slightly different from those in Table 4-3 because the majority of the vehicles not tested in the AIR program are the newest vehicles that make up only a small fraction of the on-road fleet emissions. For example, the untested vehicles account for only 5% of the total on-road HC and CO, 8% of the on-road NOx, and 18% of the fuel consumed by the total on-road fleet.

Table 4-4. On-road fleet baseline emissions and fuel use, and percent reduction from AIR program, by vehicle type.

Vehicle type	On-road fleet baseline emissions (tons per day)			Fuel use (million gallons per day)
	HC	CO	NOx	
Heavy trucks	**5** (5-5)	**32** (32-32)	NA	NA
Light trucks	**20** (20-21)	**250** (240-254)	**29** (29-29)	**1.5** (1.5-1.5)
Cars	**20** (19-21)	**279** (271-283)	**28** (28-28)	**1.4** (1.4-1.4)
Total	**45** (43-46)	**560** (543-569)	**57** (57-57)	**2.8** (2.8-2.8)
Percent change				
Heavy trucks	-20% (-15% to –23%)	-7% (-6% to –8%)		
Light trucks	-16% (-10% to –20%)	-18% (-13% to –21%)	1% (1% to 0%)	-0% (-0% to –1%)
Cars	-19% (-12% to –22%)	-16% (-12% to –19%)	0% (1% to –1%)	-0% (0% to –1%)
Total	-18% (-12% to –21%)	-16% (-12% to –19%)	1% (1% to –0%)	-0% (-0% to –1%)

4.4 CAVEATS OF THE ANALYSIS

Although we attempted to develop the most accurate estimates of emissions benefits resulting from the AIR program, our estimates do include several assumptions, and are limited by the data available. Below we list the most substantial uncertainties with our analysis.

Our analysis was limited to exhaust HC emissions only, and does not include the effect of the program on evaporative HC emissions. There may be evaporative HC benefits from repair of vehicles that failed a tailpipe HC test, and there almost certainly will be evaporative HC benefits from removal and replacement of no-final-pass vehicles.

Because the idle test does not measure NOx emissions, or mass emissions which are required to estimate fuel consumption, we could not estimate the changes in NOx emissions or fuel consumption for 1981 and older vehicles, or for heavy-duty trucks. We expect that the program results in additional, small increases in NOx emissions, and small fuel savings, for the vehicles receiving idle tests. Moreover, our estimate of HC and CO emissions and reductions from vehicles receiving an idle test is based on an extrapolation of the trend in IM240 emissions by model year to the trend in idle emissions by model year. It is not clear whether this extrapolation overstates or understates what the emissions of these vehicles would be if they were given an IM240 test. However, analysis of IM240 emission reductions by engine load indicates that operating modes requiring lower loads (such as idle) result in lower percentage reductions than modes requiring relatively higher loads (Wenzel, 2001). Thus the percent reductions in the idle test results likely overstate the percent reductions that would be observed if the vehicles were given an IM240 test. In addition, emissions and emission reductions measured under both the IM240 and the idle tests may not translate directly into on-road emissions and benefits; on-road emissions include start emissions, emissions during commanded enrichment, etc. Estimating benefits for idle vehicles in terms of IM240 emissions, and estimating benefits based on on-road emissions, could result in either higher or lower benefit estimates.

Our analysis does not explicitly include emission reductions from the 12% of vehicles that received more than one IM240 cycle within a two-year period (or a one-year period for vehicles in the idle test program), from change-of-ownership testing. Emissions of such vehicles are included in the average emissions by model year; however, such vehicles are credited with only one I/M cycle in the single year of our analysis. A vehicle receiving a change-of-ownership test would be tested on average one year after it last I/M cycle, with roughly half tested less than one year after and half tested more than one year after. Since we are estimating emission benefits for a single calendar year, only half of the vehicles receiving a change-of-ownership test would experience additional emission reductions from the change-of-ownership test. Including any emission reductions from the repair of any vehicles failing a change-of-ownership test would slightly increase our estimates of emission benefits.

Analysis of a random sample of passing vehicles that received full IM240 tests suggests that the projected fast-pass emission results overstate full test car CO emissions by 5% to 20%, depending on model year. Inaccurate predictions of the full test emissions of fail-pass vehicles, which account for most of the vehicles tested, will bias our estimates of the benefits of the I/M program. In particular, the consistently high over-prediction of car CO emissions suggests that our estimate of program benefits overstates the program's CO benefit from the repair and removal of cars. In addition, ESP does not project what fuel economy would be over a full IM240 test for vehicles that are fast-passed. Analysis of second-by-second IM240 data indicates that cumulative fuel economy at second 30 is substantially lower than cumulative fuel economy at second 240 of the IM240. Therefore fast-pass vehicles will have an artificially lower fuel economy than vehicles given a full IM240 test.

Our analysis does not account for any delays in vehicle repair or removal. For example, Table 4-5 shows the distribution of 1982 and newer fail-pass light-duty vehicles tested in 2000, by the length of time between their initial failing test and their final passing test. 19% of the vehicles passed a retest later in the day of their initial failing test[6]; 55% passed a retest within one week after the initial fail. However, nearly 3% took more than one year to pass a retest. We assumed that all repairs occurred roughly the same day as the initial fail; accounting for delays in repairing and retesting vehicles would lower our emission benefit estimates slightly.

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[6] There are several possible explanations for why these vehicles passed a retest on the same day they failed their initial test. Some of these vehicles may have failed their initial test because they were not properly warmed up prior to testing; the inspection may have suggested that the owner drive the vehicle to warm it up and then report back for a retest. Some vehicles may have passed their final test because their emissions problem was intermittent. Some vehicles were failed for faulty gas cap, and were provided with a replacement gas cap or a voucher for a replacement; they could then get retested and pass the same day. Another possibility, at least for the older vehicles without computer controlled engines, is that simple adjustments were made to the vehicles to pass the retest. One would expect that fewer vehicles would not be properly warmed up in the Colorado program (which requires most vehicles to fail two full IM240 tests before failing) than in the Phoenix IM240 program (which allows vehicles to fast fail after as little as 90 seconds of testing. However, 15% of the initial fail vehicles in the Phoenix program passed a retest on the same day they failed their initial test.

Table 4-5. Time between initial fail and final pass.

Time between initial fail and final pass	Percent of light-duty 1982+ fail-pass vehicles tested in 2000
Same day	18.6%
1 to 7 days	36.8%
8 days to 30 days	25.4%
31 days to 90 days	10.2%
91 days to 180 days	3.7%
181 days to 360 days	2.6%
361 days to 720 days	2.1%
More than 720 days	0.6%

We did not estimate benefits for the 5,000 1982 or newer light-duty vehicles that received an idle test because they could not be operated on the dynamometer used for the IM240 test. These vehicles represent less than 1% of the light-duty vehicles given an IM240 test and included in the analysis; including these vehicles in our analysis would result in a slight increase in emission benefits.

Some of the emission reductions attributed to the AIR program may have resulted from repairs that happened to coincide with the AIR test, but which would have occurred (albeit at a later time) even if the program did not exist. Likewise, some vehicle removal that we attribute to the AIR program might have occurred eventually without the program, although there is little incentive to pay for an I/M inspection and registration renewal if a household was not intending to continue to use the vehicle for the next two years.

There may well be cumulative emission benefits from previous cycles of I/M testing. Our estimate does not account for any such cumulative benefits.

Our estimate is sensitive to the estimates of annual average vehicle mileage by model year, taken from MOBILE6. Actual reductions could be higher or lower, depending on the accuracy of EPA's estimates of annual mileage.

Finally, we should note that our estimate does not account for fleet turnover that would have occurred independently of the AIR program. Some vehicles will be removed from the AIR program area for reasons unrelated to program requirements. For example, households may relocate to other areas or states, vehicles may be resold to households in other areas or states, or vehicles may be retired, all for reasons unrelated to their emissions. Fleet turnover induced by these actions will reduce vehicle emissions overall, but cannot be credited to the AIR program.

5.0 MOBILE6 ESTIMATES OF AIR PROGRAM BENEFITS

This section describes the estimated emissions benefits of the AIR Program using MOBILE6 modeling, and compares the MOBILE6 benefit estimates with the emissions benefits we estimated using AIR Program data. MOBILE6 is the Environmental Protection Agency's (EPA's) regulatory on-road emission factors model that state and local air quality planning agencies must use to estimate benefits and derive emissions reduction credits for Inspection and Maintenance (I/M) programs in their State Implementation Plan (SIPs).

5.1 SUMMARY

Overall, we found that MOBILE6 benefits estimates across all model years are higher than our estimates based on AIR Program data (which are discussed in Section 4). Benefit estimates are based on per vehicle emissions reductions. MOBILE6 estimates that carbon monoxide (CO) emissions have been reduced by almost 15 percent, hydrocarbon (HC) emissions have been reduced by about 20 percent, and nitrogen oxides (NO_X) emissions have been reduced by about 5 percent as a result of the AIR Program. MOBILE6 estimates that the largest percent of CO and HC reductions are attributable to 1980 and older light-duty vehicles, which generally have the highest emission rates. AIR Program data, however, indicate that the largest reductions are attributable to mid-1980's model year vehicles. In addition, AIR Program data show an increase in nitrogen oxides NO_X emissions for mid-1980's vehicles, and a slight decrease in emissions for 1990's model years. On the other hand, MOBILE6 shows NO_X benefits (decreases) for all model years, with significantly increasing benefits for later model year vehicles. MOBILE6 and its predecessors have not been found to be accurate in estimating vehicle emissions, and have overestimated benefits of I/M programs. We believe that the AIR Program data provide a better estimate of AIR Program benefits than MOBILE6. The National Research Council reached a similar conclusion in its report on evaluation of the effectiveness of Inspection and Maintenance (I/M) programs nationwide (NRC, 2001).

5.2 MOBILE6 MODEL INPUTS AND PROCESSING

The CDPHE provided winter scenario MOBILE6 input files with the following local inputs:

- inspection and maintenance program specifications (representing the AIR program),
- oxyfuel specifications,
- fuel Reid Vapor Pressure (RVP),
- local registration distributions (the same used in the travel fractions shown in Section 3),
- average hourly wintertime temperatures, and
- distribution of vehicle miles traveled (VMT) by hour, speed range/bin, and facility class.

The VMT data provided were specific to each of five geographic area types: central business district, fringe, urban, suburban, and rural. In addition, cutpoints for the IM240 test portion of the AIR program were provided for calendar year 2001. These were adjusted to 2000 by shifting the cutpoints (because MOBILE6 requires cutpoint inputs to be by age, not model year).

Modeling of both summer and winter seasons was performed. The summer season inputs were similar to those for the winter described above except for temperature, RVP, absence of oxyfuel, and fleet age. For temperature inputs, Denver summer 2000 average daily minimum and maximum temperatures, 60.9 and 92.4 degrees Fahrenheit, respectively, were obtained from on-line National Weather Service historical data records. Summer fuel RVP was set to 7.8 pounds per square inch per the ozone SIP[1]. Fleet turnover effects were accounted for by specifying July as the evaluation month. Two winter scenarios were modeled to determine the effects of IM: IM with oxyfuel and oxyfuel only. The two summer scenarios modeled were IM and no IM.

Total area VMT for 2000 was estimated by linearly backcasting from 2001 VMT from the proposed Denver CO Maintenance Plan VMT estimates for 2001, 2006, and 2013. The first step in the post-processing of model results was combining the five area types using VMT weights provided by the CDPHE and shown in Table 5-1.

Table 5-1. VMT used to combine area type-specific results.

Area type	VMT	Factor
Central business district	498,644	0.009
Fringe	5,097,315	0.090
Urban	18,474,354	0.325
Suburban	24,896,918	0.438
Rural	7,826,686	0.138

Per vehicle percentage emission reductions from IM implementation were estimated based on the oxyfuel only and IM with oxyfuel scenarios (for winter, or IM and no IM for summer). In both cases, the MOBILE6 emission factors for summer and winter runs were first averaged. To estimate tonnage emissions reductions for each model year, the difference in emission factors from the IM and no IM scenarios was combined with model year-specific VMT. The latter was obtained by distributing total VMT among the vehicle classes using fleet mix fractions from the modeling. Then within each vehicle class, by-model-year VMT was obtained by applying the calculated travel fractions (as shown in Section 3).

5.3 MOBILE6 YEAR 2000 BENEFITS ESTIMATES BY MODEL YEAR

The percentage IM benefits by model year estimated by MOBILE6 are shown in Figures 5-1 through 5-3 for HC, CO, and NOx, respectively. MOBILE6 shows no reductions for model years 1996 through 2000 because it considers model year 2000 of zero age and 1996 four years old. For light-duty vehicles, MOBILE6 estimates the largest percent HC and CO reductions for the older portion of the fleet, the pre-Tier 0 vehicles. These vehicles also have the highest emission rates, but lower travel fractions.

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[1] After the analysis was complete we learned that the average measured RVP is about 8.4 psi (including an ethanol marketshare). An increase of 0.6 psi RVP will have a very small effect on exhaust emissions.

Figures 5-4 through 5-6 show the tonnage reduction by model year, estimated by taking into account the estimated amount of travel as well as the absolute emission level of each model year. For comparison, our best estimates of TPD reductions by model year based on AIR program data were provided in Figures 4-36 to 4-38. These two sets of graphs are not directly comparable, however, because the MOBILE6 tonnage estimates are derived from an area-wide VMT estimate that is based on a geographic area that is larger than the enhanced I/M area (as discussed in Section 3). The total MOBILE6 estimates across all model years would therefore be expected to be greater than the estimates based on program data, which they are. For CO and HC, AIR program data show the largest tonnage reductions coming from mid-80's model years. MOBILE6, on the other hand, shows the largest tonnage reductions for the pre-Tier0 vehicles for HC and no pattern across model years for CO. For NOx, program data show NOx disbenefits for mid-80's model years and some NOx benefits for 1990's model years; MOBILE6 shows NOx benefits for all model years, with significantly increasing benefits for later model years.

Table 5-2 shows the total on-road fleet exhaust emissions for the vehicle classes in the AIR program in the Denver area. For comparison, on-road fleet emissions estimated from AIR program were shown in Table 4-4. Again, the comparison for total emissions is not direct because the MOBILE6 estimate is for a larger geographic area. Given that, one would expect the ratios of total emissions with the I/M program in Table 5-2 to total on-road fleet emissions in Table 4-4 to be similar for all three pollutants. However, while the ratios are similar for HC and NOx (MOBILE6 about 1.5 times larger with a larger geographical area), the ratio for CO is 2.5. This indicates that MOBILE6 may be significantly overpredicting CO emissions; this CO overprediction has been observed in other studies as well (e.g., McGaughey et al., 2003; Tran, Chi, and Pollack, 2002).

Table 5-2. MOBILE6 estimated on-road fleet exhaust emissions (TPD) and percent reduction by vehicle type.

Vehicle type	**On-road fleet emissions (tons per day)**		
	HC	**CO**	**NOx**
Emissions with I/M program			
Heavy trucks	1.4	43.4	4.4
Light trucks	42.8	768.3	39.7
Cars	31.7	602.1	41.1
Total	76.0	1413.7	85.3
Emissions without I/M program			
Heavy trucks	1.6	48.2	4.5
Light trucks	51.2	878.7	42.6
Cars	42.0	732.2	42.6
Total	94.7	1659.0	89.7
Percent Benefit of I/M program			
Heavy trucks	-9.9%	-10.0%	-1.5%
Light trucks	-16.3%	-12.6%	-6.8%
Cars	-24.4%	-17.8%	-3.4%
Total	-19.8%	-14.8%	-4.9%

The percent reductions estimated for the effect of the AIR program in Table 5-2 are comparable with the percent benefit estimates in Table 4-4. For CO, MOBILE6.2 a slight higher benefit for cars and heavy trucks and a slightly lower benefit for light trucks, with an overall slightly lower estimated benefit (but likely within uncertainty bounds). For HC, MOBILE6 estimates larger percent benefits for cars and heavy trucks, the same for light trucks, and overall a larger percent benefit for the affected fleet (again, though, likely within uncertainty bounds). For NO_X, MOBILE6 estimates small benefits for all vehicle classes, while the program data show very small disbenefits.

5.4 MOBILE6 PROJECTED PROGRAM BENEFITS

Specific calendar years that were modeled included 1996-2002, 2006, 2009, 2013, 2019, and 2025. As described above, the CDPHE provided winter scenario MOBILE6 input files which included inspection and maintenance program specifications (representing the AIR program), oxyfuel specifications, fuel Reid Vapor Pressure (RVP), local registration distributions (the same used in the travel fraction calculations described above), average hourly temperatures for wintertime in the Denver area, and distribution of vehicle miles traveled (VMT) by hour, speed range/bin, and facility class. Summer season inputs were as described above. For each calendar year, three control scenarios were modeled under each of two seasons. Winter runs were made for AIR and oxyfuel programs, oxyfuel and no AIR program, and no oxyfuel and no AIR program. Summer runs were made with and without the AIR program (there is no oxyfuel program in the summer).

Clean screening, which acts to exempt newer vehicles from testing requirements, was not implemented in the modeling of any calendar year because the Clean Screen utility is not yet available for MOBILE6.

The first step in the post-processing of model results was combining the five area types. This was accomplished by weighting each area by its associated 2001 daily VMT which was provided by the CDPHE. These VMT fractions are shown Table 5-1.

The VMT applied to the resulting emission factors to estimate emissions were derived from those assumed in the proposed Denver CO Maintenance Plan. The Plan presents estimates for 2001, 2006 and 2013. Linear interpolation and extrapolation were used to obtain estimates for the other years. The results are shown in Table 5-3. These fleet total VMT were then allocated to vehicle classes based upon the fleet mix from MOBILE6.

Table 5-3. VMT estimates used to estimate emissions trends.

Calendar Year	Total Daily VMT
1996	50,868,378
1997	52,054,116
1998	53,239,854
1999	54,425,592
2000	55,611,330
2001	56,797,068
2002	57,982,806
2006	62,725,758
2009	66,282,972
2013	71,045,166
2019	78,140,352
2025	85,254,780

For each season and control scenario, daily emissions were estimated as the product of vehicle class-specific emission factors and the corresponding VMT. Note that the same daily VMT was used for both seasons.

Figures 5-7 through 5-9 and Figure 5-10 through 5-12 show the winter and summer emissions trends for HC, CO, and NOx, respectively. For all three pollutants, the emission reductions from I/M are decreased in the future years. The change tends to stabilize by 2006. As expected (from examining the per vehicle emission reductions), NOx I/M benefits are the smallest. For all pollutants but NOx, oxygenated fuel alone provides significant emissions reductions (almost half the reductions from a combination of oxyfuel and I/M) far into the future. By 2015, however, emissions begin to level out regardless of the control(s) in effect.

A couple of noteworthy items to point out include the peaks in the NOx and CO trends at 2001 and 2002, respectively. A closer examination reveals that for NOx, the 1977 model year start emission factor is unusually high. That, coupled with the fact that this model year is associated with the 25+ years old registration distribution fraction in calendar year 2001, leads to the high observed emissions. For CO, EPA MOBILE6 staff suggest that the increase seen in 2001 is likely due to an anomaly in the model. NLEV vehicles, which begin sales in 2001, are modeled as extremely sensitive to gasoline sulfur content, and the model estimates that these vehicles will have emission rates higher than the Tier 1 vehicles during the calendar years when high sulfur gasoline is used; the anomaly goes away as 2004 approaches and low sulfur gasoline is phased in. The by-model-year model outputs support this assessment. In addition, as discussed above, MOBILE6 appears to significantly overpredict CO emission rates.

Second, from model validation efforts, it has been found that MOBILE6 overestimates CO emission factors. However, since the IM effect is not internally handled as a percent correction, the estimated absolute benefits are not affected by the emission factor overestimation.

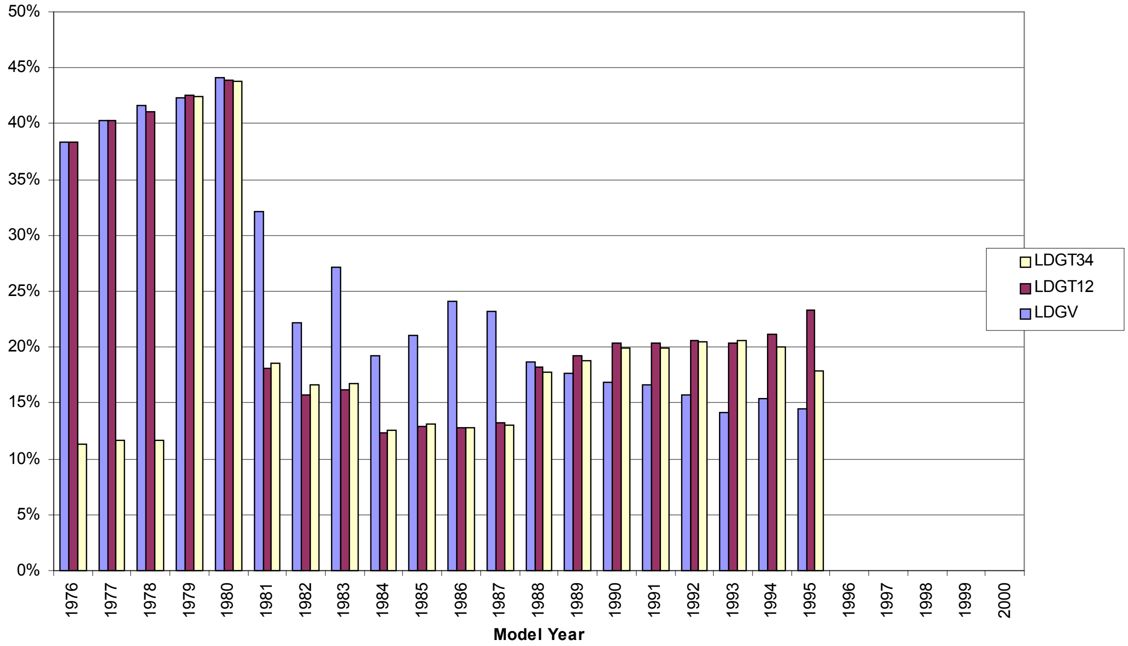


Figure 5-1. MOBILE6 percent HC emissions reduction from AIR program in 2000 by model year.

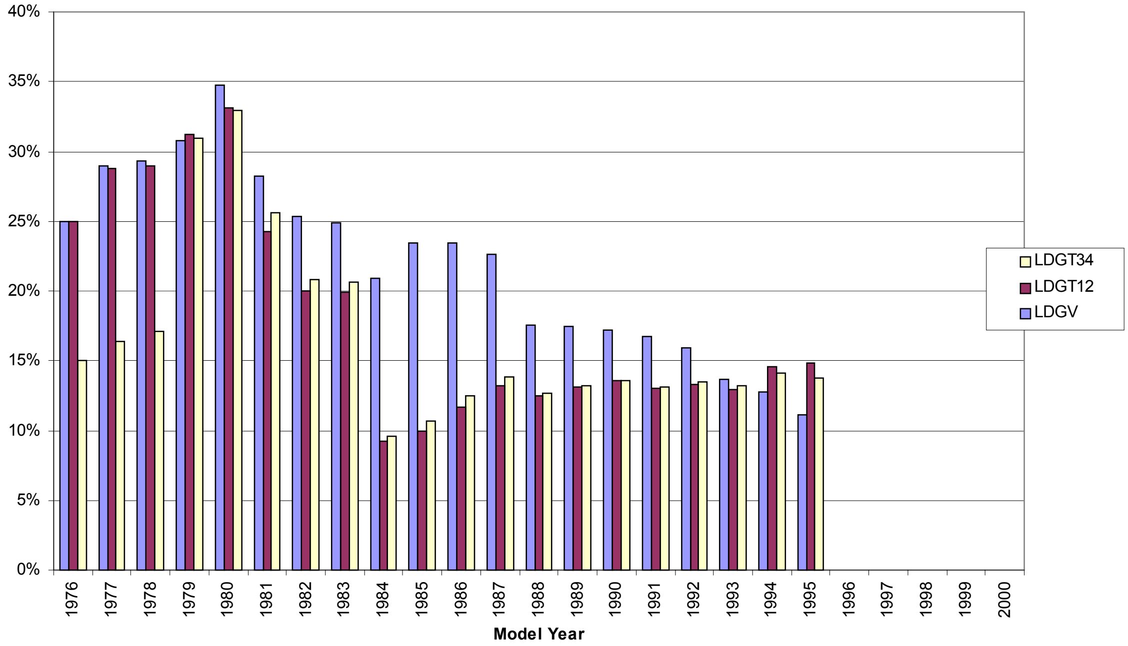


Figure 5-2. MOBILE6 percent CO emissions reduction from AIR program in 2000 by model year.

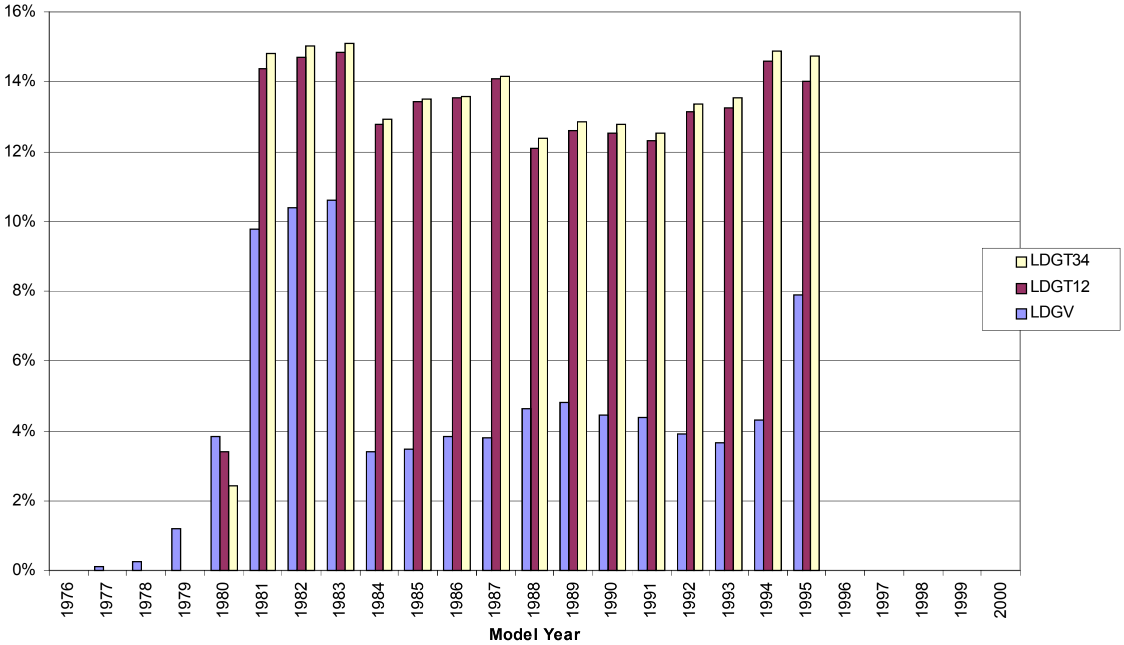


Figure 5-3. MOBILE6 percent NOx emissions reduction from AIR program in 2000 by model year.

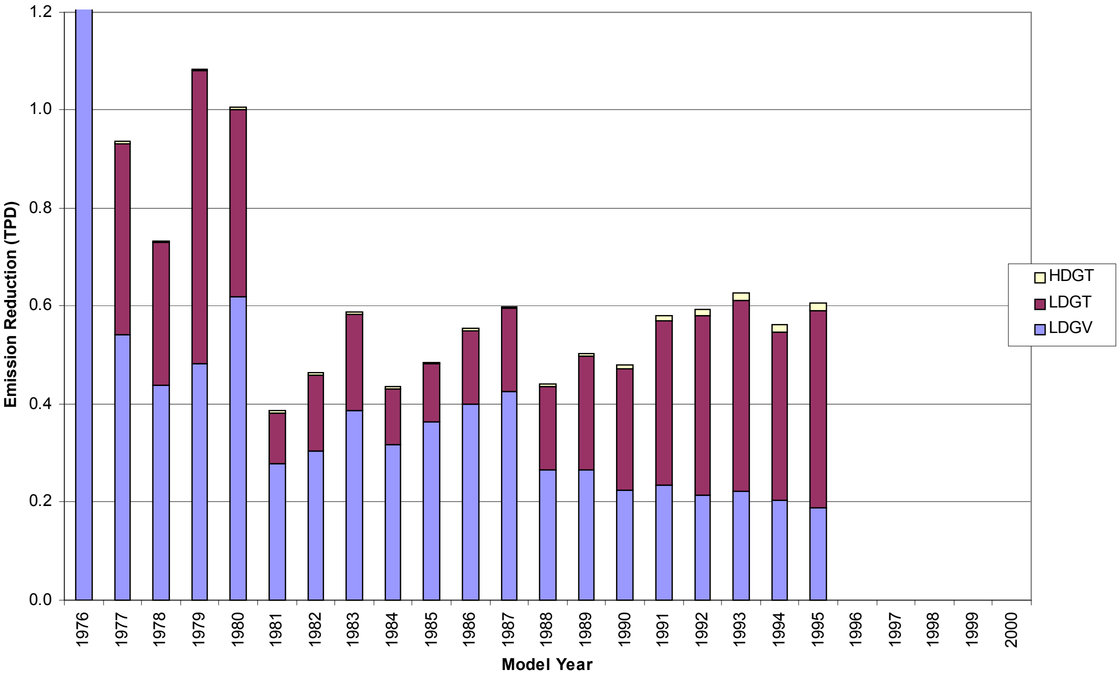


Figure 5-4. MOBILE6 HC tonnage emission reductions from AIR program in 2000 by model year.

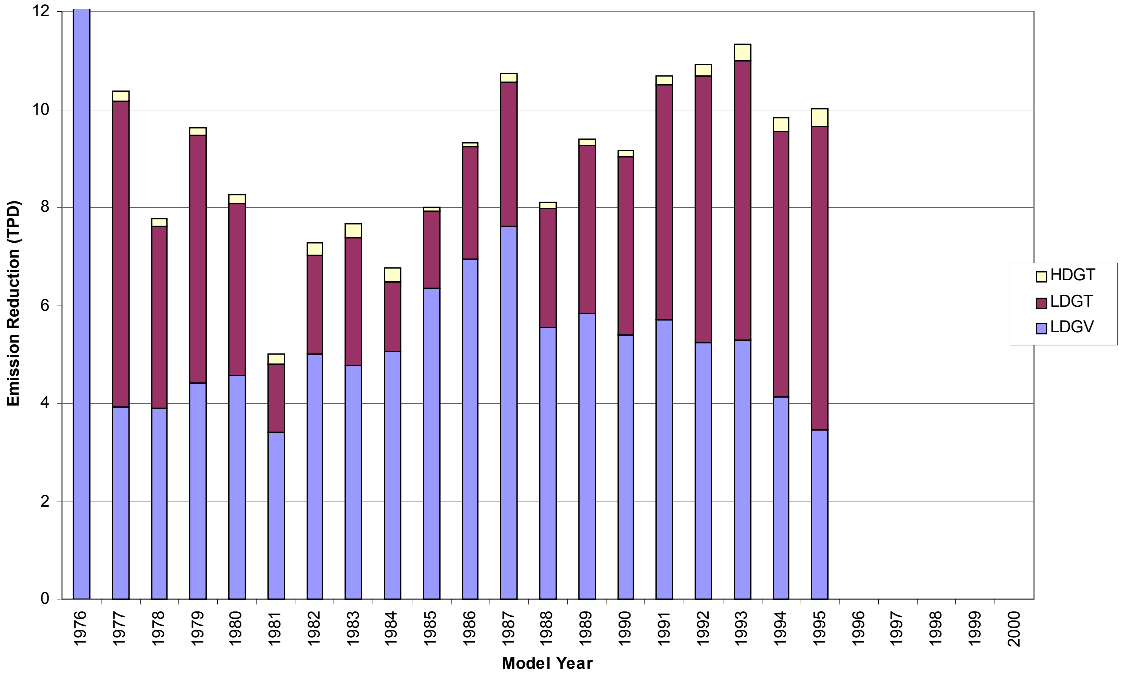


Figure 5-5. MOBILE6 CO tonnage emission reductions from AIR program in 2000 by model year.

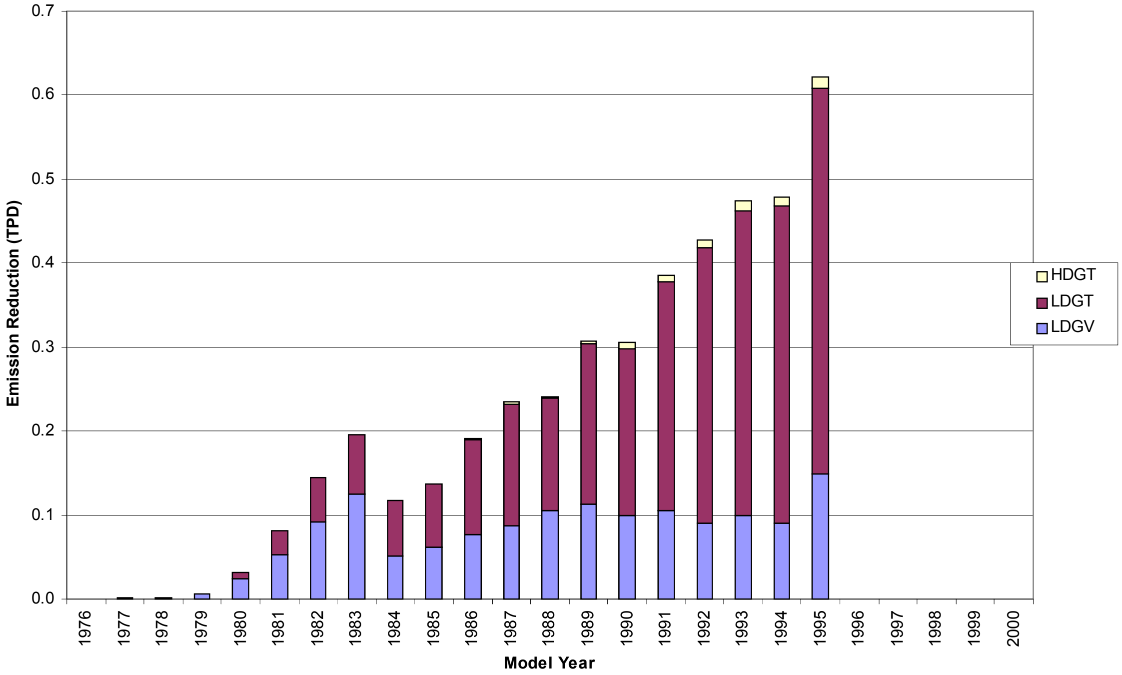


Figure 5-6. MOBILE6 NOx tonnage emission reductions from AIR program in 2000 by model year.

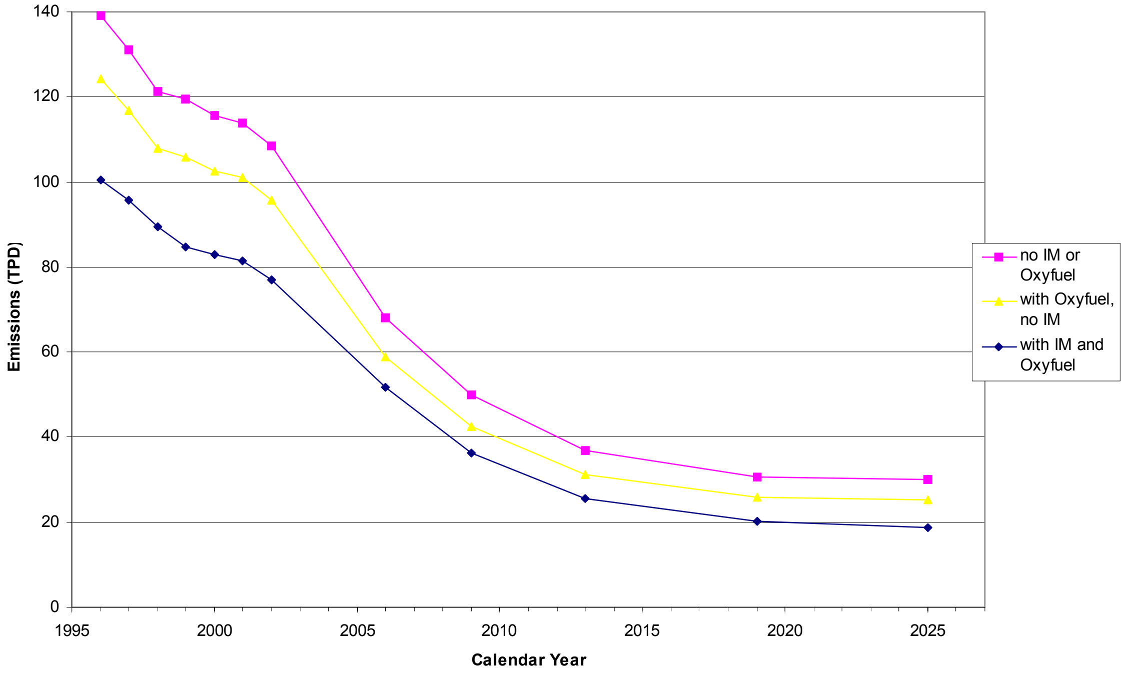


Figure 5-7. Winter season HC emissions trends. Emissions are only from vehicle classes subject to inspection.

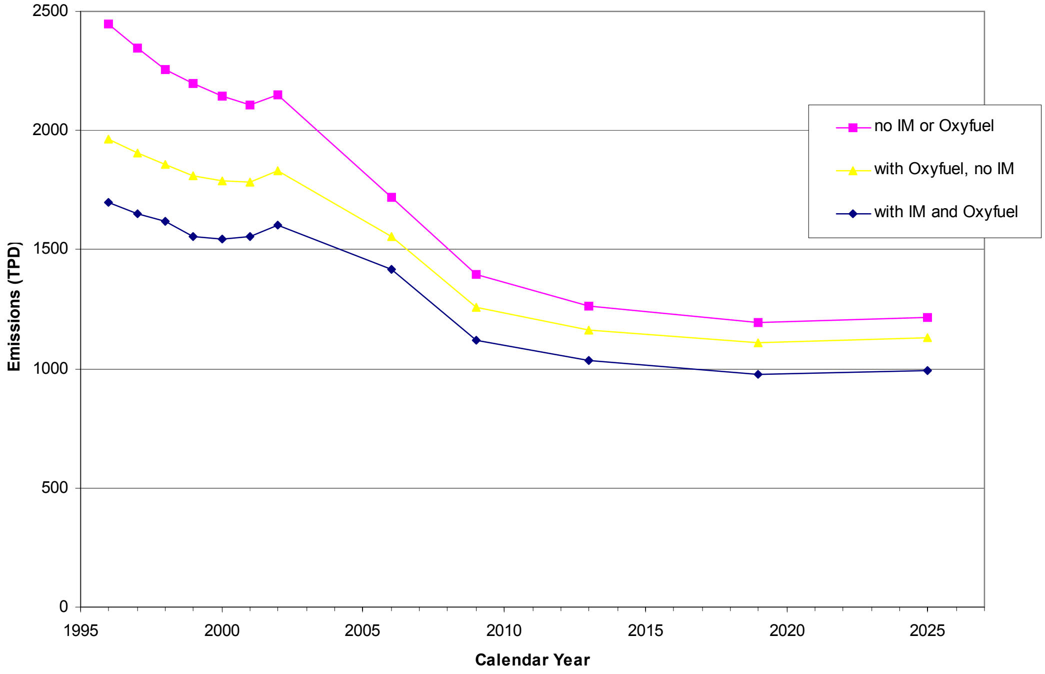


Figure 5-8. Winter season CO emissions trends. Emissions are only from vehicle classes subject to inspection.

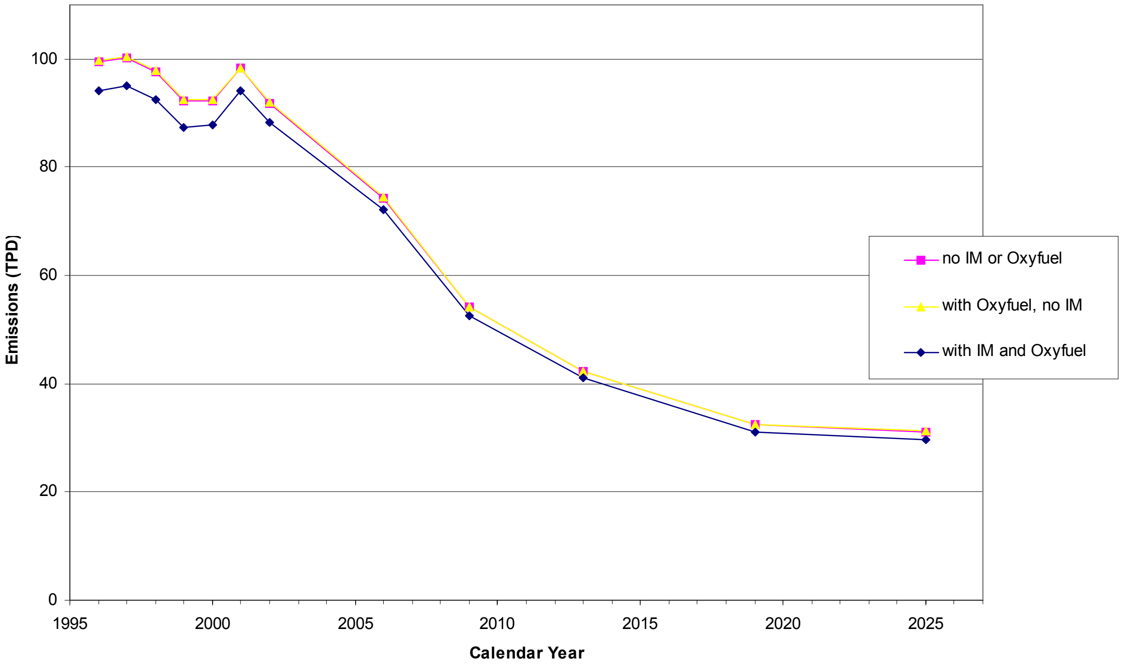


Figure 5-9. Winter season NOx emissions trends. Emissions are only from vehicle classes subject to inspection.

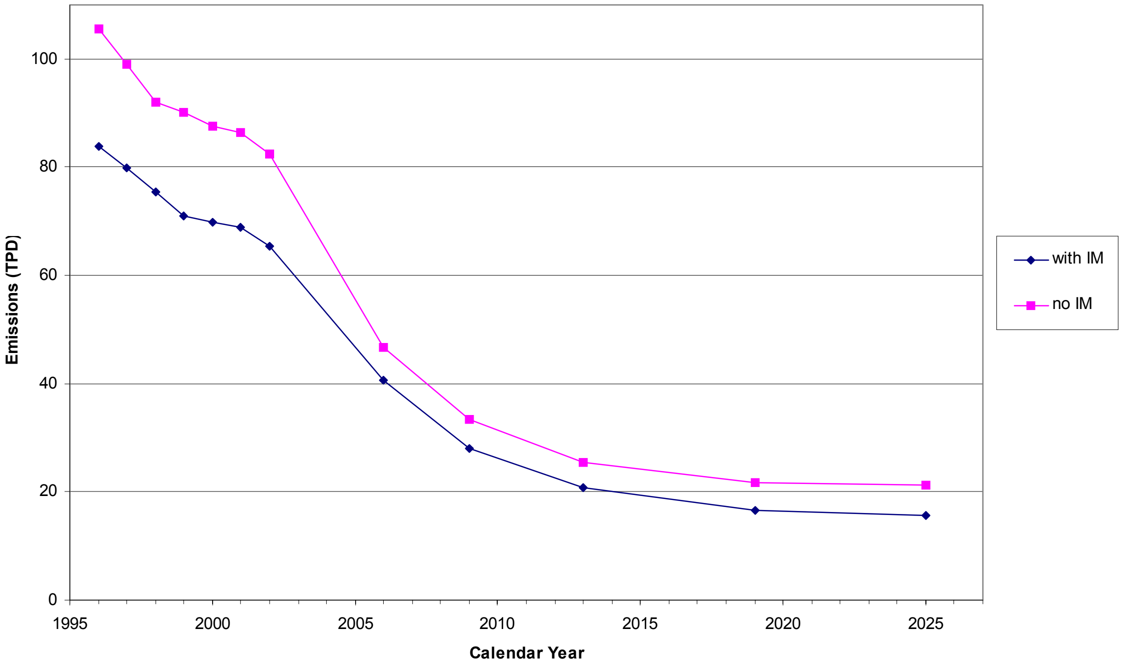


Figure 5-10. Summer season HC emissions trends. Emissions are only from vehicle classes subject to inspection.

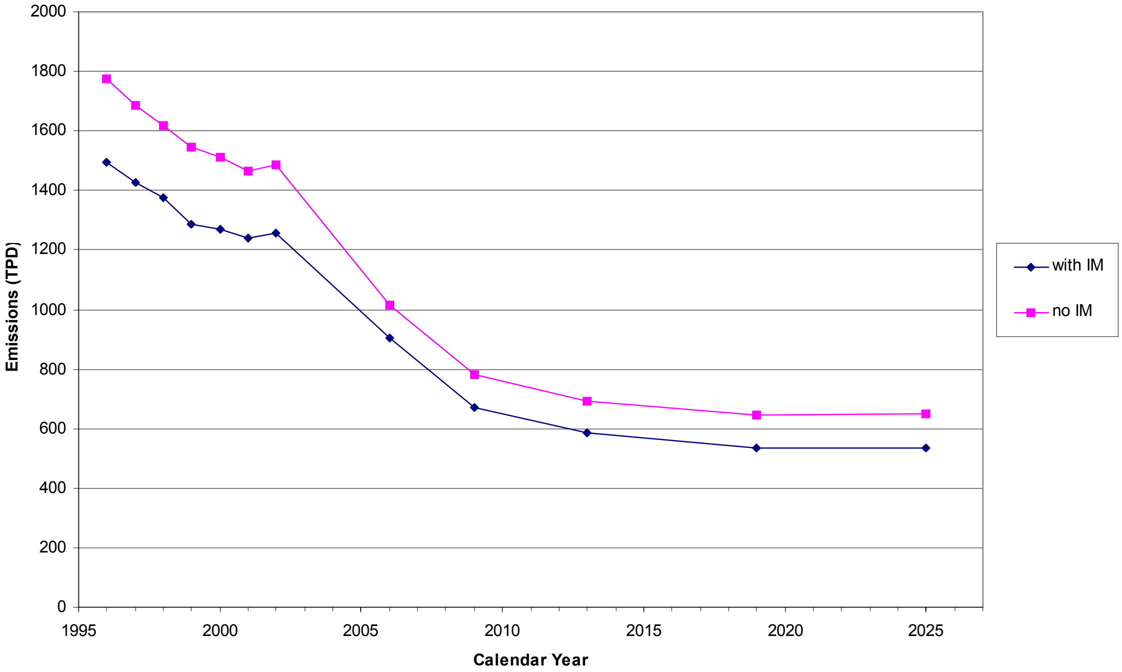


Figure 5-11. Summer season CO emissions trends. Emissions are only from vehicle classes subject to inspection.

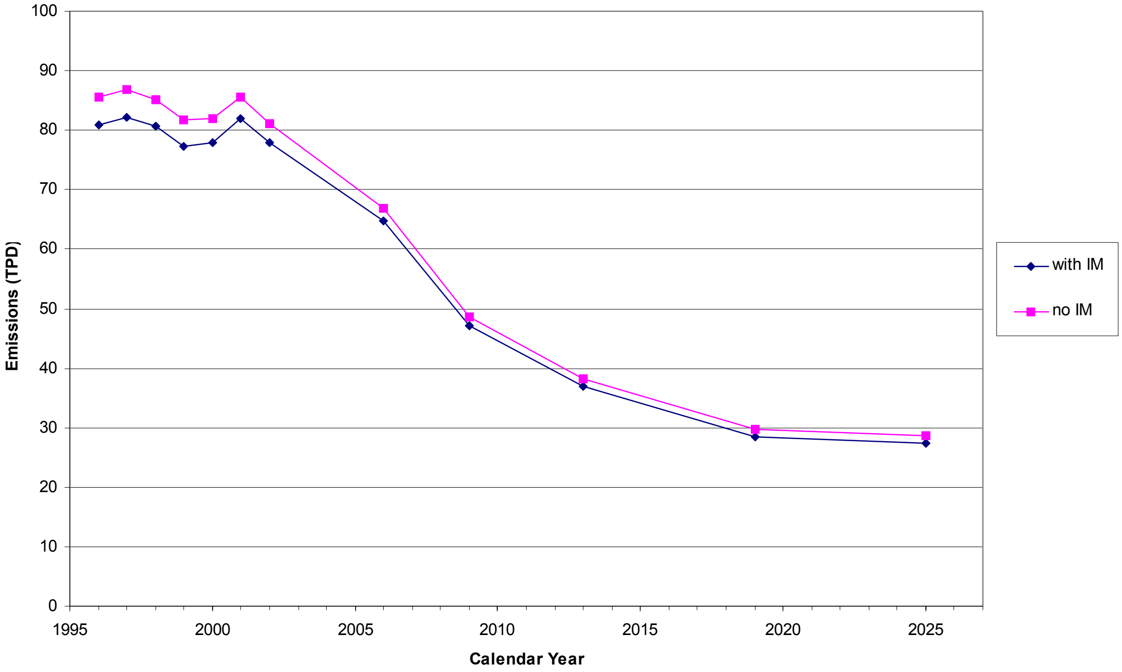


Figure 5-12. Summer season NOx emissions trends. Emissions are only from vehicle classes subject to inspection.

6.0 PROJECTION OF FUTURE FLEET EMISSIONS

In this section, we project future emissions for the Denver area for several different scenarios. To do so, we used AIR Program data and remote sensing data collected during the last several years, as incorporate the requirements of the Environmental Protection Agency (EPA) vehicle standards that will be required for all 2004 and later model year vehicles (referred to as Tier 2). We also compare these predictions with those of EPA's MOBILE6 emission factor model.

6.1 SUMMARY

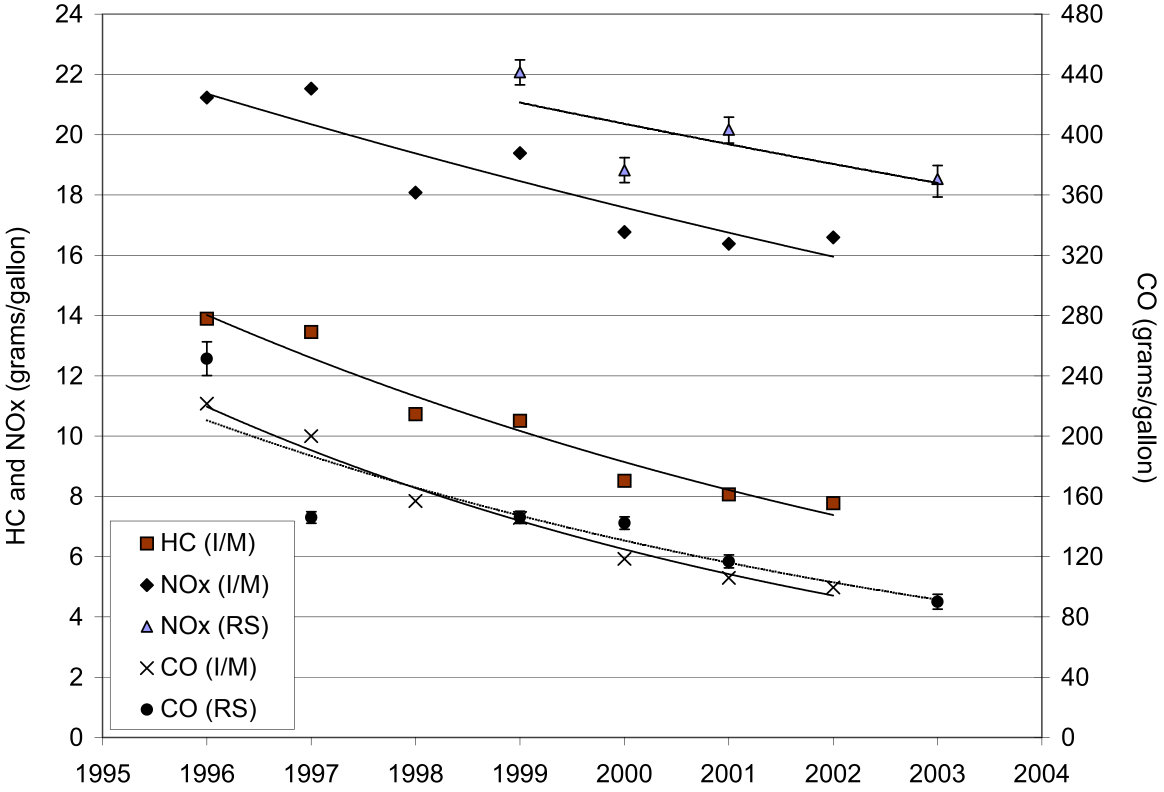
Vehicle emissions have been declining for many years, and will continue to decline. A major factor contributing to the substantial declines in emissions during the last several years is fleet turnover combined with progressive improvements in vehicles' emissions performance with each new model year. The EPA has implemented a series of progressively more stringent vehicle emissions standards and durability regulations, and manufacturers have continually improved emissions performance and durability. In fact, the automobile manufacturers agreed to a voluntary National Low Emission Vehicles Program, which began in most of the country with model year 2001 vehicles. Therefore, as older vehicles are retired, they are replaced by more recent models that start out cleaner and stay cleaner as they age.

Using AIR Program data and on-road emissions measurements, we found that in the Denver area, the average carbon monoxide emissions declined more than 50 percent between 1996 and 2002. Hydrocarbons declined about 45 percent, while nitrogen oxides declined about 25 percent. Data for individual model years show that each successive vehicle model year has average emissions lower than earlier model years, both in terms of initial emissions and long-term durability.

We used the AIR Program data and on-road emissions measurements to forecast future emissions for the Denver vehicle fleet without the AIR Program. Because there are uncertainties in the data, we developed optimistic, best estimate, and conservative projections. With all of these projections, we expect to see a continued decline in emissions as older vehicles are replaced by newer vehicles, even without the AIR Program. We predict that emissions of all pollutants will decline somewhat in the near term, with a much larger decline in the longer term. We also looked at emission projections using EPA's MOBILE6 model. Using this model, we found similar results, although MOBILE6 predicts larger hydrocarbon emission reductions than our forecasts. Overall, we conclude that future emissions would be lower with the AIR Program, but the Program is not necessary to ensure continued declines in emissions from the light-duty vehicle fleet.

6.2 EMISSION TRENDS

Both on-road remote sensing and test-lane IM240 data suggest that fleet-average emission rates have been declining. Figure 6-1 summarizes these fleet-average trends in emissions.



RS = remote sensing

Figure 6-1. Fleet-average emission trends based on I/M and on-road remote sensing data.

The emission estimates are in units of grams of pollutant emitted per gallon of fuel burned (grams/gallon). The remote sensing data could not be used to estimate HC trends, due to a variable offset problem that prevents apples-to-apples comparisons between datasets collected in different years. The remote sensing NOx trend begins in 1999, because earlier NOx data were collected with an earlier NOx sensor that had some HC interference, creating a high bias in the measurements (Stedman, D.H., Personal Communication, 2003).

The remote sensing data were collected by Don Stedman's group at the University of Denver (UD) at two freeway ramps. For calendar years 1996, 1997, and 1999-2001, data were collected in January at 6th Avenue and Interstate 25.[1] Data were also collected in December 2002 at Speer Boulevard and I-25. Most of these datasets include about 25,000 measurements, though the Speer Blvd. data include about 10,000, while the 1997 data include more than 40,000.[2] We use the UD data rather than remote sensing measurements made by ESP because the UD data were collected at only two sites by the same researchers, and therefore minimize site-to-site and inter-year variability in the vehicles and emissions measured in each year.

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[1] During some campaigns, some data were also collected during December of the previous year.

[2] The data were downloaded from http://www.feat.biochem.du.edu/light_duty_vehicles.html, a web site maintained by Dr. Gary Bishop of Professor Stedman's research group, last accessed on May 2, 2003.

Emissions vary with engine load, which is a function of speed, acceleration, and road grade, generally expressed as vehicle specific power (VSP), in kilowatts per metric ton (kW/tonne). Load varies a great deal from car to car in remote sensing data, and the load distribution varies from year to year, based on driving conditions at the time the measurements are made. In order to compare emissions across time, each dataset was adjusted to a common load distribution. The vehicle age distribution—known as the travel fraction—also varies from year to year, so emissions were also adjusted to a common travel fraction.[3]

Unlike remote sensing data, IM240 data are collected under similar conditions of engine load. Therefore only weighting by travel fraction is necessary to derive fleet-average emission rates. We used the same travel fraction for the IM240 data as for the remote sensing data to derive the estimates in Figure 6-1.[4]

Remote sensing are generally reported in grams/gallon, while IM240 data are reported in grams per mile (grams/mile). For this graph, the IM240 data were converted to grams/gallon using the average fuel economy by model year from the IM240 measurements (grams/mile * miles/gallon = grams/gallon). The apparently good agreement between the remote sensing and IM240 data, particularly for CO, may be coincidental. The IM240 data represent vehicles only up to age 14, and probably also a different range of engine loads than the remote sensing data. Furthermore, the IM240 data are probably depleted in high emitters when compared with the on-road data, due to program avoidance by some motorists (Stedman, D.H. et al., 1997, 1998). Finally, the fuel economy conversion of the I/M data from grams/mile to grams/gallon might be biased, because EPS did not adjust the fuel economy measured in "fast-pass" I/M test to full IM240 equivalents.

A major factor contributing to substantial declines in emissions during the last several years is fleet turnover combined with progressive improvement in vehicles' emissions performance with each new model-year. Figure 6-2 displays HC emissions vs. age for several model years, based on IM240 data.[5] The graph also displays data separately for cars and light trucks. Note that at each age, more recent model-years have lower emissions than earlier model-years. In other words, with each model-year, vehicles are starting out and staying cleaner, on average, when compared with vehicles built in previous years.

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[3] These adjustments were done by binning the emissions data within each calendar year into VSP groups for each vehicle age (where a vehicle's age is set equal to one plus the current calendar year minus the model year). The result is a two-dimensional matrix of average emissions by age and VSP. Average emissions for each age is a weighted average of the emissions for each VSP bin. Fleet-average emissions is a weighted average of emissions vs. age and the travel fraction. For this analysis, we used the actual travel fraction measured in calendar year 2001, and the VSP distribution measured in 2000. (We didn't use the VSP distribution from 2001 because road construction at the remote sensing site resulted in a relatively low load distribution.)

[4] IM240 data include only model years 1982 to current. Thus, in order to have a consistent fleet across the calendar years of I/M data (1996-2002) we were only able to include vehicles up to 14 years old in our estimate of fleet-average emission rate trends. For remote sensing, the fleet includes vehicles of all ages.

[5] Peter McClintock of Applied Analysis, Inc. created this type of chart for displaying trends in vehicle emission data.

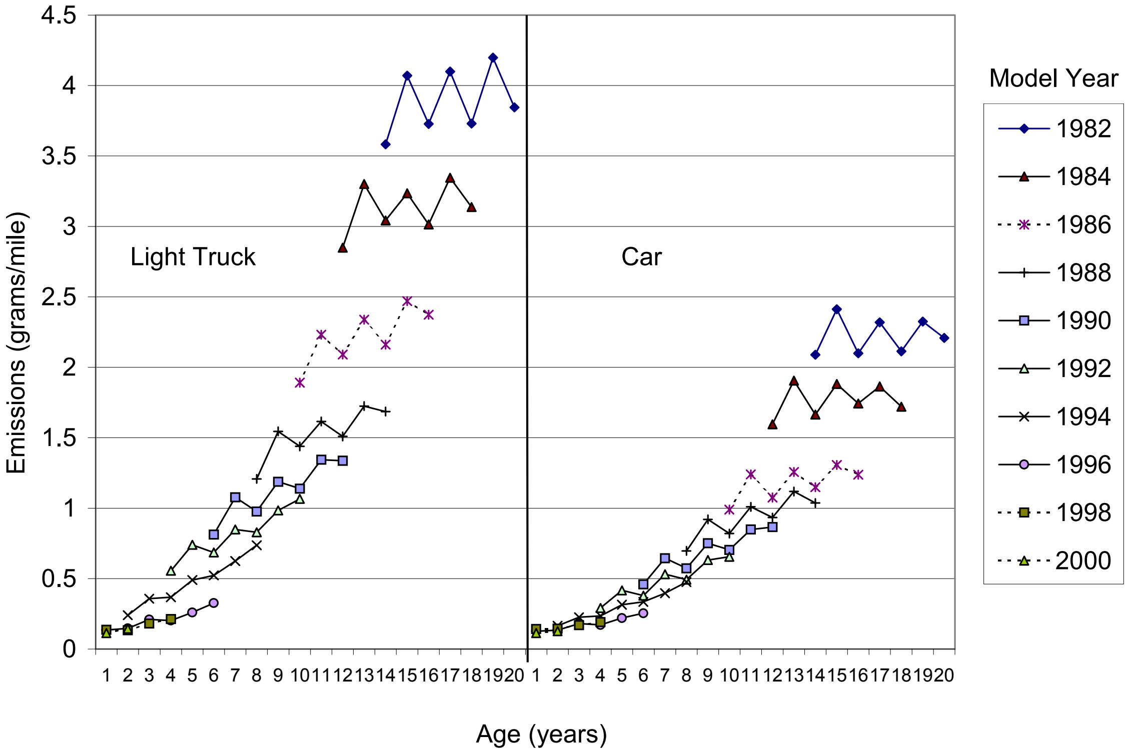

Figure 6-2. HC emissions vs. age, categorized by vehicle type and model year[6].

These improvements occurred even during periods when standards did not change. For example, Tier 0 HC standards lasted from model-years 1980 to 1993 for cars, yet HC emissions performance improved dramatically throughout this period. Results are similar for CO and NOx (though NOx did not begin improving until the early 1990s). Remote sensing data also give similar results. These data suggest that emissions will continue to improve due to fleet turnover to cleaner vehicles.

6.3 PROJECTING FUTURE EMISSIONS

Determining whether Denver needs to continue its I/M program requires an estimate of how much pollution the Denver vehicle fleet will emit in future years with and without an I/M program. The MOBILE6 model can be used for this purpose and its output is sufficient for regulatory purposes. But MOBILE6 is also limited in that it is hardwired with "generic" vehicle emissions data collected several years ago, includes many implicit assumptions of unknown accuracy, and appears to significantly overpredict CO emissions (see e.g., Tran, Chi, and Pollack, 2002; McGaughey et al., 2003). Thus, although MOBILE6 may be sufficient for regulatory purposes, we believe it is also useful to develop a more empirical emissions projection for Denver based on I/M and remote sensing emission measurements

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[6] The zigzag pattern in emissions for the older model-years is due to the AIR program's biennial testing schedule in which odd model-years are tested in one year and even model-years the next, but in which some cars break this pattern due to a change of ownership or initial registration in Colorado from another state, for which an "off-cycle" test is required. Differences between biennial cars and change-of-ownership and out-of-state cars probably accounts for the emission pattern.

specific to the Denver area, as well as explicit methods and assumptions. In this section, we use IM240 and remote sensing data collected from 1996 onward, along with assumptions about future vehicle performance, to project future emissions from the Denver vehicle fleet. Because of the seasonal nature of the air quality problems (elevated ozone typically occurs in hotter summer months, while elevated CO occurs in cooler winter months), we use summer IM240 data for HC and NOx and winter IM240 and remote sensing data for CO in our projections. I/M data show that HC and NOx emissions are indeed higher in summer, while CO is higher in winter.

Estimating fleet emissions inherently involves a series of assumptions about how existing and yet-to-be-built automobiles will perform in the future, how many vehicles of each age and model-year will be on the road in future calendar years, and how many miles those vehicles will be driven. Below, we detail our approach to these issues, and then apply our projection method to estimate the potential range of emissions for the Denver vehicle fleet. Our projections include “conservative,” “optimistic,” and “best estimate” scenarios, as well as “with I/M” and “without I/M” versions of each scenario.

6.3.1 Overview of Our Approach

The future vehicle fleet will be composed of vehicles from three certification classes: Tier 0, Tier 1, and Tier 2.[7] Figure 6-3 lists the technology composition of each model year. As the graph shows, 1994-1995 is the transition from Tier 0 to Tier 1, and 2004-2006 will be the transition from Tier 1 to Tier 2.

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[7] Vehicles built for model-years 2001-2003 were certified to NLEV standards, which are more stringent than Tier 1 standards. For the purposes of our emissions forecasts, we take the conservative approach of assuming these vehicles will perform the same as Tier 1 vehicles.

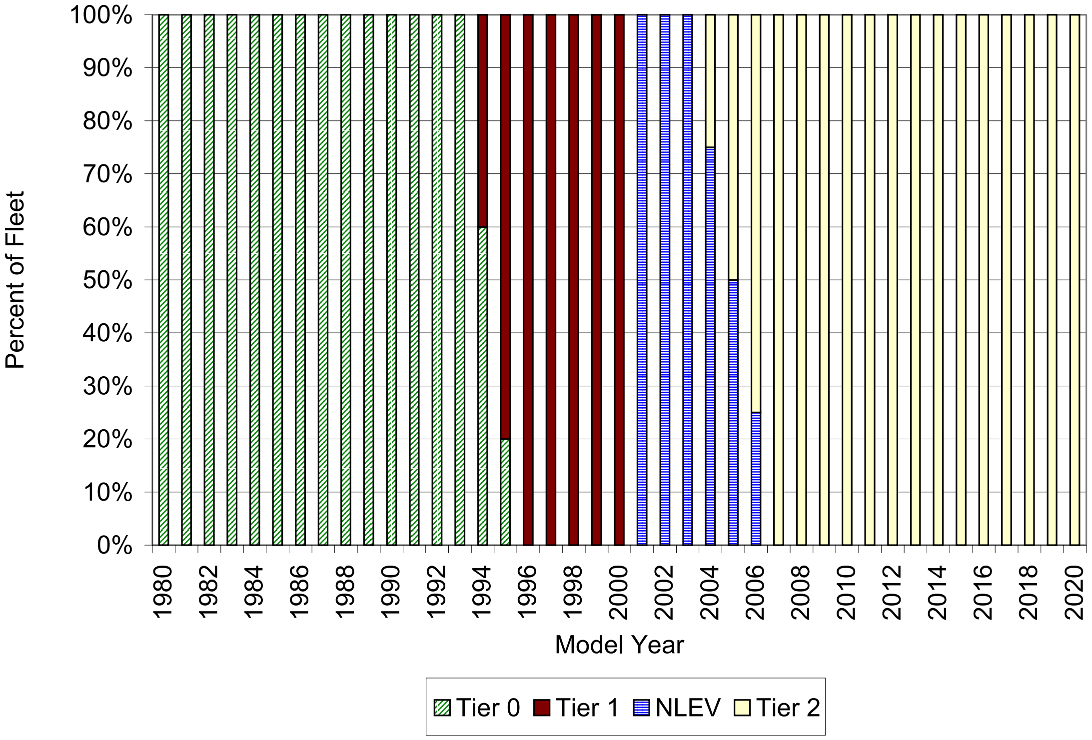

Figure 6-3. Emission certification class by model year.

We want to perform emissions projections for these vehicles in several future calendar years (CY). Future-year emissions will be based on average emissions by age of the different technology and vehicle type groups (i.e., Tier 2, Tier 1 cars, Tier 1 light trucks, Tier 0 cars, and Tier 0 light trucks)[8] weighted first by the fraction of each technology-type combination in that age cohort, and then by the overall travel fraction of each age. For each technology, we use the same distribution of emissions vs. age for all future years. We also use the same travel fraction for all future years. However, the age-distribution of technology fractions and light-truck fraction within each age vary by calendar year. The weighted average of emissions by vehicle type and travel fraction gives a forecast of fleet-average, gram/mile emissions in a given future year.

To forecast trends in total tons of pollution emitted, we combine our fleet-average emission rate forecasts with our ton-per-day pollution estimates for the light-duty fleet in CY 2000 and DRCOG's forecast of future daily VMT trends (RAQC, 2003). Finally, in order to bound the likely range of future emissions, we perform forecasts for the conservative, best-estimate, and optimistic scenarios, both with I/M and without I/M.

Table 6-1 shows what these estimates look like for HC emissions in CY 2009 under the "best estimate" scenario. The first two columns give the model-year (MY) associated with each age in CY 2009. The third column is the travel fraction, which comes from MOBILE6. The next

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[8] Strictly speaking, the standards categories, Tier 2, Tier 1, and Tier 0 don't refer to specific technologies, but to emission certification standards. We use "technology" only as a convenient shorthand to refer to these certification categories.

five columns give average emissions by age for each of the five technology/vehicle type combinations, which are the key portion of our forecasts. Note that there are no emissions listed for Tier 0 vehicles less than 11 years old. This is because CY 2006 is the first calendar year for which we forecasted emissions—a CY in which no Tier 0 vehicle was less than 11 years old.

The next three columns form a matrix giving technology fraction by age—a quantity which is tied to model-year and therefore is calendar-year specific. Note, for example, that in CY 2009, only ages 15 or greater include Tier 0 vehicles, because no Tier 0 vehicles were manufactured after CY 1995. The last column gives the fraction of light trucks for each age. Once again, this is tied to model-year and is therefore calendar-year specific. There is no truck fraction listed for MYs 2008 and 2009. Because Tier 2 standards make no distinction among light-duty vehicles, we don’t forecast Tier 2 emissions separately for cars and light trucks. The truck fraction is therefore irrelevant for emissions forecasting purposes.

Table 6-2 summarizes the data elements that go into our forecasts, and the assumptions we used to derive them. We provide the analytical basis for these assumptions below.

Table 6-1. Example of data for projecting future fleet average emissions, in this case for HC in calendar year 2009.

			Emissions vs. Age by Technology Std. and Vehicle Type (in grams/mile)					**Technology Fractions by Age in CY 2009**			
MY in CY 2009	**AGE**	**Travel Fraction**	**Tier 2**	**Tier 1 PC**	**Tier 1 LT**	**Tier 0 PC**	**Tier 0 LT**	**Tier 2**	**Tier 1**	**Tier 0**	**Light Truck Fraction by Age in CY 2009**
2009	1	8.7%	0.075	0.09	0.09			100%	0%	0%	
2008	2	12.2%	0.075	0.11	0.11			100%	0%	0%	
2007	3	11.3%	0.075	0.13	0.14			100%	0%	0%	50%
2006	4	9.3%	0.075	0.15	0.18			75%	25%	0%	50%
2005	5	8.2%	0.077	0.16	0.20			50%	50%	0%	50%
2004	6	7.4%	0.079	0.18	0.23			25%	75%	0%	50%
2003	7	6.0%	0.081	0.20	0.26			0%	100%	0%	50%
2002	8	5.9%	0.083	0.21	0.29			0%	100%	0%	47%
2001	9	4.9%	0.084	0.23	0.31			0%	100%	0%	38%
2000	10	4.3%	0.086	0.25	0.34			0%	100%	0%	48%
1999	11	3.4%	0.088	0.27	0.37	0.65	1.09	0%	100%	0%	49%
1998	12	3.3%	0.090	0.29	0.41	0.76	1.22	0%	100%	0%	50%
1997	13	2.7%	0.092	0.31	0.44	0.88	1.41	0%	100%	0%	45%
1996	14	2.3%	0.094	0.34	0.48	0.96	1.48	0%	100%	0%	43%
1995	15	1.9%	0.096	0.36	0.53	1.07	1.45	0%	80%	20%	41%
1994	16	1.5%	0.097	0.39	0.57	1.20	1.85	0%	40%	60%	44%
1993	17	1.2%	0.099	0.42	0.63	1.34	2.01	0%	0%	100%	40%
1992	18	0.9%	0.101	0.46	0.68	1.40	2.12	0%	0%	100%	35%
1991	19	0.7%	0.103	0.50	0.74	1.47	2.36	0%	0%	100%	35%
1990	20	0.4%	0.105	0.54	0.81	1.49	2.93	0%	0%	100%	31%
1989	21	0.3%	0.107	0.58	0.89	1.70	3.38	0%	0%	100%	35%
1988	22	0.2%	0.109	0.63	0.97	1.96	3.48	0%	0%	100%	35%
1987	23	0.2%	0.111	0.68	1.05	2.00	3.98	0%	0%	100%	35%
1986	24	0.3%	0.113	0.74	1.15	2.35	4.30	0%	0%	100%	38%
1985	25 and greater	2.4%	0.114	0.80	1.25	2.27	4.36	0%	0%	100%	40%

Bold model-years in the left column mark transition periods between Tier 0 and Tier 1, and Tier 1 and Tier 2. We include 2 or 3 significant figures to illustrate the actual results of our forecasting approach. This should not, however, be taken as an estimate of the real precision of fleet-average emissions estimates.

MY = model year
CY = calendar year
PC = passenger car
LT = light truck

Table 6-2. Summary of emission forecast assumptions and methodology.

Goal		**Forecast daily light-duty fleet emissions of HC, CO and NOx in CYs 2006, 2009, 2013, 2019, and 2025**
Future Emissions by Technology Category		Forecast of emissions vs. age for each of three vehicle emissions certification categories: Tier 0, Tier 1, and Tier 2. • Same emissions vs. age forecast used for each future CY. • Tier 0 and Tier 1 include separate forecasts for cars and light trucks. • Tier 1 and Tier 2 include forecasts for three separate scenarios: "conservative," "optimistic," and "best estimate" (hereafter abbreviated C, B, and O). A single Tier 0 forecast is used for all three scenarios.
	Tier 0	• Forecast of emissions in CY 2006 based on linear extrapolation of emissions measured from CY 1996-2002. • Separate forecast for each Tier 0 MY, with age for each MY assigned based on its age in CY 2006.
	Tier 1	Three scenarios: C: Emissions from age 1-5: average emissions for Tier 1 vehicles as measured in the I/M program at the given age. Age 6-10: deterioration rate = average deterioration rate measured in I/M program for MYs 1996-2000 (based on linear fit). Exponential deterioration after age 10 based on percentage change from age 9 to 10. B: Average of C and O for each age. O: Emissions at age 1 = the lowest age-1 emissions measured in the I/M program for any Tier 1 MY. Deterioration rate = lowest deterioration rate measured in I/M program for MYs 1996-2000 (based on linear fit). Exponential deterioration after age 10 based on percentage change from age 9 to 10.
	Tier 2	Three scenarios: C: 2 x B B: California LEV for HC; Tier 2 for NOx;[9] "Tier 2 equivalent" for CO.[10] O: California ULEV for HC; Tier 2 for NOx; 75% of B for CO.
Travel Fraction (TF)		Percent of vehicle travel in a given CY accounted for by each vehicle age cohort. • Based on MOBILE6 travel fraction. Same TF for each CY.
	Light -Truck Fraction	For MY ≤ 2002, actual light-truck fraction in I/M vehicles. For MY 2003-2007, Tier 1 assumed to be 50% light trucks. All light-duty vehicles must meet same certification standards for Tier 2, so truck fraction was not a factor in Tier 2 emission projections.
VMT Growth		Same as Draft Denver CO Maintenance Plan Amendment, (RAQC, 2003) which gives estimated daily VMT for CY 2001 and forecasted daily VMT for CYs 2006 and 2013. VMT in earlier or later years was forecasted based on linear extrapolations. The Maintenance Plan projects daily VMT will increase by about 1.2 million miles per day each year—about 2% at current estimated daily VMT—and a 25% increase between 2001 and 2013.
I/M Status		Base forecast assumes existence of I/M program. Forecast for "without I/M" assumes emissions increase concomitant with our estimated percent I/M benefit for each pollutant.

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[9] The standards are somewhat ambiguous, so we had to make assumptions that are explained in the main text.

[10] The Tier 2 CO standard is the same as Tier 1, but CO emissions performance has been steadily improving with each MY and is well below the Tier 1 requirement already. We therefore created a "Tier 2 equivalent" CO standard, which is explained more fully in the text.

6.3.1.1 Tier 0 Forecast

Table 6-3 is a matrix of HC emissions by MY and CY for cars measured in the Denver I/M program. Model years 1982 to 1993 are 100 percent Tier 0 vehicles. Because each Tier 0 MY was measured over several CYs, we can use past emissions to project future emissions. The column labeled “2006” presents a forecast of Tier 0 vehicle emissions in CY 2006 based on a linear extrapolation of emissions from CYs 1996-2002—that is, an extrapolation of the data for each row out to CY 2006. The rightmost column, labeled “Age” gives the corresponding age of the vehicles associated with each emissions forecast. These two rightmost columns are shaded as a reminder that they represent a forecast, rather than measured emissions.

MYs 1994 and 1995 include both Tier 0 and Tier 1 vehicles so we could not use data for these MYs to predict Tier 0 emissions at ages 11 and 12 in CY 2006. Instead, we extrapolated “vertically” via a linear extrapolation of the estimated CY 2006 emissions for vehicles aged 13-16 to estimate emissions for ages 11 and 12. We estimated emissions for 25 year-old vehicles in CY 2006 using a similar approach, starting with CY 2006 emissions of vehicles aged 21-24. These results are in red text as a reminder that they are not based on extrapolations of measured emissions for these model-years.

In total, we performed six Tier 0 forecasts by this method—three pollutants times two vehicle types (cars and light trucks). Although we performed the forecasts for CY 2006, to simplify the modeling we applied the same distribution of emissions vs. age to all future CYs. This is a relatively conservative approach, since it results in higher emissions by age in later calendar years than would have been obtained by continuing the linear projection used to derive the forecast for CY 2006.

Table 6-3. Data and results for forecast of Tier 0 HC emissions for cars.

	Calendar Year								
MY	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2006**	**Age**
1995	0.13	0.19	0.18	0.27	0.29	0.32	0.44	*0.65*	11
1994	0.18	0.24	0.25	0.35	0.40	0.41	0.54	*0.76*	12
1993	0.26	0.33	0.35	0.46	0.49	0.53	0.67	0.88	13
1992	0.31	0.44	0.39	0.57	0.53	0.66	0.71	0.96	14
1991	0.41	0.49	0.51	0.61	0.70	0.69	0.84	1.07	15
1990	0.46	0.65	0.57	0.80	0.73	0.87	0.91	1.20	16
1989	0.61	0.70	0.79	0.82	0.92	0.92	1.10	1.34	17
1988	0.69	0.96	0.81	1.08	0.98	1.14	1.09	1.40	18
1987	0.93	0.97	1.04	1.08	1.17	1.14	1.28	1.47	19
1986	0.98	1.28	1.09	1.33	1.19	1.35	1.26	1.49	20
1985	1.38	1.36	1.53	1.45	1.53	1.44	1.63	1.70	21
1984	1.52	1.97	1.69	2.02	1.78	1.92	1.73	1.96	22
1983	1.89	1.87	2.05	1.88	2.09	1.87	1.95	2.00	23
1982	2.11	2.62	2.23	2.38	2.19	2.28	2.40	2.35	24
1981								*2.50*	25

The shaded area represents our forecast for Tier 0 emissions in CY 2006 by vehicle age in CY 2006. Numbers in *italics* were not forecasted from the IM240 data, but were derived by linear extrapolation of the CY 2006 values that were forecasted (see text for additional details) from the actual emissions data.

We judged the Tier 0 forecasts to have a relatively high degree of certainty due to the long time period over which the fleet was measured, and the short time horizon over which we extrapolated. Because of this, and also because the contribution of Tier 0 vehicles to total emissions is declining relatively rapidly, we used this forecast for all three scenarios (“conservative,” “best estimate,” and “optimistic”) in our emission projections.

6.3.1.2 Tier 1 Forecast

The fleet is composed solely of Tier 1 vehicles for MY 1996 onward. MY 1996 has now been measured from ages 1-7, MY 1997 from ages 1-6, MY 1998 from ages 1-5, etc. For the conservative scenario, we used the average emissions of Tier 1 vehicles for each age from 1-5 (which means that fewer model-years are included in the average for higher ages). This is equivalent to an assumption that Tier 1 vehicles built for MYs 2003-2007 will perform no worse (and no better) than the average for Tier 1 MYs that have been measured already in the Denver I/M program. Between 5 and 10 years of age, vehicles are assumed to deteriorate at the average rate observed in the I/M data for MYs 1996-2000, based on the slope of a linear fit to emissions vs. CY for each Tier 1 MY using all CYs in which a given Tier 1 MY was measured (which means earlier MYs were measured in more CYs). This assumption is conservative because the deterioration rate of Tier 1 vehicles has been improving with each successive model-year, and the average deterioration rate is higher than the observed deterioration rates for the most recent model-years. In effect, our forecast assumes that Tier 1 vehicles built for MYs 2001-2007 will not perform any better than the average for MYs 1996-2000.

Figure 6-4 shows the declining trend in deterioration rate for Tier 1 vehicles from model-years 1996 through 1999, all measured at ages 1 through 4. The unknown in our forecast is whether Tier 1 vehicles will deteriorate from ages 5 to 10 at a rate similar to the observed rate for earlier ages. Presumably, EPA’s 100,000-mile certification requirement and OBDII are encouraging automakers to design vehicles with greater durability than Tier 0 models. The data presented in Figure 6-2 confirms that this has indeed been true so far.

After 10 years of age, emissions are assumed to deteriorate exponentially, with the percent increase each year equal the percent increase from age 9 to 10. For older vehicles, this approach resulted in higher NOx emissions for Tier 1 vehicles than for Tier 0 vehicles. Tier 1 NOx emissions were set to the corresponding Tier 0 level at ages in which this occurred.

In the optimistic Tier 1 scenario the average vehicle starts out with the lowest average emissions measured for a Tier 1 model-year at one year of age, and then deteriorates up to age 10 at the lowest rate observed in Tier 1 MYs. The best-estimate scenario is the average of the C and O scenarios.

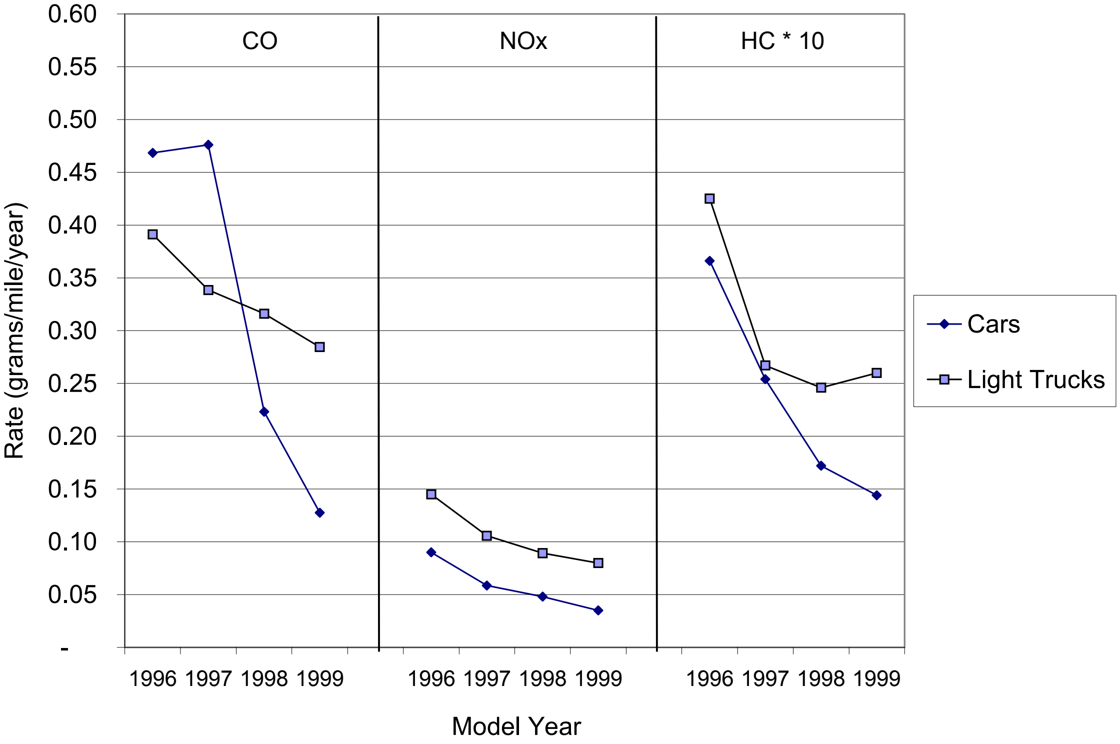

Figure 6-4. Trend in deterioration rate by model-year for Tier 1 vehicles aged 1 to 4 years. More recent Tier 1 model-years have lower deterioration as they age.

6.3.1.3 Tier 2 Forecast

No Tier 2 vehicles have been built yet, so we based our Tier 2 forecasts on the requirements of Tier 2 standards, along with assumptions where the standards are ambiguous. The Tier 2 standards generally specify 50,000-mile and 120,000-mile emission limits that vehicles must meet on a fleet-average basis. In the best estimate scenario, for all three pollutants, we assume that the average light-duty vehicle emits at the Tier 2 50,000-mile limit through age four, deteriorates linearly up to the 120,000-mile limit at age 12, and then continues at the same deterioration rate thereafter. Emissions in the conservative scenario are twice the emissions in the best estimate scenario, while the optimistic scenario is pollutant-specific. Here are the assumptions for each pollutant:

- **NOx.** The Tier 2 NOx standard requires that fleet-average emissions not exceed 0.07 grams/mile at 120,000 miles (EPA, 2000). Although there is no fleet-average requirement at 50,000 miles, we assumed a 50,000-mile fleet average of 0.05 grams/mile, which is equivalent to "bin 5" of the Tier 2 requirements; the same bin for which the 120,000-mile standard is 0.07 grams/mile. The optimistic scenario is the same as the best estimate.

- **HC.** There is no explicit overall Tier 2 HC standard. The Tier 2 rule allows manufacturers to certify cars to meet the requirements of one of several "bins," each of which has a given set of NOx, HC, and CO requirements associated with it. The Tier 2 rule requires that the resulting distribution of cars among bins result in a fleet-average NOx level of 0.07 grams/mile at 120,000 miles. The corresponding HC level depends on how auto manufacturers end up distributing cars among bins to meet the NOx requirements. In the absence of a direct requirement, we chose the California low-emission-vehicle (LEV) HC requirement for the best-estimate scenario—an HC limit of 0.075 grams/mile at 50,000 miles, and 0.09 grams/mile at 120,000 miles (CARB, 2001). This is a relatively conservative approach, as EPA's NLEV standard for MY 2003 already requires a fleet-average HC limit of 0.075 grams/mile (EPA, 2000). For the optimistic scenario, we chose the California ultra-LEV (ULEV) standard—an HC limit of 0.04, and 0.055 grams/mile, at 50,000 and 120,000 miles, respectively.

- **CO.** The Tier 2 50,000-mile CO standard remains at the Tier 1 level of 3.4 grams/mile, but cars are already outperforming this standard. We assumed that Tier 2 vehicles will have even better CO performance than Tier 1. For our best estimate, we assumed initial emissions would start out 25 percent below the CO performance of new Tier 1 vehicles (which was about 1 gram/mile for late 1990s MYs. After age 4, emissions would deteriorate at the same rate as for HC vehicles in the Tier 2 best estimate. In the optimistic scenario, emissions are assumed to be 25 percent below the best estimate.

To summarize, the conservative scenario assumes that Tier 2 vehicles exceed the best-estimate emission levels by a factor of 2, and that Tier 1 vehicles deteriorate as rapidly as the worst-performing Tier 1 model-year measured so far in the I/M program. The best-estimate scenario assumes that Tier 2 vehicles perform at the Tier 2 standard, or an approximation to the Tier 2 standard where that standard is ambiguous, and that Tier 1 vehicles perform at a level equivalent to the average of the conservative and optimistic scenarios. The optimistic scenario assumes that Tier 2 vehicles perform at or below the Tier 2 requirements, and that Tier 1 vehicles deteriorate as slowly as the best-performing Tier 1 model-year measured so far in the I/M program. The Tier 0 emissions forecast is the same under all three scenarios. Figures 6-5, 6-6, and 6-7 display average emissions vs. age for each Tier-vehicle type combination and for each scenario. The scenarios are labeled using the following shorthand:

C	Conservative
B	Best Estimate
O	Optimistic

Remote sensing CO data collected in CYs 1996, 1997, 1999-2001, and 2003[11] were also used to forecast future CO emissions. We used the same methods as for the I/M data. Remote sensing data provide emissions in units of grams of pollutant per gallon of fuel burned (grams/gallon). To estimate grams/mile, we used fleet-average fuel economy from Denver IM240 tests for CYs 1996-2002 to convert the remote sensing data to grams/mile. Figure 6-8 displays gram/mile CO emission forecasts based on the remote sensing data.

Note that the Tier 0 emissions are much lower in the remote sensing case than in the IM240-based estimates, while Tier 1 emissions are similar. Nevertheless, the IM240 and remote

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[11] Actually December 2002 in this case. We refer to this campaign as January 2003 to avoid confusion about the amount of time separating each campaign, since the other campaigns occurred in January of their calendar year.

sensing data are not directly comparable, because they measure emissions under different engine-load conditions, and because the on-road fleet differs from the I/M fleet in a number of ways—for example, the on-road fleet includes vehicles not participating in the I/M program because they are legally exempt or because they are illegally avoiding the program. In addition, the on-road data includes all model years driving on the road, while the IM240 data includes only vehicles from MYs 1982 and newer. Furthermore, the conversion of remote sensing grams/gallon measurements to grams/mile introduces error, since it is based on fleet averages, rather than on the unknown instantaneous fuel economy of each car at the engine-load conditions under which it was measured.

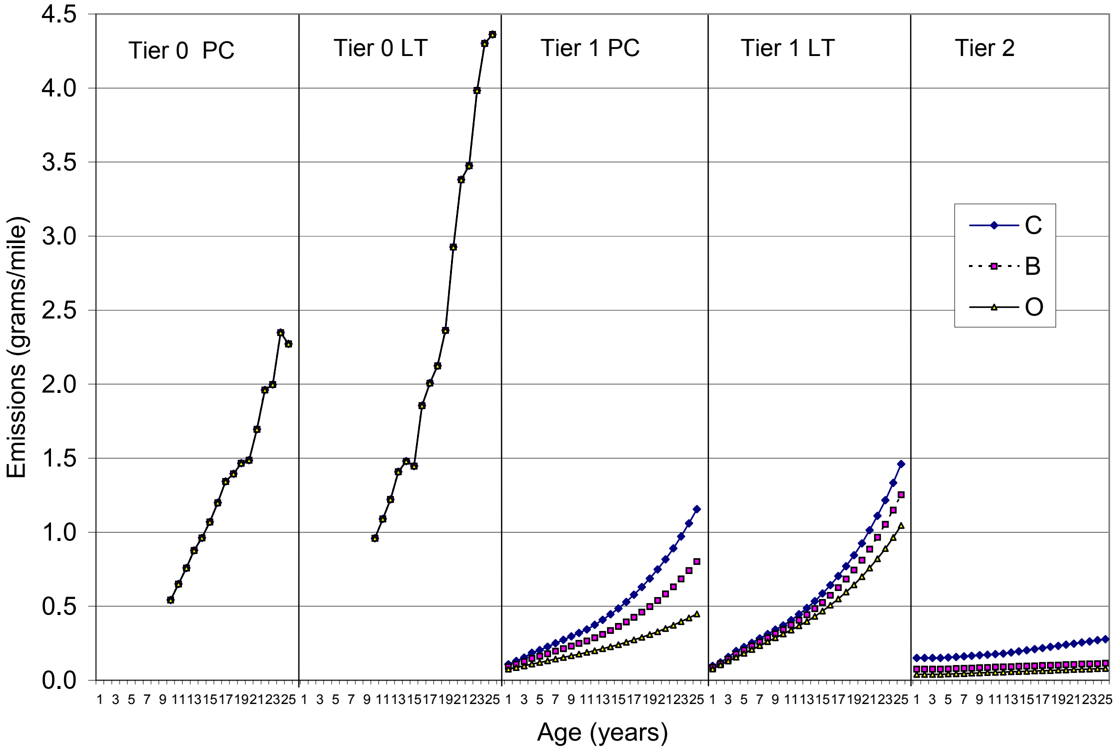

Figure 6-5. Forecast of HC emissions by age for each tier and vehicle type.

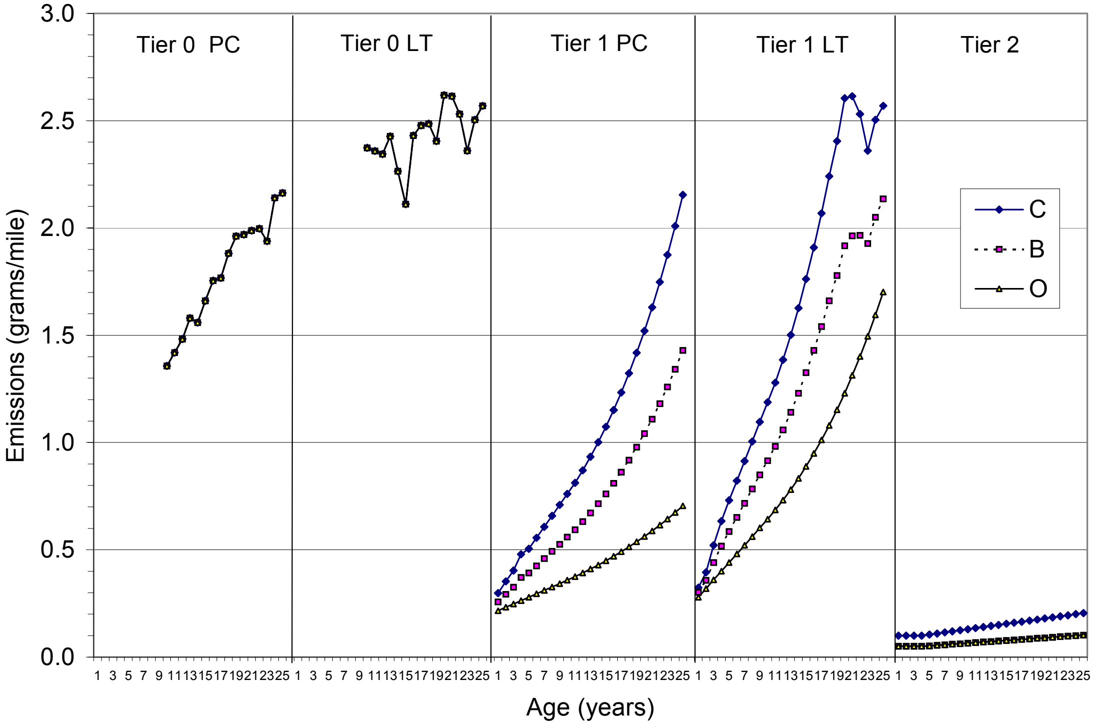

Figure 6-6. Forecast of NOx emissions by age for each tier and vehicle type.

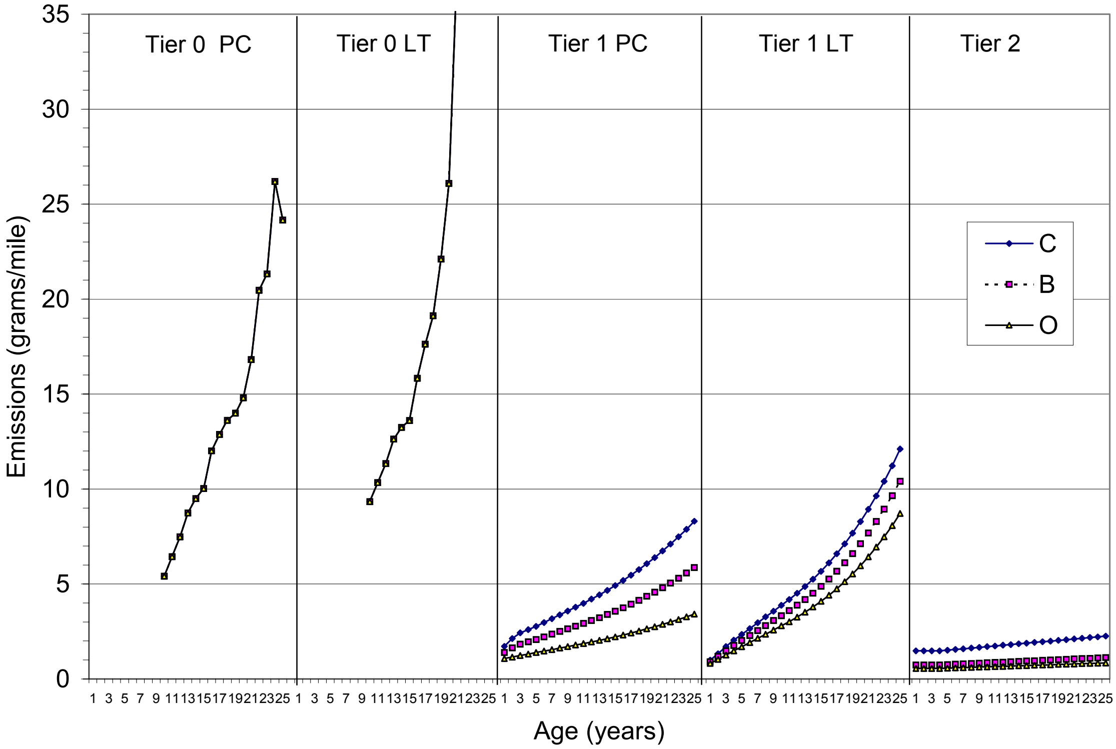

Figure 6-7. Forecast of CO emissions by age for each tier and vehicle type.

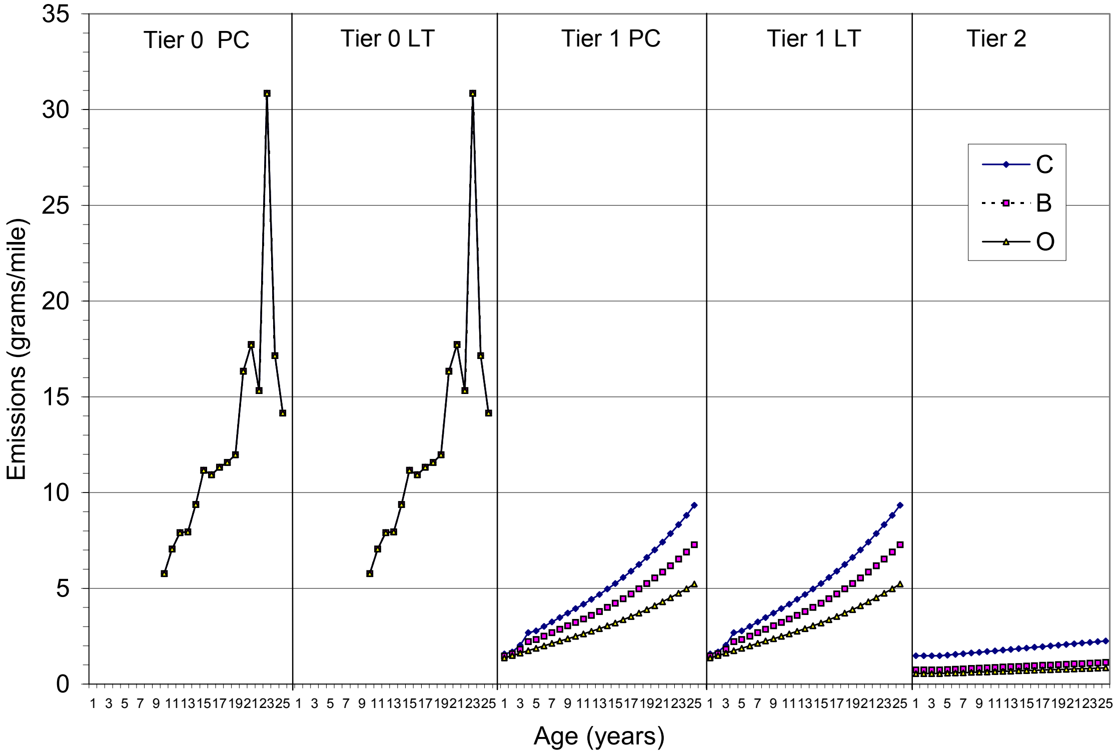

Figure 6-8. Forecast of CO emissions by age for each tier and vehicle type based on remote sensing data.

6.3.1.4 Vehicle Miles Traveled (VMT)

The Regional Air Quality Council's latest revision to its CO maintenance plan includes an estimate of total daily VMT in the Denver metro area in 2001, and forecasts for 2006 and 2013 (RAQC, 2003). These estimates were drawn from DRCOG's Regional Transportation Plan and are displayed in Table 6-4. DRCOG's VMT forecast assumes a linear increase in VMT. For our ton/day emissions forecasts, we assumed a continued linear VMT increase beyond 2013, as well as a linear decrease from the CY 2001 base for our estimates of emissions for CYs 1996-2000.

Table 6-4. VMT Forecast for the Denver metro area.

Year	Daily VMT in Attainment/Maintenance Area (in millions of miles)	Percent Increase
2001	59.8	--
2006	62.7	10%
2013	71.0	25%

6.3.1.5 I/M

We forecast future emissions both with and without an I/M program. Because our forecasts of emissions vs. age are based on emissions of Tier 0 and Tier 1 vehicles that have been in an I/M program, we assume that our base-case forecast as described above represents the "with I/M" scenario. To be conservative, we also assume that our forecast of Tier 2 emissions represents a with-I/M scenario.

There is no way to know whether and how I/M effectiveness would change in the future should Denver elect to keep its I/M program. In the absence of any analytical basis for forecasting future I/M effectiveness, we simply assume that the I/M program would generate the same percentage reductions as we estimated for the current I/M program in CY 2000 (as described in Benefits section). Our estimate of what vehicle emissions would have been without I/M is for the current I/M cycle only; we cannot estimate how much the cumulative effect of over several years of the enhanced I/M program reduced emissions from what they would have been without I/M. We did find that only about half of MY 1990-1994 vehicles tested in CY 1996 were tested again in either 1999 or 2000, but also that only 10 percent of MY 1982-1995 vehicles tested in 2001 or 2002 had never had an I/M test before. This suggests that the vast majority of vehicles have had at least two cycles of I/M, but that much of the fleet has not had more than two cycles. If I/M benefits are cumulative, our without I/M case might underestimate actual fleet-average emissions without I/M. To derive emissions in the without-I/M case, we take the with-I/M results for each scenario, and increase them based on the estimated effect of I/M using Equation 1:

$$E' = E / (1 - P_{IM}) \qquad (1)$$

E' emissions without I/M
E emissions with I/M
P_{IM} estimated percent reduction from without-I/M base

6.4 RESULTS

In this section, we present the results of our emission forecasting process in terms of fleet-average grams/mile and overall tons/day for the light-duty vehicle fleet. The grams/mile forecasts present the change in fleet-average emission rates over time. The tons/day forecasts add in the effect of VMT increases over time on total emissions. In each case, we present six emissions forecasts—the conservative, best estimate, and optimistic scenarios for each of the with I/M and without I/M cases. In the graphs that follow, the scenarios will be labeled based on the following shorthand:

C –IM	Conservative, without I/M
C +IM	Conservative, with I/M
B –IM	Best estimate, without I/M
B +IM	Best estimate, with I/M
O –IM	Optimistic, without I/M
O +IM	Optimistic, with I/M

Figures 6-9, 6-10, and 6-11 display grams/mile results for HC, NOx, and CO. In each case, the without-I/M forecasts have solid lines and filled markers, while the with-I/M forecasts have dotted lines and unfilled markers. A bold vertical line denotes the transition from "actual" emissions as measured in the I/M program to forecasts of emissions in future years.[12] A broken horizontal line marks fleet-average emissions in 2002 for comparison with future years. The regression line through the "actual" emissions estimates for CYs 1996-2002 represents an exponential fit to the data. For NOx, only the without-I/M results are shown, because we estimated that the I/M program has virtually no effect on NOx emissions. Figure 6-12 presents grams/mile CO forecasts based on remote sensing data.[13]

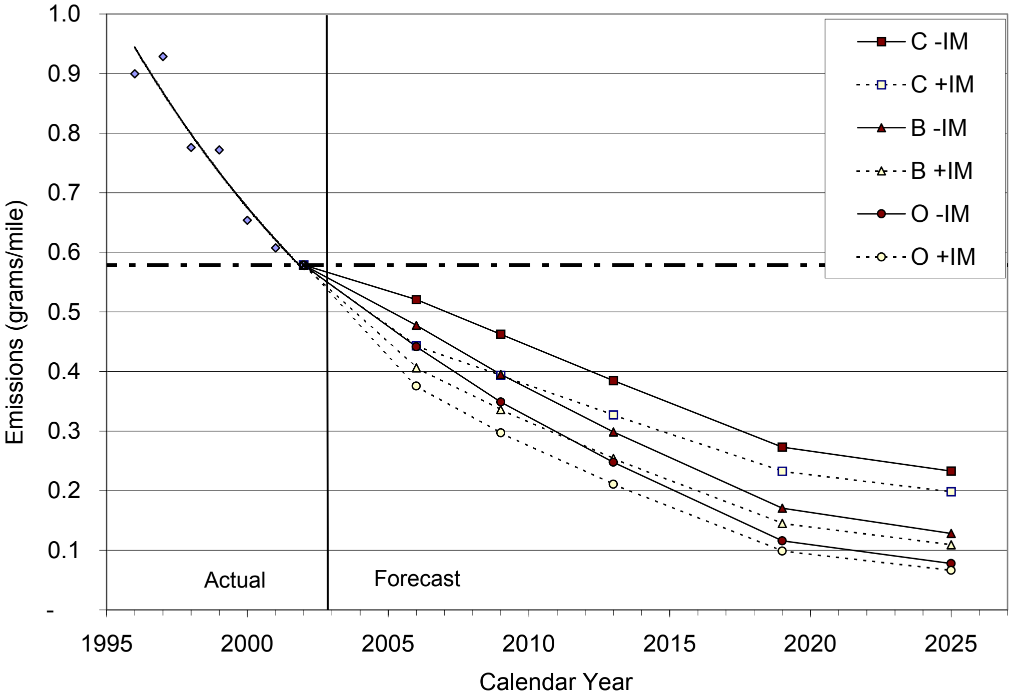

Figure 6-9. Forecast of fleet-average light-duty tailpipe HC emission rate.

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[12] "Actual" is in quotes as a reminder that these results are based on IM240 data, which might differ from actual on-road emissions.

[13] Although the remote sensing data were collected on the road, these data might also give results that differ from actual emissions in the Denver area as a whole, since they were collected at only two sites that might not be representative of the Denver fleet in general.

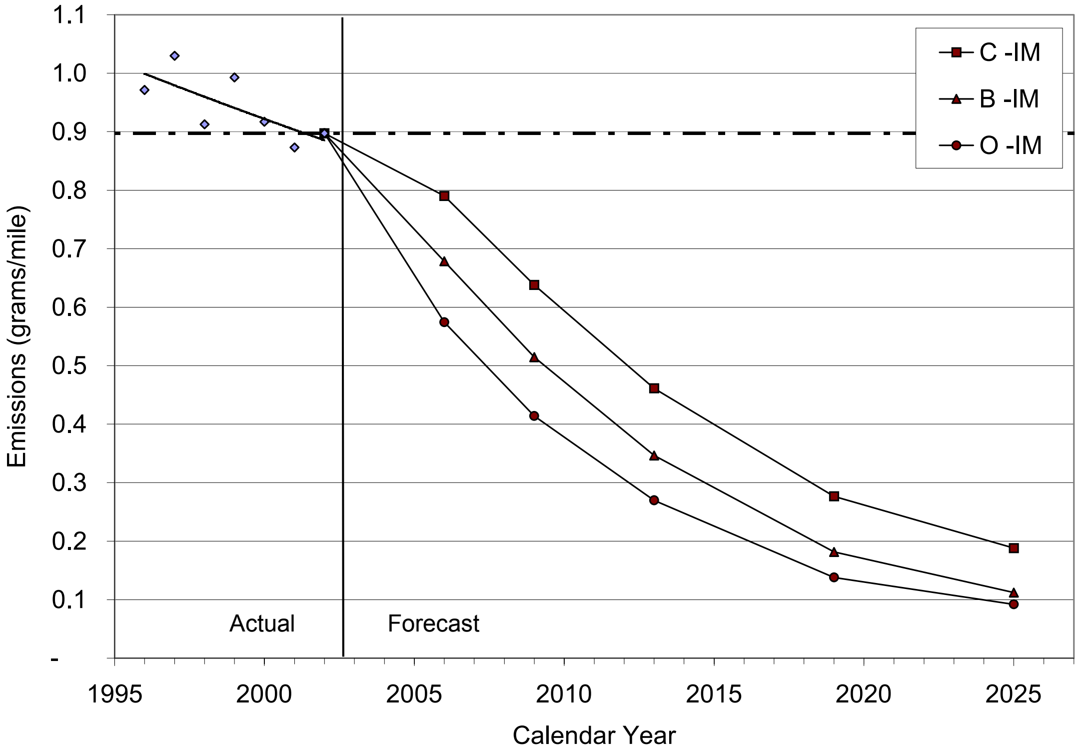

Figure 6-10. Forecast of fleet-average light-duty NOx emission rate.

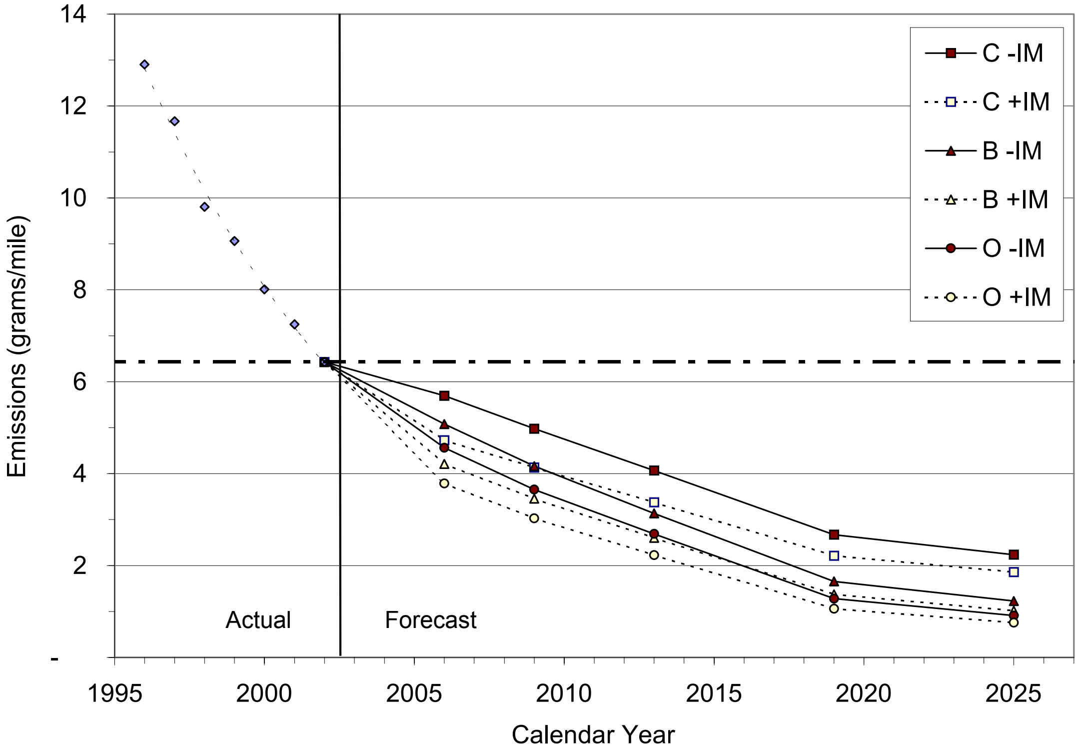

Figure 6-11. Forecast of fleet-average light-duty CO emission rate.

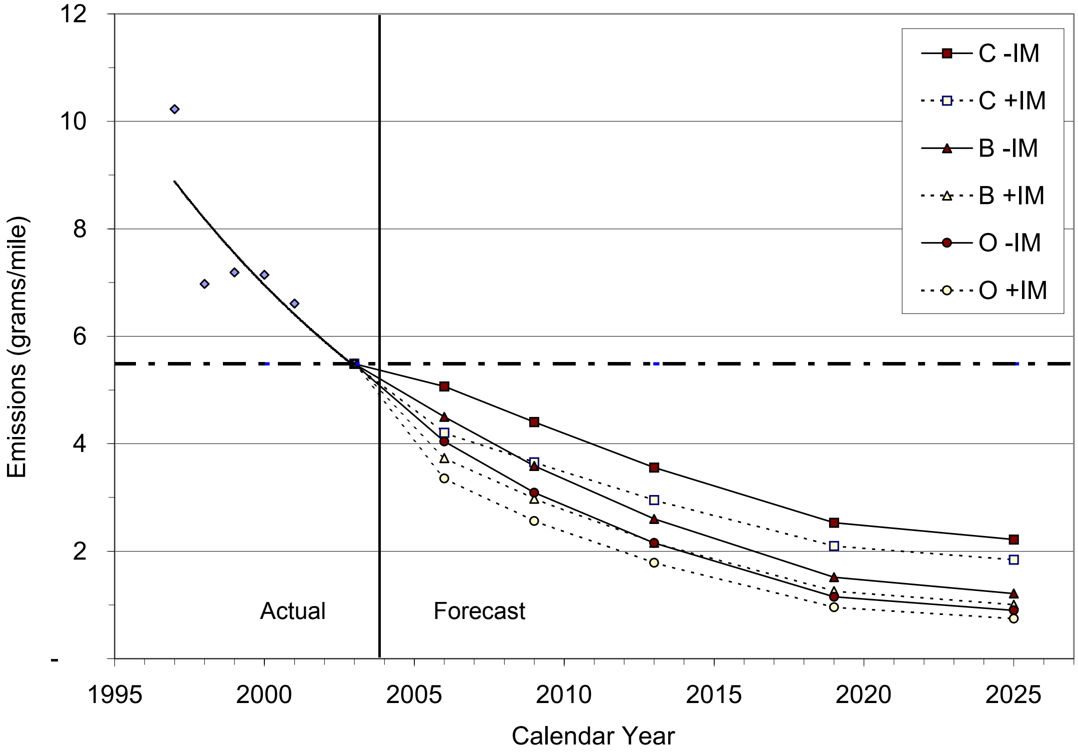

Figure 6-12. Forecast of fleet-average light-duty CO emission rate based on remote sensing data.

The graphs show that, even in the conservative, without-I/M scenario, the fleet-average emission rate can be expected to remain below the CY 2002 baseline in the short term, and to decline substantially in the intermediate and long term. The short-term declines are due to a progressive shift from early Tier 0 vehicles to later Tier 0 vehicles among the older portions of the fleet, and from later Tier 0 vehicles to Tier 1 vehicles in the intermediate-age portions of the fleet. The intermediate-term and long-term declines are due to an additional shift from Tier 1 to Tier 2 vehicles. Our conservative Tier 2 scenario assumes that Tier 2 vehicles exceed Tier 2 requirements by a factor of two. This suggests that even if automakers fail miserably to achieve Tier 2 requirements, emissions of the average vehicle would still decline substantially during the next 20 years.

Figures 6-13, 6-14, and 6-15 present our forecasts for tons/day emissions for the three pollutants using the same naming and display conventions as the grams/mile graphs. The tons/day estimates begin with our estimate of CY 2000 tons/day emissions from the I/M fleet, adjusted to represent the full on-road fleet (see Table 4-4 in Section 4). To estimate tons/day in previous and future years, we multiplied these baseline emissions by the percent change in grams/mile emissions and by the percent change in VMT from the CY 2000 base, as represented in Equation 2 below. Figure 6-16 presents CO tons/day results based on remote sensing.

$$T_X = T_{2000} * E_X * VMT_X \qquad (2)$$

T_X tons/day emissions in calendar-year X

T_{2000}	tons/day emissions in calendar year 2000
E_X	ratio of fleet-average grams/mile emissions in year X to year 2000
VMT_X	ratio of total daily VMT in year X to VMT in 2000.

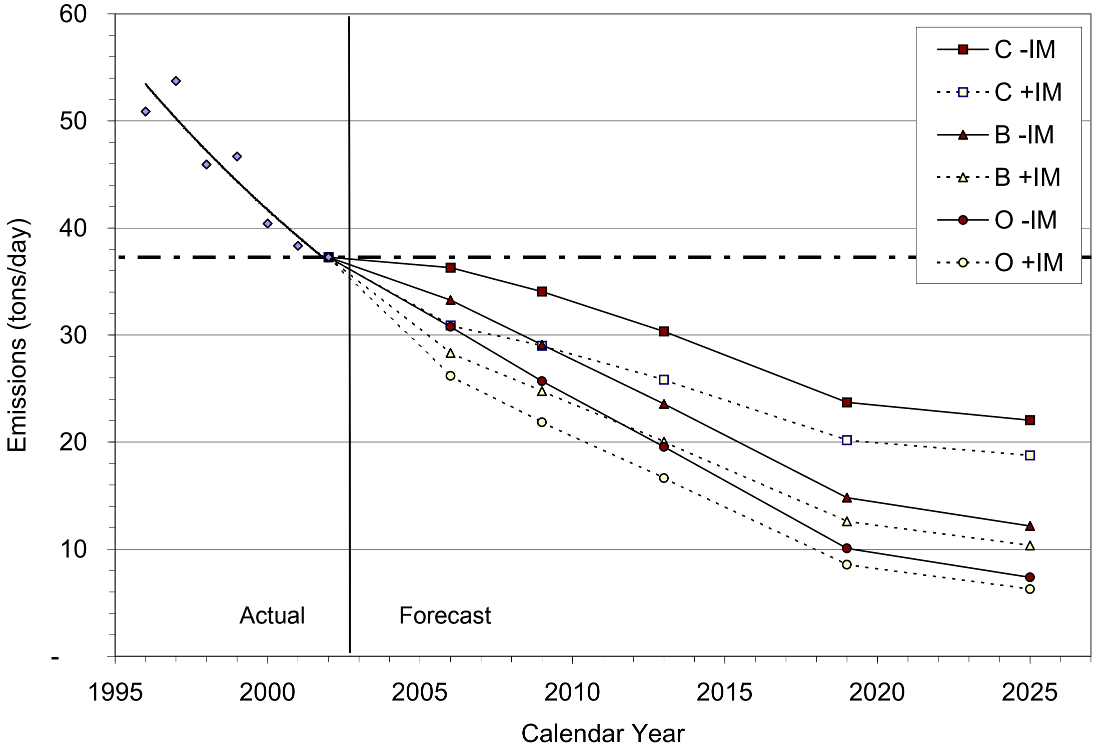

Figure 6-13. Forecast of light-duty tailpipe HC emissions.

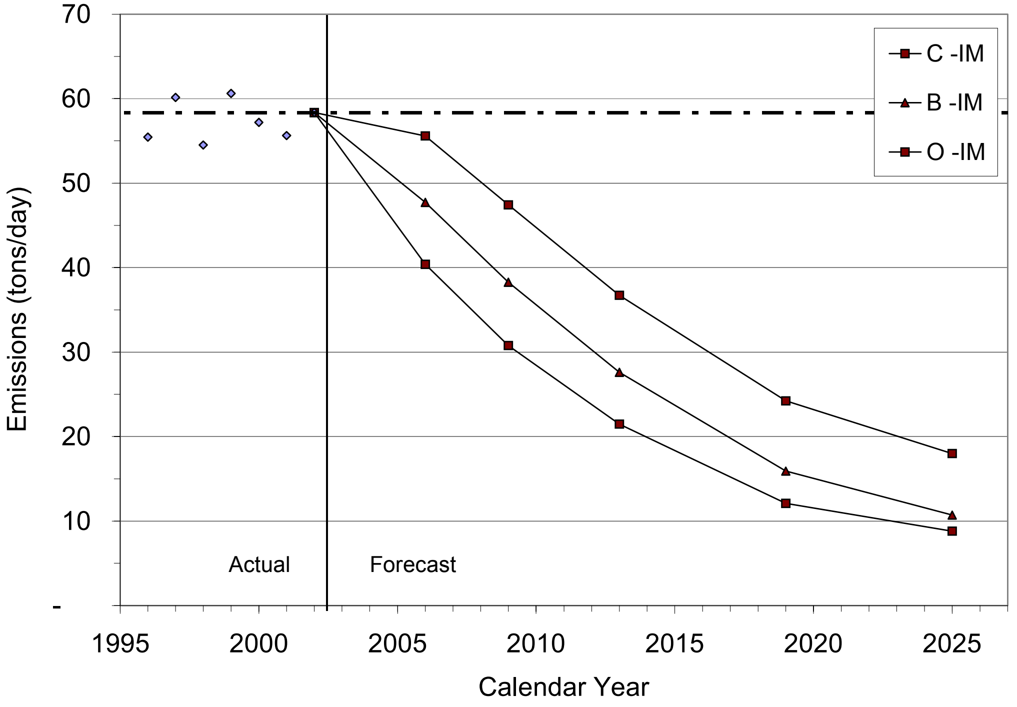

Figure 6-14. Forecast of light-duty NOx emissions.

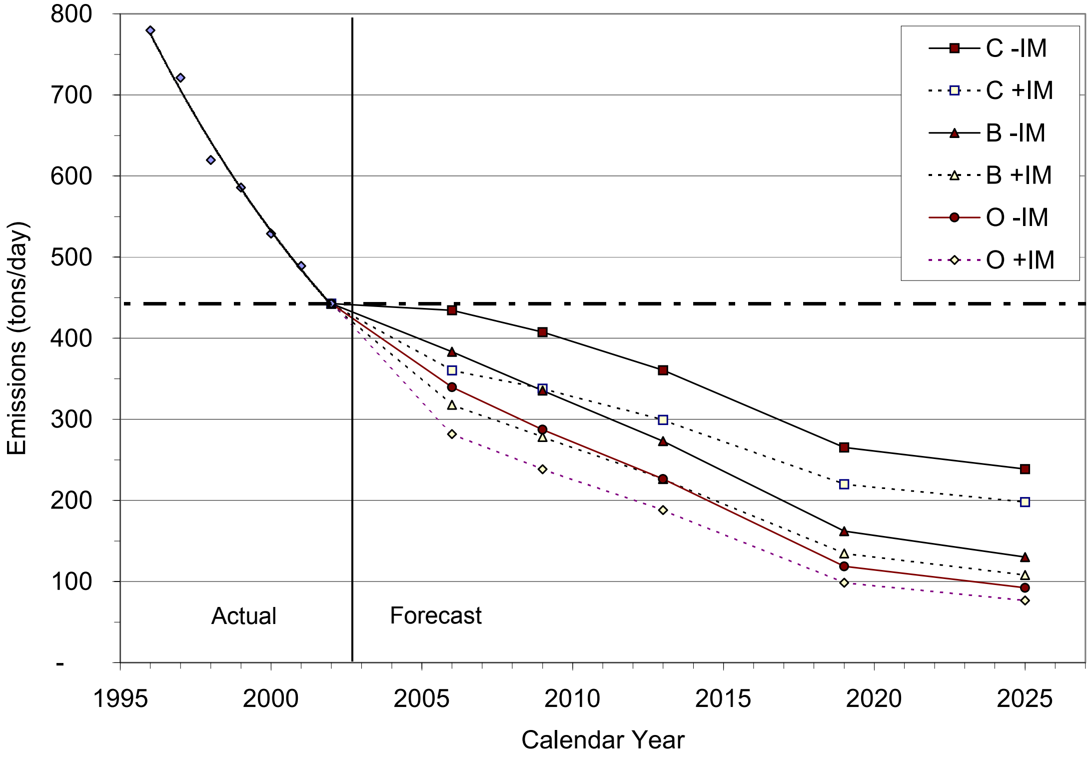

Figure 6-15. Forecast of light-duty CO emissions.

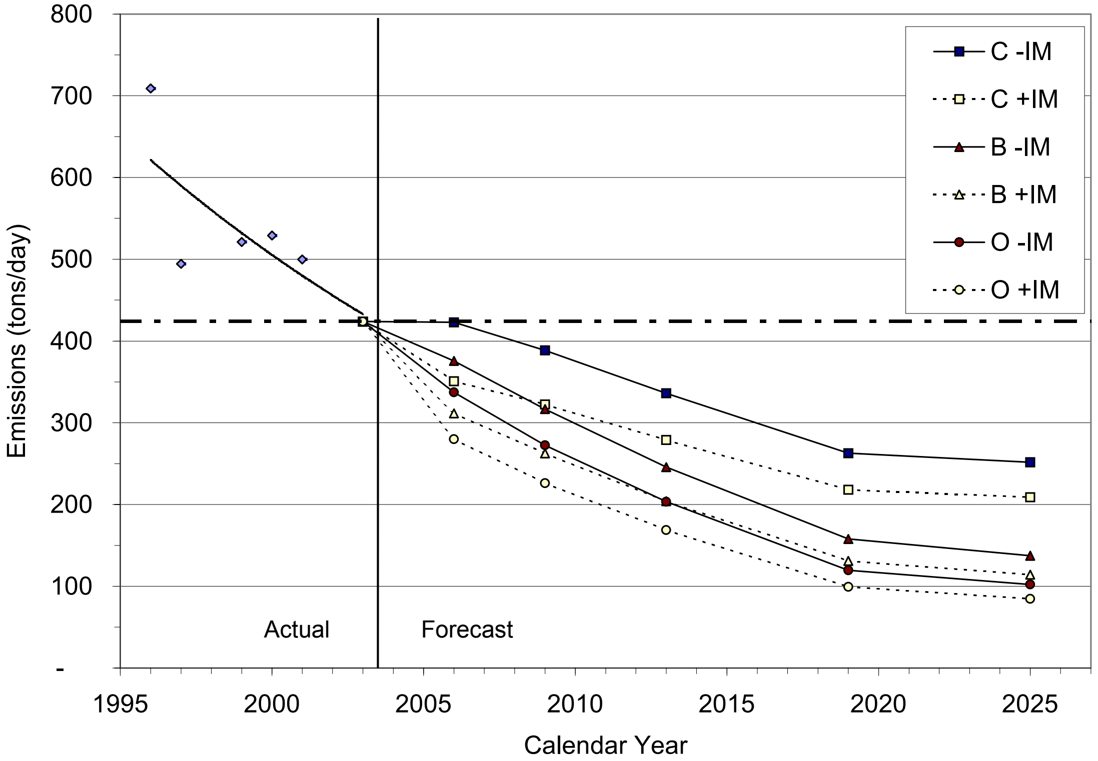

Figure 6-16. Forecast of light-duty CO emissions based on remote sensing data.

In the intermediate and long term, we forecast substantial reductions in total emissions from the light-duty fleet, even in the conservative, without I/M case. This means that VMT growth will not hinder the Denver area's progress on air pollution. Even in the short term, our conservative, without I/M forecasts for CY 2006 suggest emissions will continue to decline even without an I/M program. The only exception is the forecast for CO based on remote sensing data, which suggests no change in short-term CO emissions in the conservative, without I/M case, while still forecasting reductions in later years.

We believe our conservative forecast is a genuine upper limit on potential CY 2006 emissions and that emissions of all pollutants will in fact decline regardless of whether the I/M program is continued. Our conservative scenario for Tier 1 vehicles aged 1 to 5 years is based on the average emissions observed in recent Tier 1 vehicles. Deterioration from ages 5 to 10 years is based on the *average* deterioration rate observed for Tier 1 from model-years 1996 to 2000 in the I/M program and (for CO) in remote sensing data. But deterioration rates of Tier 1 vehicles have been declining with each successive model-year, and we assumed a deterioration rate higher than observed for the most recent Tier 1 vehicles measured in the I/M program. Non-Tier 2 vehicles built in MYs 2001-2007 have to meet stricter NLEV standards, yet our conservative case assumes they will behave no differently from the average Tier 1 vehicle built for MYs 1996-2000. Furthermore, EPA's 100,000-mile durability requirement, along with OBDII, would be expected to provide automakers with an incentive to design more-durable vehicles. These factors suggest that future emissions will fall below those of our conservative scenario, and will decline even if there is no I/M program.

Another factor that makes our projections conservative is that we implicitly assumed that no emissions-reducing repairs would be performed in the absence of an I/M program. Our method for estimating emission reductions from the AIR program inherently captures all emission changes to vehicles after their 1999/2000 I/M cycle.[14] We attributed all observed emission reductions to the AIR program when generating our I/M effectiveness estimates. However, some of these emission reductions might occur even in the absence of an I/M program, even if motorists never undertake repairs for the purpose of reducing emissions. The reason is that some, and perhaps many motorists maintain and repair their cars out of a desire to maintain or improve performance, durability, and/or reliability, and some of these activities will improve emissions as a side effect. We have no way of estimating the size of this effect, but some fraction of the emission reductions we attribute to the AIR program would occur even if the program did not exist.

For regulatory purposes, EPA requires the use of the MOBILE6 model to forecast fleet emissions. Figures 6-17, 6-18, and 6-19 compare our conservative and optimistic without-I/M scenarios with the MOBILE6 forecast of future emissions. For NOx we include only the MOBILE6 without I/M scenario, because MOBILE6 predicts little I/M effect for NOx. For CO, we include the MOBILE6 prediction for emissions without the oxyfuels program.
We use the same VMT-growth assumptions for the MOBILE6 forecast as for our own emission forecasts to remove that source of variability.

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[14] "Pre-test" repairs that reduce emissions before the I/M test are not included in our estimates. We did not find evidence for pre-test repairs in our analysis of on-road remote sensing measurements, but our analysis of pre-test repairs had relatively low statistical power to detect an effect, should one exist.

MOBILE6 estimates much higher absolute emissions of all three pollutants than we observe. There are three reasons for this. First, and most important, comparison of MOBILE6 with on-road measurements shows that MOBILE6 greatly overestimates CO emissions (see e.g., Tran, Chi, and Pollack, 2002; McGaughey et al., 2003). Second, the I/M and remote sensing emissions data we used for our forecasts do not include emissions from cold starts. Third, the MOBILE6 results are for the entire on-road gasoline-vehicle fleet, while our emission estimates are for the light-duty fleet.[15] Since we are interested here in comparing predicted trends in future emissions relative to a base year, we set the MOBILE6 prediction of absolute tons/day emissions in CY 2002 equal to the same value we estimated for the I/M fleet. We then use the MOBILE6-predicted percentage change in emissions between the base year and year X to generate the MOBILE6 forecast. In the graphs below, we display our estimate of "actual" emissions for CYs 1996-2002 (just as in previous graphs), along with the MOBILE6 prediction. For reference, Table 6-5 shows the absolute difference in total tons/day emissions predicted in 2002 between our estimates and MOBILE6.

Table 6-5. Comparison of estimated tons/day emissions in CY 2002 based on Denver IM240 data and MOBILE6.

	HC	CO	NOx
MOBILE6	60	1,602	78
IM240	37	443	58

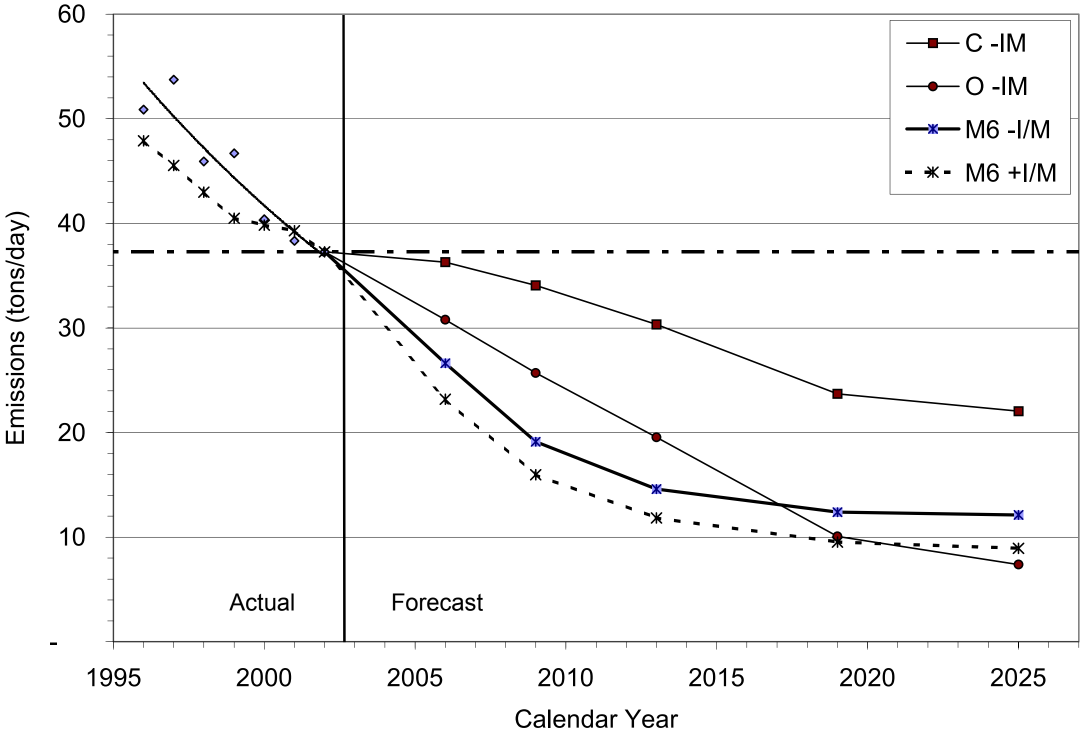

Figure 6-17. Our HC emission forecasts compared to MOBILE6 output.

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[15] The remote sensing data do include emissions from heavy-duty vehicles that have exhaust pipes a few inches above the ground, such as some delivery trucks.

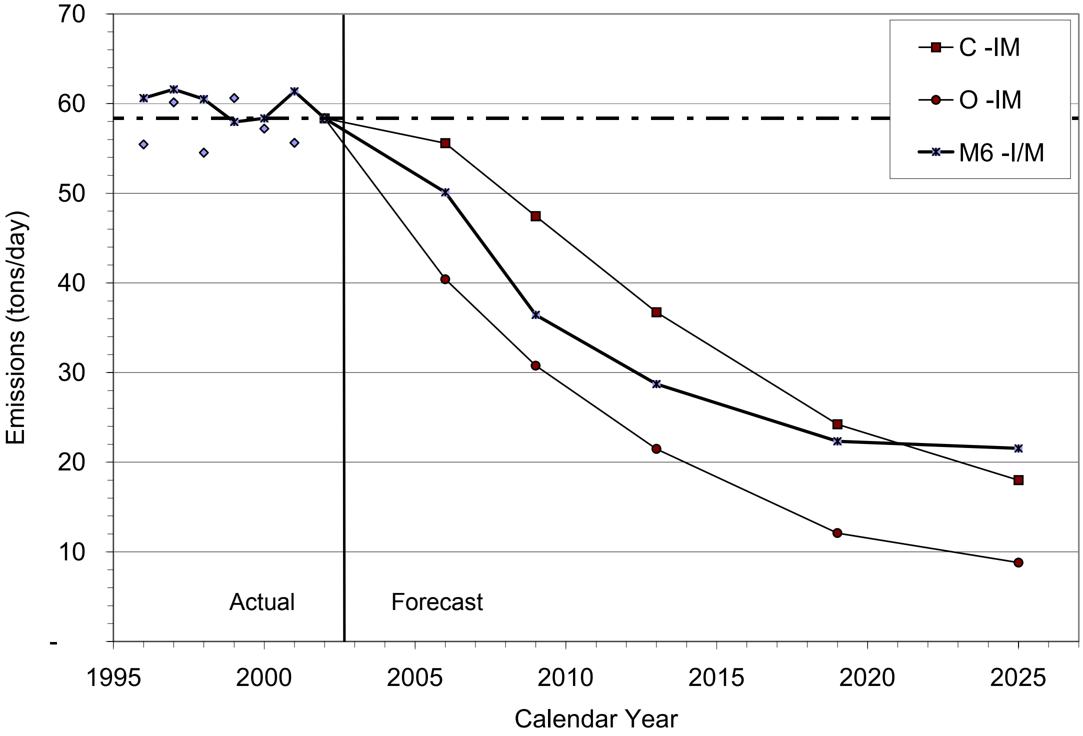

Figure 6-18. Our NOx emissions forecasts compared to MOBILE6 output.

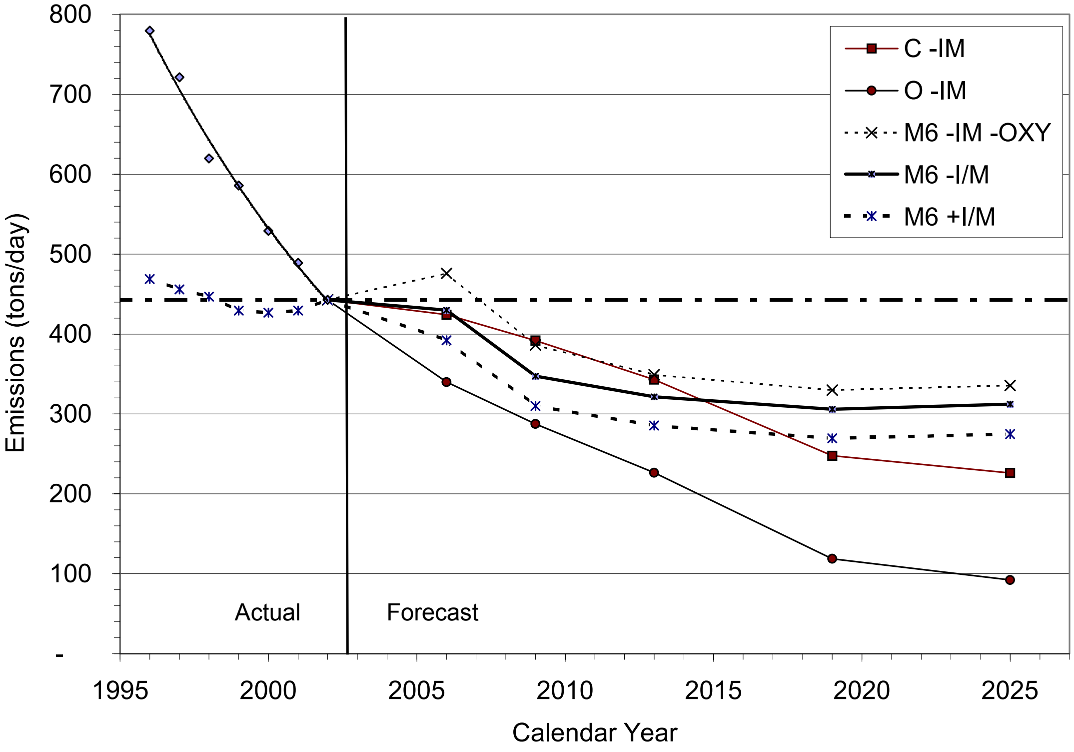

Figure 6-19. Our CO emissions forecasts compared to MOBILE6 output.

Just as in our forecasts, MOBILE6 predicts substantial declines in emissions, regardless of the existence of an I/M program. However, for HC, the MOBILE6 prediction seems to be extremely optimistic about the future emissions performance of Tier 1 and Tier 0 vehicles, when compared with even our most optimistic scenario. Given that our estimates are tied relatively closely to the actual emissions of the I/M fleet, MOBILE6 appears to have a serious problem in its HC emissions assumptions for Tier 0 and Tier 1 vehicles. For NOx, MOBILE6 essentially agrees with our predictions. For CO, MOBILE6 fails to exhibit the substantial downward trend observed in CO emissions from the I/M fleet (and the RSD fleet as well) between CYs 1996 and 2002. The MOBILE6 forecast of future emissions is similar to our conservative forecast in the short and intermediate term. Note also that MOBILE6 predicts a small short-term increase in CO emissions if both the I/M and oxyfuels programs are discontinued, with declining emissions after CY 2006.

Overall we conclude that future emissions would be lower with I/M, but that I/M is not necessary to ensure continued declines in emissions from the light-duty vehicle fleet.

6.5 UNCERTAINTIES

Emissions forecasts inherently include a number of uncertainties. We tried to account for this through assumptions that place reasonable upper and lower bounds on the future performance of current and yet-to-be-built vehicles. Nevertheless, it’s worth keeping in mind the sources of uncertainties in our emissions estimates and how they might affect future emissions. We focus on uncertainties as they relate to the conservative, without I/M scenario, since this is the most policy-relevant forecast.

VMT. We made no independent prediction of future VMT, but used DRCOG’s VMT forecast in all of our emissions forecasts. If VMT grows more rapidly than DRCOG predicts, future emissions would be higher than we predict.

Travel fraction. We used the same travel fraction for all calendar years. Given this decision, uncertainty in the travel fraction has hardly any effect on the *relative* differences in emissions between calendar years. However, future emissions could be different if the travel fraction changes with time. For example, if future cars last longer, the average age of the fleet would increase with time. This would slow down the rate of emission reductions, and would increase long term emissions up to a few percent above our predictions. Since this factor couldn’t have a substantial effect on short-term emissions, it doesn’t affect our predictions for CY 2006, which is the only year in which the conservative, without I/M forecast approached the CY 2002 baseline.

I/M effectiveness. We assumed that I/M in the future would cause the same percent reduction in fleet-average emissions as we estimate for the current program. There doesn’t appear to be any way to determine whether this assumption is optimistic or conservative. Absolute I/M benefits will certainly decline as the fleet becomes inherently lower emitting. But percentage benefits might go up or down, depending on, among other factors, how the future vehicle technology mix performs, how a future I/M program is structured, and how much it costs to repair vehicles that will be on the road in the future.

The I/M program might also be achieving cumulative benefits due to cars going through multiple cycles of the program. We could not assess the potential amount of cumulative benefits for this study. If there are cumulative benefits, our without-I/M scenarios would *underestimate* future emissions. The extent of cumulative benefits depends on several factors, including (1) the fraction of fail-pass vehicles at any given time that have gone through multiple I/M cycles, (2) the long-term pattern of emissions deterioration of fail-pass vehicles with and without I/M, (3) how long fail-pass vehicles remain on the road with and without I/M, and (4) the degree to which multiple repair cycles can achieve marginal emissions benefits over and above those of a single cycle.

We assumed that all emissions reductions during an I/M cycle are caused by I/M and would not occur in the absence of I/M. But many motorists repair and maintain their cars for reliability and drivability reasons, and some and perhaps many of these repair and maintenance actions would reduce emissions as a side effect. Thus, an unknown portion of the I/M-attributed emission reductions would occur even without an I/M program.

Tier 0 forecast. We extrapolated emissions measured from CY 1996-2002 out to CY 2006. Because of the relatively short time period over which we extrapolate, and the long emissions history for Tier 0 vehicles, we believe this is a relatively safe approach. However, we do know that the I/M fleet differs from the on-road fleet in being somewhat depleted in high emitters (Stedman, D.H., 1998, 1997) and most of the high emitters are Tier 0 vehicles. It's not clear how this would affect our forecast, since our forecast is based on the rate of change in emissions of Tier 0 vehicles over time, rather than the absolute level of emissions. However, since we obtained similar results for CO from I/M and on-road data, the differences between the two fleets might not have had much effect on our predictions.

Tier 1 forecast. The main uncertainty in our Tier 1 forecast is how Tier 1 vehicles will perform after age 5, since we used actual emissions measurements in the I/M program for emissions up to age 5. Our conservative scenario assumed Tier 1 vehicles would deteriorate from ages 5-10 at the average rate observed for Tier 1 vehicles tested from CY 1996-2002. Since the Tier 1 deterioration rate has declined with each successive model-year, this appears to be a conservative assumption. To add an extra safety margin, we assumed NLEV vehicles, which replaced Tier 1 starting with MY 2001 and which must meet tougher standards than Tier 1 vehicles, would nevertheless perform no better than Tier 1 vehicles. Our Tier 1 estimates are unlikely to be affected by bias in the I/M data due to motorists preparing for the I/M test or avoiding the program. The reason is that our forecast is based on newer vehicles, so motorists would probably expect to pass the I/M test without making any special preparations.

Tier 2 forecast. The emissions performance of Tier 2 vehicles is unknown since none have been built yet. Thus, for our conservative case, we used the very conservative assumption that emissions of Tier 2 vehicles would exceed Tier 2 requirements by a factor of two.

Overall assessment. Near-term emissions depend mainly on our Tier 1 and Tier 0 forecasts, while long-term emissions depend mainly on our Tier 2 forecasts. Because we have a great deal of experience with the emissions of Tier 0 and Tier 1 vehicles, there's less uncertainty than for Tier 2 vehicles. To offset the uncertainty in Tier 2 vehicle emissions, we chose a particularly gloomy conservative scenario.

The key uncertainties are likely to be the degree to which the I/M program achieves cumulative benefits from multiple cycles of I/M. If the cumulative benefits are a substantial fraction of the single-cycle benefits, future emissions approach those of our conservative scenarios, and few or no benefits attributed to the existence of I/M would occur in the absence of I/M, then HC and CO emissions could conceivably increase slightly above the 2002 baseline by CY 2006, but would still decline substantially in the intermediate and long term. For comparison, MOBILE6 includes the assumed effects of multiple I/M cycles in its emissions assumptions and does not predict an increase in the emissions of any pollutant in the without-I/M case.

7.0 COSTS AND COST EFFECTIVENESS OF THE AIR PROGRAM

In this section we summarize the results of our analysis of the costs and cost-effectiveness of the current AIR Program in the enhanced Inspection and Maintenance (I/M) area of the Denver region for the year 2000. We first provide an overview of the cost results, and then examine each of the cost components in some detail. We then display and summarize the cost-effectiveness results.

7.1 SUMMARY

Overall, we found that the AIR Program cost the State and the public about $44 million in year 2000. This amount included the following five types of costs:

- Administrative costs incurred by the Department of Public Health and Environment and the Department of Revenue.
- Inspection costs incurred by Environmental Systems Products, Inc. (Note: We were unable to obtain information on revenues earned by ESP, Inc.).
- Repair costs (net of associated fuel savings) incurred by vehicle owners.
- Motorist time and convenience costs.
- Lost value to owners of vehicles that are scrapped or leave the area because they failed the emissions inspection.

Inspection costs account for almost 40% ($17.5 million) of the total program costs and are the result of inspecting about 800,000 vehicles during 2000. Repair costs also make up a substantial portion of the total program costs – 24% or $10.4 million. The lost value to owners of vehicles that are scrapped or removed from the region represent 16% of the total costs ($6.9 million), while motorists time and convenience costs represent 12% ($5.5 million), and administrative costs account for the remaining 9% ($3.8 million).

We also estimated the cost-effectiveness of the AIR Program, defined as the average cost per ton of emissions reduced. Overall, we found that it cost about $1,300 per ton of carbon monoxide reductions and $12,700 per ton of reductions for pollutants contributing to ozone formation.

7.2 OVERVIEW OF COSTS

The overall costs of the current program in 2000 were found to be about $44 million. This is about $25 per registered vehicle in the I/M area.[1] This total is estimated from five categories of cost: (1) administrative costs, (2) inspection costs, (3) repair costs and associated fuel savings, (4) costs of vehicles that leave the area as a result of the I/M program, and (5) motorists costs, including time and convenience costs. We provide a single best estimate of costs for each of these components, and not a high and a low value as we did for the emissions

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[1] Note, however, that less than half of all vehicles registered in the region are inspected in 2000.

reductions analysis. There are a number of areas of uncertainty about the costs, and we will highlight the areas of greatest uncertainty in the discussion below.

The different components of these costs are summarized in Table 7-1, and the shares of the total costs are displayed in Figure 7-1. The largest share of costs, over $17 million, are for inspecting more than 800,000 vehicles during 2000; these costs account for nearly 40 percent of total program costs. The next two largest components result in direct emissions reductions, 24 percent in repair costs (net of fuel economy savings), and 16 percent in costs from the lost value of vehicles that are removed from the area because they cannot pass the I/M test. Vehicles that are sold outside the region because they cannot pass the test reduce emissions but result in a loss in the value of driving services in the region. Finally, there are the motorists' costs, 12 percent of the total, and the program operation and oversight, at 9 percent of the total.

Table 7-1. Total costs of the enhanced I/M program in 2000.

Category	Costs
Program Op and Oversight (Registration Fee)	$3,818,100
Inspection	17,611,880
Repair and Fuel Economy	10,436,970
Cost Associated with Replaced Vehicles	6,985,400
Motorists Costs	5,518,700
Total:	$44,371,000

The 1999 audit report estimated total program costs as $33.4 million (AIR, 1999). Our cost estimates are higher because we included two cost components not considered in the previous audit: costs associated with replaced vehicles, and motorist costs.

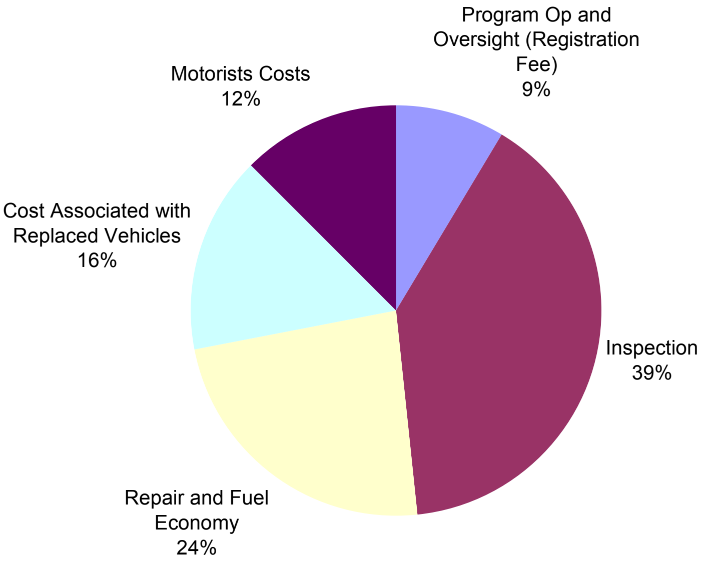


Figure 7-1. Cost components of the Denver I/M program in 2000 (Total costs = $44 million).

The total costs of the program can also be broken into two separate parts: costs associated with identifying vehicles with high emissions, and costs associated with the actual reduction of emissions in the region. Figure 7-2 shows the cost breakdowns for these two parts. A large share of the total cost is spent testing all eligible vehicles to identify those with high emissions.

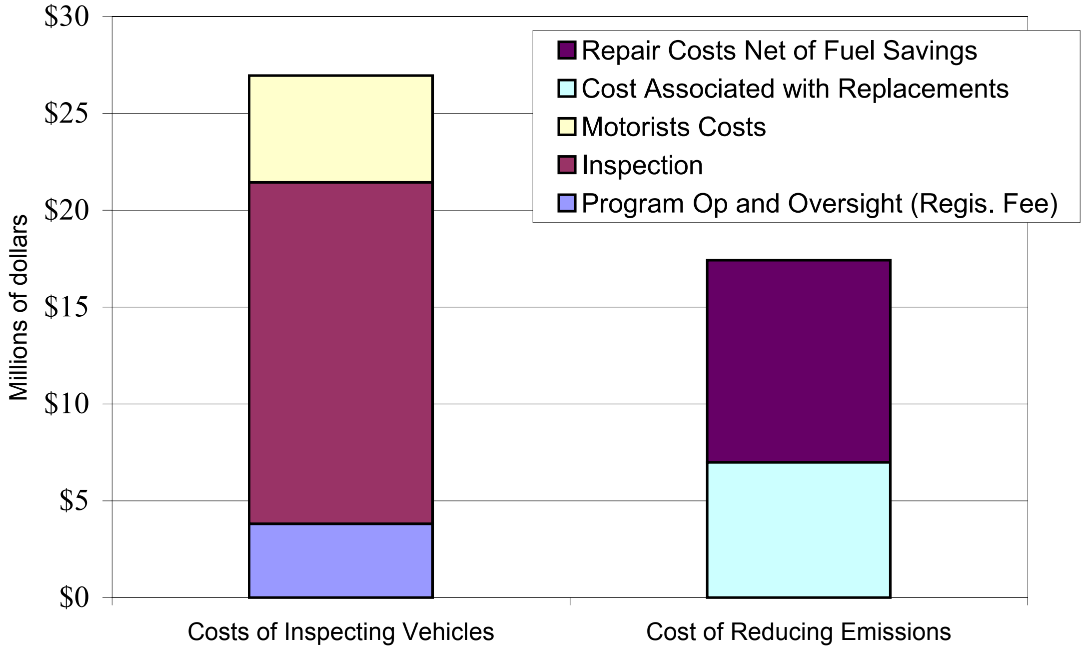
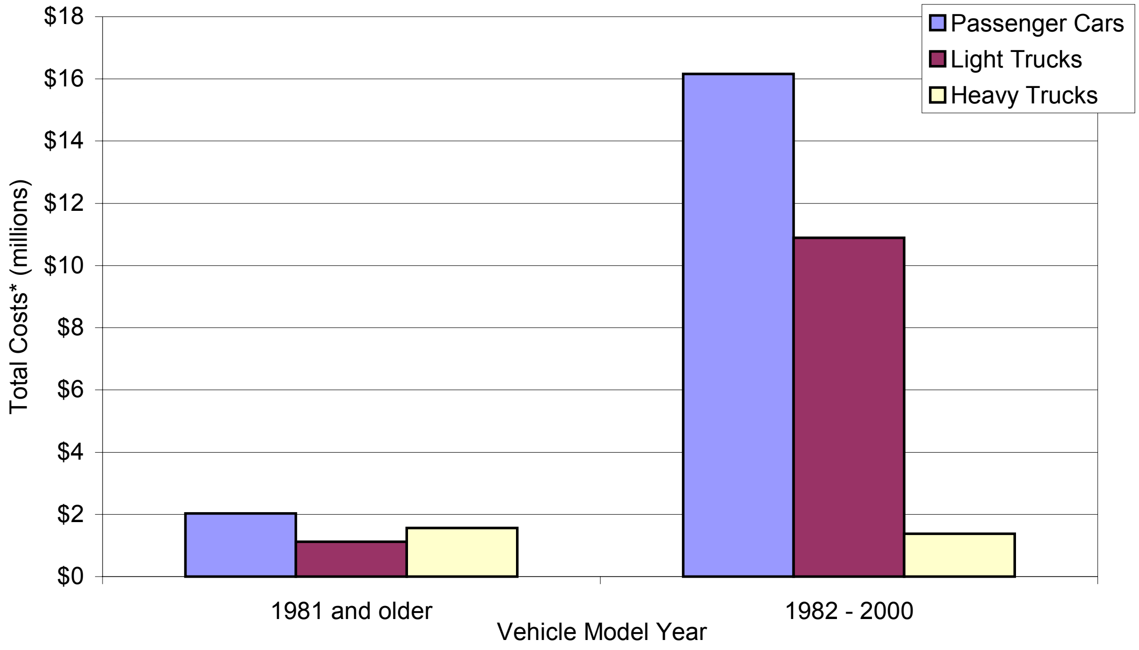


Figure 7-2. Cost components of the Denver I/M program in 2000.

We also estimated costs by model year and type of vehicle. The 1981 and older vehicles are tested using an idle test, and most of the 1982 and more recent model year vehicles are tested using an IM240 test (except for heavy trucks which are all idle-tested). We summarize the costs of testing by two groups of model years, and by type of vehicle, in Figure 7-3. Most of the costs are associated with post 1981 model year passenger cars and light trucks. The cost of the program attributed to the heavy trucks is quite small, primarily because of the small numbers of trucks inspected.



*Total Costs = Motorists Costs + Inspection Costs + Repair Costs.
Additional Fixed Administrative Costs that do not vary by model year = $3.8 million

Figure 7-3. Costs of 2000 program, by vehicle type and model year.

7.3 COST COMPONENTS

In this section, we describe how each component of the cost estimates presented above was determined. Methods of estimation are briefly explained and the sources of our assumptions are provided. Areas of greatest uncertainty in costs are highlighted.

7.3.1 Administrative Costs

The AIR program is administered by the Colorado Department of Public Health and Environment, the Department of Revenue, and the various offices of the County Clerks. The costs of administration by these various agencies are fully and exclusively funded by two different fees related to the AIR program. The first is a $2.20 registration fee paid each year on each registered vehicle. Of this fee, $1.50 is shared between CDPHE and the Department of Revenue for the administrative costs of the program. The remaining $0.70 goes to the various County clerks for registration enforcement of the program. The second is a $0.25 fee on each inspected vehicle, which also goes to the two state agencies for administration of the program. These two sources of funds are the sole source of the administration and enforcement of the program; there are no general funds from the State directed to the program.

7.3.2 Inspection Costs

The costs of inspection are all covered by the fees for inspection, net of the $0.25 that per inspection that is paid to the state as part of the administrative costs. The inspection fee for the IM240 test was $24.25 per vehicle for all post-1981 model year in 2000, and $15.00 per vehicle for the idle test on 1981 and older model years. Vehicles that fail an I/M test, whether it is the first failure or subsequent failure, are not required to pay a fee for retesting if they are retested within ten days. Individual stations are allowed to charge for additional testing if it is after the ten day period, but very few did in 2000; we did not to include an estimate of retesting costs here. The number of vehicles used to determine inspection costs is the unique number of vehicles tested in 2000 (i.e. the cost of change-of-ownership tests is not included, as the benefits of those tests are not explicitly included in the estimate of program benefits; see Section 4).

7.3.3 Repair Costs Net of Fuel Economy Benefits

The AIR program data base includes information about repair costs and repaired parts, in addition to the data on the vehicle and results of the emissions inspection. Owners of vehicles that fail the inspection are given a form to fill out with the types of repairs performed and the cost of those repairs; the forms are required to be turned in to the inspectors at the time of the retest. Unfortunately, as in most I/M programs, reporting on repair costs and component repairs is not enforced, and very little data are actually collected. About 10% of failing vehicles that get retested report costs at all; of the 10% many report costs of $0. Appendix 7A shows costs of repair reporting rates as a function of model year. Model years 1982 – 1996 have slightly higher reporting rates, close to 15%, compared to the oldest and newest model years, which report at a rate of only about 5%. Reported repair costs of zero are much more frequent for pre 1982 model years than for later model years.

In addition, there are some vehicles that report repair costs higher than $1,000; some report costs as high as $5,000 (2% reported over $1,000). In the Colorado program in 2000, vehicles can receive a waiver if repair expenditures exceed $450, but only one waiver can be obtained over the life of the vehicle.[2] Therefore, it is possible that owners of some vehicles that are outside the manufacturer's warranty period and have received a waiver in the past, may spend considerable amounts to be in compliance. However, it is also likely that some of the very high reported repair costs could be due to data entry errors or reporting errors. In the calculations below, we use only those estimates of repair costs (including all rounds of repair for vehicles that failed more than once) less than $1,000.[3]

Using the reported cost of repair data (including all repair costs reported less than $1,000 per vehicle, and including $0), we found some variation in repair costs by type of vehicle and by type of failure. The types of failures include: (1) vehicles that fail and then eventually pass; (2) vehicles that fail and are then waived from further testing; and (3) vehicles that fail one or

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[2] Very few vehicles take advantage of the waiver: in 2000, less than 1% of all vehicles that failed their initial test received a waiver.

[3] We note that recently the state has moved away from OBD and check engine light on requirements, to an advisory status on each of these for motorists. As a result, average repair costs may now fall, because fewer repairs are required.

more times and never appear in the data record as having passed (the "no-final pass" vehicles (NFP)). The average repair costs by groups of vehicles are shown in Table 7-2. The table shows the total repair costs including all rounds of repair (some vehicles fail the test and return for after-repair testing more than once) for each vehicle over all observations for the years 1999 and 2000.

Table 7-2. Average repair costs by test and vehicle type.

	Idle Test		IM240 Test	
	Mean	Number reporting	Mean	Number reporting
Fail/Pass				
Heavy Trucks	$263	2,573		
Light Trucks	$75	6,171	$278	4,954
Passenger Cars	$82	8,390	$264	6,522
Fail/Waiver				
Heavy Trucks	$515	26		
Light Trucks	$405	74	$460	58
Passenger Cars	$440	75	$415	57
No Final Pass				
Heavy Trucks	$204	86		
Light Trucks	$89	208	$211	183
Passenger Cars	$134	335	$200	303

Lower average repair costs are expected for vehicles failing an idle test than for those failing an IM240 test, as relatively simple and inexpensive repairs, such as adjusting engine timing, often suffice to pass the idle test.

For the most part, repair costs are lower for vehicles that receive the idle test (earlier model years) than for the IM240, and they are highest for vehicles that eventually receive waivers. Waivered vehicles are supposed to have spent $450 to obtain a waiver, but some vehicles appear have more spent on repairs than the limit. In fact, the average repair costs for heavy trucks is higher than $450. There are also some hardship waivers granted, which means some vehicles can spend less than $450 before receiving the waiver. We used the reported data on costs to calculate average repair costs for each vehicle type and category. These repair costs are only slightly higher than those used in the last audit of the AIR program. The earlier audit reported repair costs for the IM240 test of $244; we used a slightly higher estimate for passenger cars ($264) and for trucks ($278), but slightly lower costs for vehicles that fail and never have a passing test (about $200 for cars and trucks).

The repair costs reported in Table 7-2 are used in combination with the number of vehicles of each type of failure, and each type of vehicle by model year, to estimate total repair costs. The results by model year (net of fuel savings) are shown in Figure 7-4. The fuel economy benefits were discussed in detail in Section 4 of this report. The gallons saved were converted to dollars saved by using the average gasoline price in the Rocky Mountain states in the year 2000, $1.50 a gallon. From the figure, it is clear that most of the repair costs are incurred for model years 1985 through 1991. More detail on repair costs can be found in Appendix 7A.

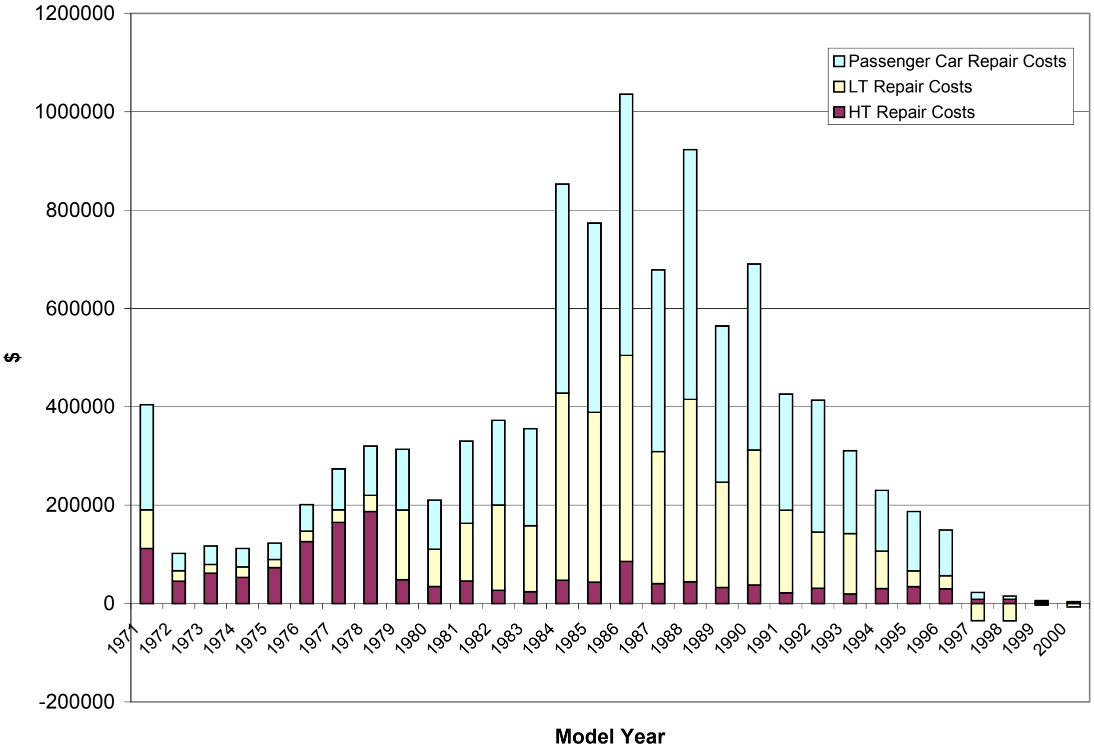

Figure 7-4. Total repair costs by model year (net of fuel savings).

7.3.4 Costs Due to Vehicles Leaving Region as a Result of the AIR Program

Because of the requirements of the I/M program, many vehicles will have difficulty passing, and will either be scrapped or sold outside the region. As described in Section 4, we examined three different scenarios for what might happen as a result of the no-final-pass (NFP) vehicles leaving the region (and we estimated that 82% of the NFP leave the region as a result of the I/M program). We assume that vehicles are not scrapped, but rather sold outside the region, since if they were going to be scrapped, the owners would not bother to go through the inspection and repair process. The three scenarios are that the NFP vehicles are sold outside the region and not replaced, are sold outside the region and replaced by a vehicle of the same model year that passes the I/M test, and replaced by a vehicle that is five years newer.

We estimated the costs based on the middle scenario: the share of the NFP vehicles that are sold outside the region are replaced with a vehicle of similar model year that passes the I/M test. The costs should reflect the lost value to owners because their vehicles have failed the inspection and must be sold outside the region, as well as the cost of replacing the vehicle, if the vehicle was replaced. To estimate this value, we used records from the “Black Book” (described in Appendix 7B), which provides auction and market-based estimates of used car prices. We calculated the loss in value as the difference between the retail and trade-in value of vehicles. When a vehicle fails the I/M test and cannot pass or get a waiver, it loses a good deal of its value in the I/M area. It may be picked up in an auction and sold outside the region, in which case the owner will be lucky to get the standard used car trade-in value, and certainly not the retail value. Conversations with used car dealers in Colorado confirmed this approach. One used car dealer said he likely would not accept a vehicle in trade-in that did not have a passing AIR program sticker. Hence, our approach, described below, may be somewhat conservative – the loss in value may be even greater than our estimate.

The Black Book includes estimates of both the trade-in and retail values of particular vehicles in excellent, average and rough condition for model years 1989 and newer for the Denver region. We looked up the rough condition retail and trade-in values for a number of specific vehicle models over five model years, 1989 - 1993. It seems likely that vehicles failing their I/M test and traded out of the region would most likely fall in the rough condition category. The average difference between the retail and trade-in values for these models is about $1100, as shown in Appendix 7B. The results were similar for cars and light trucks.[4] We extrapolated these results back to earlier years using an exponential function, since on average older vehicles have lower value and thus a lower proportionate difference between retail and trade-in value (there were no data from Black Book before the 1989 model year). For example, our estimate of the difference in value between retail and trade-in value for the 1975 model year was roughly $500.

We assumed that owners lose this difference between the retail and trade-in value of the vehicle that does not pass and is sold outside the region, if they do not replace the vehicle. If they do replace the vehicle with one of similar age and quality, they must spend this difference to buy another "rough" vehicle at retail. In either case, the lost value is the same. We multiplied this lost value by the number of vehicles assumed to be traded outside the region as a result of the AIR program. The results are shown in Figure 7-5. We made another assumption that vehicles sold outside the region will be older than 8 years, or older than the 1993 model year. Vehicles 1992 and younger may still have some emissions control parts still under warranty, and are also more likely have sufficient value to make repair economic. For the high estimate of benefits scenario, motorists are assumed to replace vehicles they sell outside the area with a vehicle that is five years newer. We made no assumption about the increased cost from that decision.[5]

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[4] We were unable to find data on heavy trucks, so we used the same estimate per vehicle as for cars and light trucks.

[5] Evidence on used cars sales shows only slight differences between vehicles of different vintages when they are over about 12 years old, but we did not make an estimate of that difference for the analysis here.

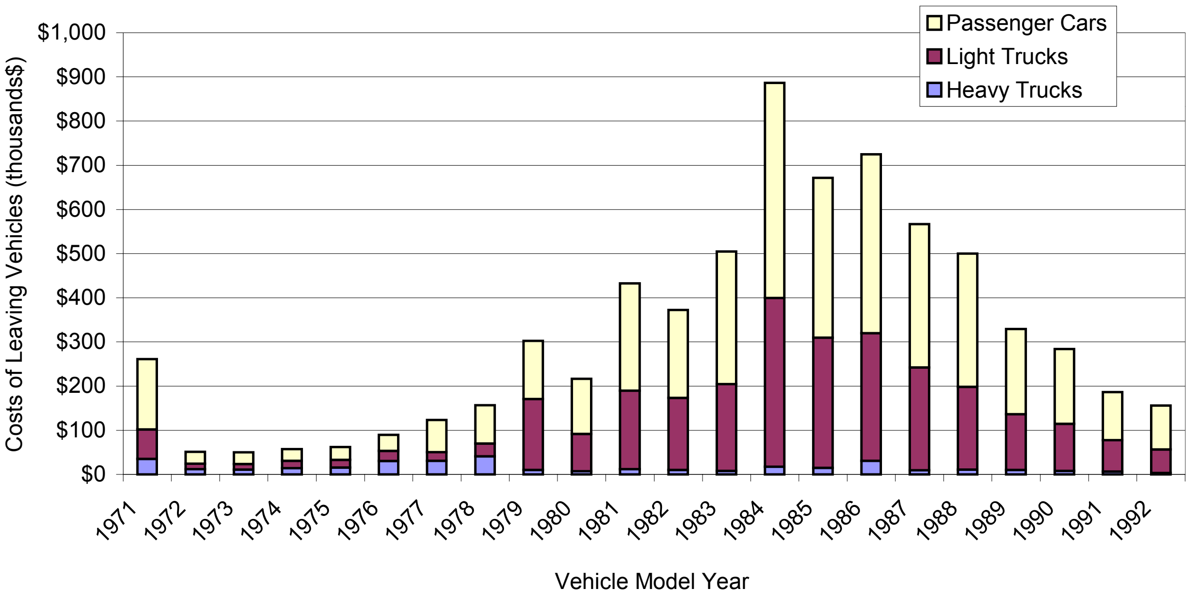

Figure 7-5. Costs due to vehicles being sold outside region as a result of AIR program, by vehicle type and model year.

7.3.5 Motorists Costs

We estimated the costs to motorists as the expenses for driving to the inspection station, and the value of time lost associated with getting the vehicle inspected and repaired. The out-of-pocket expenses are the average round trip distance to the inspection station times the per mile costs of driving. The American Automobile Association (AAA) estimates the cost per mile of driving a new vehicle are close to $0.50 per mile, but for older vehicles the costs drop off rapidly. We used an average per mile cost of $0.25.[6]

The time costs include the time it takes to drive to and from the station, and the time spent at the station. Colorado's AIR program requires that inspection stations be located so that 80 percent of households live within 5 miles of a station, and that 95 percent live within 12 miles. We estimated that residents live an average of 5 miles from a station. Estimates for the value of time is quite variable across individuals[7], but one commonly used assumption for time spent in a vehicle in congested highways is about one half the average wage rate. Time spent at the station is based on the fact that stations are fined if the average wait is longer than 15 minutes, averaged over a two hour period. We used 10 minutes as the average wait, and 10 minutes for the test.[8] The cost assumptions for motorists' costs are shown in Table 7-3.

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[6] See Harrington and McConnell *Vehicles and the Environment*, RFF Report 2003.

[7] See Calfee and Winston (1998), and Small, Winston and Yan Brookings Institution Working Paper (2003).

[8] See Harrington, McConnell and Ando (2000) for more detail on time for IM240 testing and queuing.

Table 7-3. Assumptions for the cost to motorists' calculations.

Cost Component	
Cost per mile, driving	$.25/mile
Round trip distance to the station	10 miles
Value of time	1/2 the average after tax wage in Colorado
Average wage rate – all occupations; Denver (BLS)	$15.15 hour
Tax rate (all taxes)	.37
Time spent traveling	30 min (10 miles rt. x 20 mph)
Time spent at the station	20 min
Resulting Total Motorist Cost/inspection	$6.60

7.4 COSTS AND UNCERTAINTY

We have not provided any estimates here of high and low costs, reflecting the degree of uncertainty in the estimates provided. However, it is important to emphasize that there is a good deal of uncertainty in some of these costs.

Repair. There is substantial uncertainty regarding the average repair costs as applied here to the vehicles repaired. The reported repair costs are only for a small share (roughly 10 percent) of the vehicles repaired. There is no way to tell if there is any systematic bias in the reported costs. For example, if motorists who paid larger amounts of money for repair were more inclined to report costs, then the repair costs reported here may be too high; or if motorists with newer cars are more likely to report repair costs, then costs may be underestimated here. Also, some vehicles may have virtually no repairs, but return to a station and pass the test. In our estimates, we did include those vehicles with reported costs of $0, but there may be more who just do not report when the costs are zero. Fifteen to twenty percent of failing cars pass within a couple of hours, and that many of these report zero repair costs. The hypothesis is that they're not doing anything to repair the car, but are banking on inter-test variability. Or, the very high estimates of costs of repair that we did not include here could accurately reflect the costs of obtaining a pass for some vehicles. In summary, there are many reasons why there is a fair amount of uncertainty about repair costs. However, it should be noted that the average costs of repair have now been reported from a number of different programs and they are reasonably consistent across programs – the reported average estimated costs seem to range from $150 to about $300, and depend on the type of test, the number of times the vehicle fails and, of course, the types of repairs done.[9]

Value of Vehicles that Leave the Area. There is a fair amount of uncertainty about how many vehicles are driven out of the area or scrapped as a result of the AIR program. We have provided a good estimate of that number here, and for the first time, an estimate of the cost of the value lost from those vehicles. However, we know little about which vehicles actually leave the area, and how they are replaced by motorists. We have provided a reasonable estimate of the value lost, but it may be an underestimate of the per vehicle cost if a vehicle that cannot pass the test loses almost all of its value, as suggested by discussions with Denver used car dealers. We attributed a loss of roughly $500 - $1,000 per vehicle sold outside the area, but the value could be larger than that for many vehicles.

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[9] See Ando, Harrington and McConnell (2000) for a summary of repair costs.

7.5 COST EFFECTIVENESS OF THE CURRENT PROGRAM

To estimate cost-effectiveness of the AIR program in the year 2000, we combined the costs as described above with the best, high and low estimates of the emissions reductions benefits (from Section 4). The resulting cost effectiveness results are shown in Tables 7-4 and 7-5. Cost-effectiveness is defined as the average cost per ton of emissions reduced. In the case of the Colorado program, we look separately at operating the program to target CO reductions, and operating it to reduce ozone precursors. In the tables below, we show both costs divided by CO reductions, and costs divided by ozone precursors, which we define as HC + CO/60. This measure of ozone precursors reflects the reactivity of CO in forming ozone[10], and we refer below to the combination of HC and CO as Ozone.[11]

Table 7-4 summarizes the overall cost-effectiveness results, with the results broken out by the costs associated with emission reductions from repair, and from vehicles leaving the area. The best, high and low scenarios reflect only the differences in estimates of emissions reductions, not in the costs; the cost estimates are the same in all three scenarios. The cost per ton reduced from vehicles leaving the area tends to be lower than the cost per ton from repair. This suggests that scrapping or removing older vehicles from the region may be a cost-effective policy. We examine that possibility in the next chapter on program alternatives.

Table 7-4. Cost effectiveness of the AIR Program in 2000.

	High Benefit Scenario		**Best Benefit Scenario**		**Low Benefit Scenario**	
Cost Effectiveness	**CO ($/ton)**	**Ozone ($/ton)**	**CO ($/ton)**	**Ozone ($/ton)**	**CO ($/ton)**	**Ozone ($/ton)**
Cost-effectiveness associated with repairs *	$1,059	$9,721	$1,262	$12,002	$1,823	$20,341
Cost-effectiveness associated with replacement vehicles *	$856	$8,657	$993	$10,068	$1,166	$11,790
Total **	$1,113	$10,416	$1,320	$12,711	$1,818	$19,784

* Fixed Registration Costs ($3.8million) not included in cost-effectiveness calculation.

** Fixed Registration Costs ($3.8million) included in cost-effectiveness calculation.

Table 7-5 shows the cost-effectiveness of repair by pollutant, by type of vehicle and model year. The cost per ton is highest for both pollutants for heavy-duty trucks. Light-duty trucks have the lowest cost per ton removed for both pollutants and for all model years except for one category, 1971-1981 model years for CO. In general, the older model year vehicles (1971-1981) are less costly to repair, though, of course, there are relatively few of them and so they do not contribute large quantities of emissions reductions.

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[10] See cite on CO as precursor.

[11] NOx can also a precursor to ozone formation, but in Denver, additional NOx likely does not contribute to ozone formation (see Section 2).

Table 7-5. Cost effectiveness of inspection and repair* in Denver I/M Program in 2000, by vehicle type (best benefit scenario).

	CO ($/ton)		HC+ ($/ton)	
Vehicle Type	**1971-1981**	**1982-2000**	**1971-1981**	**1982-2000**
Passenger Cars	$1,105	$1,499	$6,126	$16,856
Light Trucks	$1,551	$865	$5,223	$11,086
Heavy Trucks	$6,084	$3,312	$8,675	$70,700
Total	$1,672	$1,195	$6,492	$13,711

* Fixed registration costs ($3.8million) and replaced vehicles not included in cost-effectiveness calculation.

Figure 7-6 shows the cumulative percent of emissions reduced (each pollutant shown separately), and the associated cumulative cost for successively newer model years. This figure suggests what Table 7-5 also suggested -- that for reducing CO only, targeting the early model years does not make sense because costs rise faster than CO emissions reductions. For HC and for CO in the later model years, much of the emissions reductions benefits can be attained even when the more recent model years are exempt from the program. In fact, about 80 percent of the CO and HC+ emissions reductions can be attained for about 60 percent of the costs if the most recent 10 years of vehicles are exempt. We discuss this policy in more detail in the next section.

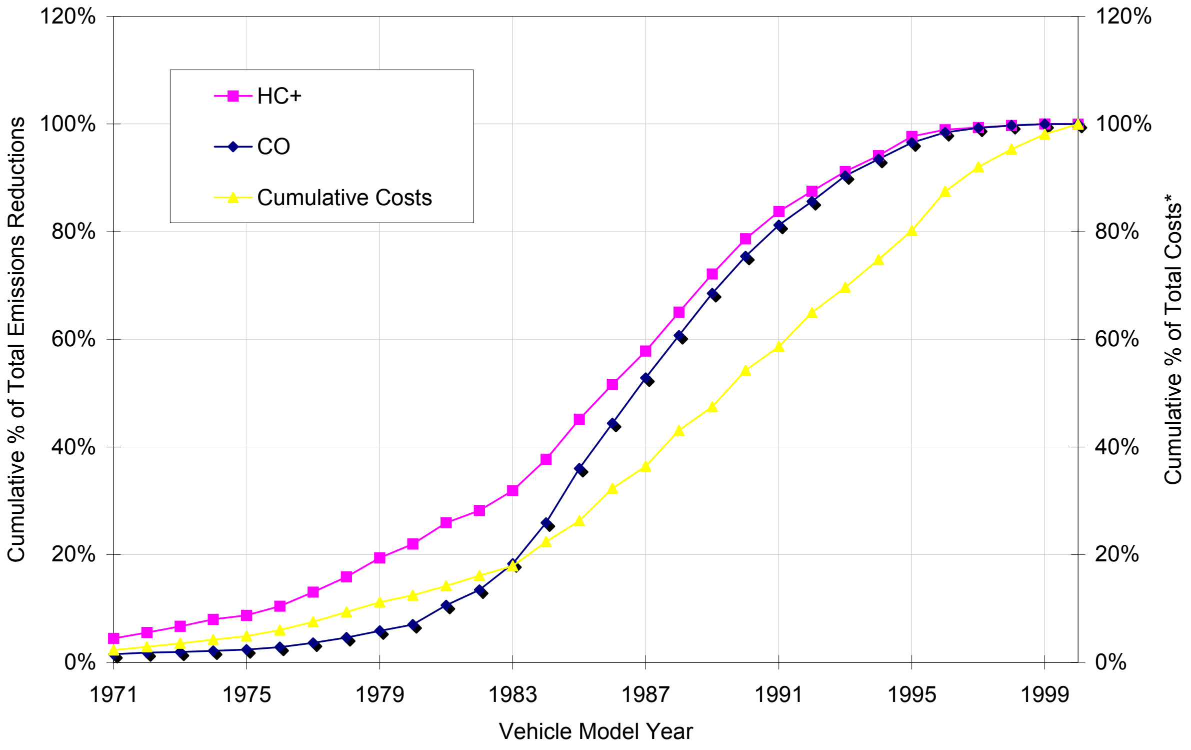

Figure 7-6. Cumulative share of total costs and total benefits from repair by model year inspected.

8.0 MODIFICATIONS AND ALTERNATIVES TO THE CURRENT PROGRAM

In this section, we review several possible modifications and alternatives to the current AIR Program that may be more cost-effective.

8.1 SUMMARY

We evaluated the following alternatives to the current AIR Program that could help reduce costs, while allowing the Denver area to maintain air quality consistent with national standards.

- **Exempt additional model years of vehicles from scheduled inspections and eliminate the inspection requirement when there is a change of ownership or when new vehicles are initially registered in Colorado.** New vehicles are not required to have an inspection for their first four years unless there is a change of ownership or upon its initial registration in Colorado. Increasing the number of years a new vehicle is exempt would result in substantial cost savings, with a relatively small loss of emissions benefits.

- **Implement a "clean screen" program in which vehicles that have low emissions are exempted from their next scheduled emissions inspection (akin to the program that was recently approved but has not yet started).** Low-emitting vehicles identified through remote sensing devices will have the opportunity to opt out of their next scheduled inspection. However, these vehicles must still pay the inspection fee as part of their registration payment to fund the additional contractor costs for the clean screen program. Our analysis indicates that adding this type of program will result in slightly reduced costs and emissions benefits compared to the current AIR Program.

- **Implement a program that uses on-road remote sensing to identify the highest emitting vehicles, and requires owners to bring in these vehicles for inspection and possible repair.** A “scrappage” component could also be added to this alternative. Under this scenario, the State would pay the owners of the highest emitting vehicles to “scrap” or retire their vehicle. Whether the scrappage component is added to this scenario or not, this type of program would have significantly lower costs than the current AIR Program. However, the emissions benefits would also be much lower.

8.2 MODIFICATIONS OF THE EXISTING PROGRAM

8.2.1 Exempt Additional Model Year Vehicles from the IM240 Test

The first modification we examined is the exemption of more model year vehicles from the test program. Currently, the AIR program exempts the first four model years from regular biennial inspections. In the year 2000 for example, model year vehicles 1997-2000 would be exempt from testing unless they change ownership. Any time a vehicle changes ownership in the Denver region, it must have an emissions test before the sale, and then it is immediately put into a two-year cycle of testing. In addition, vehicles that were previously registered outside Colorado are required to be tested upon initial registration in the State. We examined the costs and emissions impacts of allowing additional across-the-board exemptions. Our analysis focused only on the effect of additional exemptions on the costs and emissions changes related to inspection and repair. We assumed that the emissions impacts and associated costs resulting from vehicles leaving the area would be unaffected by the exemption of more recent model year vehicles.

In our first scenario, we examined the case in which all post-1996 vehicles are exempted from testing, including vehicles that change owners and vehicles entering the region from out-of-state. The results of our analysis, shown in Table 8-1, indicate a 12.5 percent reduction in costs with only a 1-2 percent reduction in HC and CO emissions under this scenario. It is clearly cost-effective to exempt these recent model year vehicles from testing. Table 8-1 also shows additional model year exemption scenarios in which a wider range of model years are exempted, including change of ownership and out-of-state vehicles.

Exempting a full ten model years would reduce repair-related costs by almost half (46 percent), and repair-related emission reductions by only 21 percent for HC and 25 percent for CO. This policy of additional exemptions clearly makes the I/M program more cost-effective. Motorists with new vehicles that are likely to be clean will not have to travel to inspection stations; however, much of the emissions reductions from the repair of failing vehicles in the rest of the fleet are retained.

Table 8-1. Changes in repair-related costs and emissions reductions resulting from additional exemptions.

	Cumulative % Reduction in Total Cost	Repair-related Total Costs[1]	Cumulative % Loss in HC Reduction	Cumulative % Loss in CO Reduction	CO Cost Effective-ness ($/ton) [2]	Ozone Cost Effectiveness ($/ton) [3]
Current Program[4]		$33M			$1,262	$12,002
Exempt all 1997-2000 Model Years[5]	13%	$29M	1%	2%	$1,107	$10,473
Exempt all 95-00	25%	$25M	6%	7%	$997	$9,411
Exempt all 93-00	35%	$21M	12%	14%	$945	$8,790
Exempt all 91-00	46%	$18M	21%	25%	$896	$8,164

[1] Total costs of the current I/M program are $44 million from Section 7 above. The costs considered here are only the repair related costs including inspection costs, motorists costs and repair costs.

[2] CO cost effectiveness (repair costs +inspection costs + motorists costs)/emissions reductions.

[3] Ozone cost effectiveness (total repair related cost /(HC+CO/60)).

[4] Exempts model years 1997-2000, but requires inspection at change of ownership and on initial registration from out of state.

[5] Exemption from change of ownership and all other inspections.

Exemption policies examined here provide an example of how the I/M program could be made more cost-effective if the program focused inspection and repair only on those vehicles most likely to be high-emitters. There are various ways to target inspection and repair on higher emitting vehicles in addition to exempting more model years. These include profiling based on past testing or other information, and remote sensing clean screen and high emitter identification programs. We briefly discuss Colorado's planned clean screen program below followed by examination of a RSD high emitter identification program.

8.2.2 Allow Vehicles to be Exempt from Testing by RSD Clean Screen

Denver is getting ready to begin a "clean screen" program as part of the AIR program, in which vehicles that have a high probability of having low emissions are exempt from their next scheduled emissions inspection. The clean screen program uses remote sensing units deployed at numerous locations around the region to remotely measure tailpipe exhaust emissions as vehicles drive by the sensors. A photo is made of the vehicle license plates to identify each measured vehicle. Vehicles that are measured with low emissions by the remote sensing units are exempt from their next scheduled inspection. However, clean screened vehicles must still pay the inspection fee as part of their registration payment, in lieu of the inspection.

A version of a Clean Screen program for the Denver region was reviewed as part of the 1999 audit. We reviewed the assumptions made in that analysis, and updated them where possible based on recent evidence from on-going clean-screen programs.

The Denver Clean Screen program will start by trying to screen 20 percent of the fleet; it is hoped to increase to as much as 80 percent in later years. With the addition of clean screening, the testing fee will increase to $25.00 for each vehicle at the time of inspection, $.75 higher than the current test. Hence, all motorists will have to pay $.75 more than under the current test. For the vehicles that continue to have IM240 tests (not clean screened), of the additional $.75 payment, $.25 will be used to cover the costs to the contractor of the clean screen program, and the other $.50 is to go to an escrow account that will be used to design and begin to implement a high emitter identification program. Vehicles that are clean screened will still have to pay $25, of which $1.15 are administrative fees (paid to County Clerks, and other funds for administration of the program)[1], and the remainder goes to the contractor to operate the clean screen program.

With the additional $.75 per vehicle, there will be added expenditures of about $600,000 on the AIR program with the addition of the clean screen ($.75 per vehicle times about 800,000 vehicles inspected her year). Some of money will go into an escrow account for development of a high emitter profiling program, and about $150,000 is earmarked to cover additional administrative costs (the $.90 on each of the clean screened vehicles). The contractor will have reduced costs from fewer inspections under the clean screen program, but higher costs for setting up a remote sensing network. The previous audit assumed that costs of setting up the clean screen infrastructure to cover 50 percent of the fleet would be about $2 million (p.145, 1999 Audit Report). Under the current contract in Colorado, it appears that the actual

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[1] Of the $1.15, $0.83 is paid to the County clerks, $.07 is paid to an operations fund, and $.25 goes to the state for administration.

costs to the contractor may be lower than that, but it is difficult to know what the savings will be for each vehicle that is no longer inspected in the traditional high volume setting.

In addition, large savings will result from motorists whose vehicles are clean screened that will not have to incur the time and cash costs required to get an inspection. These savings are about $6 per vehicle or about $1 million total. The costs of adding the clean screen program therefore appear to lower the overall costs of the inspection program: inspection costs rise by about $600,000 but motorists costs fall by close to $1 million.

The earlier audit assumed that about 42 percent of clean screen readings would be valid and matched to license plates (see below in the section on RSD high emitter program for further discussion of validity). There is some evidence from the Missouri program that valid readings for a clean screen program can be much higher – up to 70 percent. In a program in Austin, TX the valid reading rate was recently about 50 percent.[2]

Rough estimates of the emissions reductions and costs from this analysis and the previous one indicate that both are slightly less than those of the current program. A complete assessment of the cost-effectiveness of the program should be conducted once the program is underway. The program offers the opportunity for the state to collect data on important outcomes of the program, including the coverage of the RSD units, the participation of motorists, and effect on the estimated emissions reductions of the overall AIR program.

8.3 ALTERNATIVES TO EXISTING PROGRAM

We examined two alternatives to the existing program: (1) a stand-alone remote sensing program to identify high emitting vehicles, and (2) a combined RSD high emitter plus scrap program.

8.3.1 RSD Program to Identify and Repair High Emitting Vehicles (RSD HEI Program)

A great deal of uncertainty exists regarding both the costs of and the potential emissions reductions from a RSD high emitter identification program for a large area like the Denver region. Previous analysis has suggested that high emitter identification RSD programs have the potential to be very cost-effective (Lawson et al. 1996, Harrington and McConnell, 1993). However, the only large-scale high emitter identification program implemented to date was in the Phoenix area; that program was ended after five years because of its limited effectiveness. Currently, programs are being developed in both Texas and Virginia to use remote sensing to identify high emitters, but neither program is fully operational yet in terms of obtaining readings from large segments of the fleet, or in recruiting vehicles that fail. There is some information about the extent of the network needed to identify high emitting vehicles, and the associated costs, which we drew on for our analysis as described below. We attempted to build in the uncertainty in both costs and effectiveness for reducing emissions by including a range of estimates of key parameters.

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[2] The Austin program information is from a conversation with research staff at ERG in Austin, Texas. The Missouri program information is from Peter McClintock, consultant to ESP.

The state is currently moving toward some type of RSD high-emitter identification program. They will be starting a pilot program this summer to identify and recruit a small number of high emitting vehicles. Plans are to develop a larger more comprehensive program in the future, but the design of such a program is still in the planning stages.[3]

We began by examining two possible RSD programs, similar to those considered in the last audit. The first assumed the program would measure about 50 percent of the registered on road fleet and the second assumed 80 percent coverage of the registered fleet. At least two measurements on any one vehicle are desirable in an RSD program, because taking two readings improves the probability that vehicles identified as high emitting by RSD will also have high emissions on a tailpipe test. In our analysis below, the prototype programs we developed relied on evidence available from previous studies about what is feasible. We assumed enough readings to give a minimum of one reading on 50 or 80 percent of the vehicles, and two or more readings on a large share of the others that are identified. We assumed that the high emitter criteria are set at very high levels, in order to identify and recruit only the dirtiest vehicles.

Before looking in detail at some of the assumptions of our analysis of the RSD stand-alone program, we summarize the major results of both the 50 percent coverage and 80 percent coverage programs. The details of the costs calculations for the 50% program are in Appendix 8A, Table 8A-1. Below, Table 8-2 compares the cost-effectiveness of the current AIR program to the RSD program. We focused only on the costs of administering the program and on the costs of identifying and repair high emitting vehicles. We did not address here the costs or benefits from vehicles leaving the region due to having a mandatory I/M or RSD program in place. In the absence of additional evidence on this issue, we assumed both would have roughly the same effect on owner decisions to remove vehicles from the region.

Table 8-2. Costs, emissions reductions and cost-effectiveness RSD high emitter identification program.

	RSD High Emitter Identification Program Totals		**Current AIR Program[1]**
	50% coverage	**80% coverage**	
Total cost ($/year)	$4 million	$10 million	$37 million
% of current program total costs	11%	27%	
Total tons HC	305	488	2,236
% of current program reductions	13%	21%	
Total tons CO	4,259	6,814	25,578
% of current program reductions	17%	27%	
Cost-effectiveness			
Cost per ton Ozone (HC + CO/60)	$9,413	$15,911	$13,396
Cost per ton CO	$831	$1,406	$1,447

[1] Includes only cost associated with repair and registration (does not include cost of vehicles that leave area).

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[3] It should be noted that the EPA has not yet specified how a stand-alone RSD high emitter program can be given credit for emissions reductions.

We estimated that the RSD program would identify as high emitting a very small fraction of the fleet – equivalent to about 2 percent of the fleet of vehicles that would be subject to the current emissions inspection program every year. Of those, about half would be brought in for testing and subsequently found to be high emitting and repaired. A higher emitter RSD program with strict enforcement might do better than this, with results more similar to our optimistic case below.

Under the RSD program, total inspection costs, motorists' costs, and repair costs are all much lower than for the current program. There is instead the cost of setting up, operating, and administering the remote sensing system, and ensuring that vehicles found to be high emitting are identified and repaired.

Costs of the 50 percent coverage program are about 11 percent of the repair and registration-related costs of the current program. However, the emissions reduced as a percentage of current program reductions are about 13 percent for HC and 17 percent for CO. The cost-effectiveness of the high emitter program is somewhat better than for the current program, with ozone cost-effectiveness just over $9,000 per ton, while the current program is about $13,000 per ton. On the other hand, a remote sensing program that measures 80 percent of the registered vehicles is slightly less cost effective in reducing ozone precursors ($16,000 vs. $13,000 per ton) than the current program. This is because the costs of the additional remote sensing readings needed to identify 80 percent of the fleet compared to 50 percent of the fleet increase more than in proportion to the additional vehicles identified and the associated emissions reduced.

Because there is so much uncertainty about a number of key parameters in a remote sensing program, we performed a sensitivity analysis on our "best" assumptions about the costs and benefits (shown above), looking at both an optimistic set of assumptions and a more pessimistic set for the potential of RSD. The results in terms of costs and emissions reductions for the three sets of assumptions are summarized in Table 8-3. Key assumptions in this analysis are:

- *Number of remote sensing readings required to get 50 percent coverage of the fleet*. We relied on the relationship between the desired fraction of the registered fleet to be measured on road, and the ratio of RSD measurements to registrations needed to achieve that coverage as estimated in a recent study of RSD networks in Virginia (ESP, February 2003). That study found that the number of valid and matched RSD measurements has to be about 110 percent of the registered vehicles in the region to observe 50 percent of all vehicles at least once on the road. Many of those individual vehicles will have valid measurements two times, and some more than two times.

  To be considered valid, readings must be done at specified ranges of speed and acceleration rates, and must be on vehicles registered in the region and matched to a vehicle in the registration database. For the best case, we assumed that about 50 percent of RSD reading are valid. Therefore, in the Denver region, in order to get approximately 2 million valid readings, double that number of total readings will be needed.

  For the optimistic case, we assumed that the same number of valid RSD readings is needed as there are registered vehicles, and we assumed that 75 percent of readings are valid (this has been the rate in Missouri's clean screen program). For the pessimistic case, we assumed that valid readings will need to be double the number of registrations, and that only 40 percent of readings are valid.

- *Vehicles identified as high emitting.* We assumed in all cases below that the remote sensing high emitter criteria will be lax, so only the dirtiest vehicles will be identified by the sensors. We assumed that the dirtiest 1.5 percent of the fleet, both in HC and CO, or 2 percent of the overall fleet will be identified, and that notices will be mailed to owners with the requirement that every identified vehicle have a confirmatory emissions test. We used this assumption for all of the scenarios.

- *Vehicles confirmed as high emitters by IM test.* Of the vehicles identified, we assumed in the best estimate that 70 percent of them will be brought in for the required testing. We assumed that 80 percent of these vehicles will fail their I/M test. BAR, in California pullover studies, has found that vehicles which are read once by RSD tend to fail the roadside ASM test about 85 percent of the time.

  For the optimistic estimate, we assumed that 80 percent of identified high-emitting RSD vehicles will be brought in for required testing, and that 90 percent of these will fail the confirmatory I/M test. For the pessimistic estimate, the share that come in for testing was assumed to be only 50 percent, and the failure on the confirmatory test was also set at 50 percent. This pessimistic case simulates what occurred in the Arizona remote sensing program. Although vehicle owners were threatened with suspension of their vehicles' registration in that program, no suspensions were made. A program that has either more incentives to participate, or that is strictly enforced, is more likely to resemble our optimistic case.

- *Emissions reductions from vehicles repaired.* We estimated the emissions reductions from the vehicles that are repaired by the following method. First, we identified the 1.5 percent of vehicles in the I/M database with the highest annual HC and CO emissions. We estimated annual emissions by multiplying the gram/mile emissions on their initial I/M test by their assumed annual miles driven (from MOBILE6). We identified vehicles using their annual emissions rather than their emission rate in order to weight the highest emitters by the likelihood that they would be measured on road by the remote sensors. Since a 1996 vehicle is driven over twice as many miles per year than a 1981 vehicle (12,178 v. 5,701), a 1981 vehicle would have to have an emissions rate (i.e. grams/mile) twice that of a 1996 vehicle to be selected over the 1996 vehicle. Ninety-six percent of the highest emitting vehicles failed their I/M test, based on their gram/mile emissions (the other 4 percent had gram/mile emissions lower than the I/M cut points, but annual emissions within the top 1.5 percent of vehicles tested). Because some of the highest emitting CO vehicles also are among the 1.5 percent highest emitting HC vehicles, the highest emitters represent almost 2 percent of the overall I/M fleet. Figure 8-1 shows the model year distribution of the highest 1.5 percent CO and HC emitters (on the basis of estimated annual emissions) in the I/M fleet. Most of the vehicles (45 percent) come from model years 1984 to 1987.

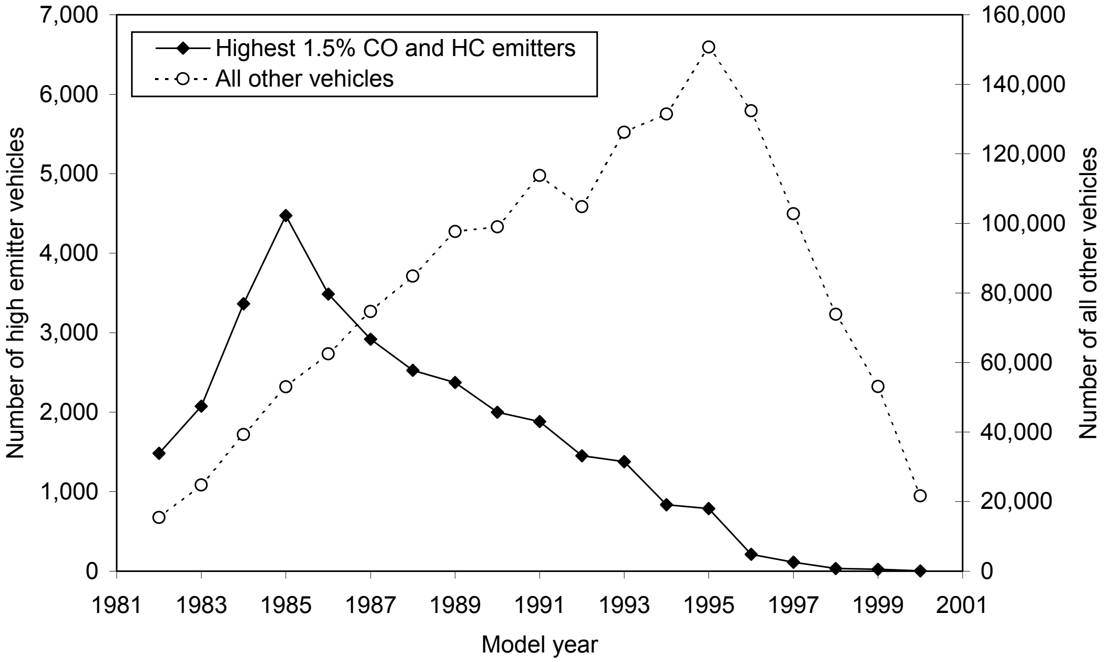

Figure 8-1. Number of vehicles by emissions stratum and model year.

We took the average emissions of this 2 percent of the overall I/M fleet on their initial and final I/M test to estimate the average emission reduction from repair for each pollutant. We used assumptions similar to those used for the repair benefits of the I/M program: we assumed that the emissions of these highest-emitting vehicles would not increase if there were no I/M program (nearly one-quarter of them are no-final-pass vehicles). For our high estimate of repair benefits, we assumed that emissions would increase to halfway between the initial and final I/M test by two years after the I/M test. For our low estimate, we assumed that the emissions would deteriorate to halfway between the initial and final I/M test immediately after their I/M test. The best estimate of repair benefits is simply the average between the low and high estimates. To estimate total emissions we multiplied by miles driven. We used the average annual miles driven from the entire I/M fleet (11,068 miles), since older vehicles identified as high emitters on road likely are driven more miles than the average vehicle of a given older model year.

- There are several ways to estimate costs. One can use a bottom-up approach, in which the costs are estimated by finding the costs of the equipment, labor and usage over time. The alternative is to look at the average costs per remote sensing reading, either for each vehicle read by RSD, or for each valid reading. We used the latter approach, drawing on recent evidence on costs in Texas and Virginia. The price paid in Texas is $1.58 for each unique vehicle identified (i.e., if a reading is on a vehicle that has already been measured by remote sensing, it does not count as a reading for a unique vehicle). Because it would take more readings to get each unique vehicle, the cost per valid reading should be less than this. In fact, several contractors felt this was about double the price needed for a valid reading. In Virginia, the cost was estimated at about $.34 per reading; the cost per valid reading would be at least double that. These costs do not include enforcement or analysis of the program. We used $.90 per valid reading as our best estimate, $.80 as the optimistic estimate, and $1.00 as the pessimistic estimate. Costs of $.90 per valid reading are also consistent with the bottom-up approach we used to estimate the cost of the RSD infrastructure. [4]

There are siting difficulties in implementing a remote sensing program, and these will affect costs. Remote sensing devices are designed to operate on a single lane of traffic, and so use of the devices on more than single lanes requires funneling traffic into a single lane. At the same time vehicle speed and acceleration need to be of a certain range, and so heavily traveled times of day on multiple lane roads cannot usually be measured (else congestion would be induced and motorist time/cost would be increased). There are also permit fees. All of our costs should be reevaluated when the planned clean screen program is underway and actual program data are available.

- We assumed that inspection costs are roughly what they would be under the current program. That may be too low, because with lower volume, the costs of IM240 testing are likely to increase. Also, if the number of testing stations is reduced, motorists may have to drive farther to have their vehicles tested. However, we did not vary these costs because we had no way of estimating their magnitude.

Table 8-3 shows the results of the three scenarios; Appendix 8A shows the results of each in much more detail. Again, the best set of assumptions results in costs that are a fraction of those in the current AIR program, but provides reasonably cost-effective emissions reductions, just a bit lower than those of the current program. Costs are so low for the program because it only requires testing of about 2 percent of the registered fleet, while the current program requires that all eligible vehicles be tested every two years. The optimistic scenario results in cost effectiveness of about a third of the current program, while the pessimistic scenario results in cost-effectiveness that is a good deal higher than what we found for the current program.

Several points are important to note in the discussion of this RSD high emitter program. One is that we have focused here for the comparison of the current program and the RSD program on repair costs and repair emissions reductions. Recall from the discussion above that the current AIR program also has a deterrent effect – some vehicles are permanently removed from the area because they cannot pass the IM test. There would probably be a similar effect with an RSD program; this effect would likely be higher in the RSD program (nearly 25 percent of the highest emitters are no-final-pass vehicles, as opposed to 1 percent of the entire I/M fleet). Motorists know that if they are driving a dirty vehicle, there is a possibility they will be identified as a high emitter. To avoid this possibility, or because they are found to be high emitting, they may decide to sell their vehicles outside the area. We have no way of knowing how large this effect may be relative to the replacement of vehicles in the current program; therefore, we have not made any estimate of this effect in the RSD analysis.[5]

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[4] Costs of the RSD infrastructure are projected to fall in the future with the introduction of unmanned remote sensing units.

[5] There are both costs and emissions reductions associated with vehicles leaving the area, but we found in the analysis of the current program that the vehicle replacement component was relatively cost-effective.

Table 8-3. Costs and emissions reductions from remote sensing to identify high emitting vehicles, 50% coverage, alternative scenarios[1]

	Best Estimate	Optimistic Estimate	Pessimistic Estimate
Number of valid and matched readings needed, Denver fleet 1.7 (millions)	1.9	1.7	2.6
Total measurements needed (millions)	3.8	2.3	6.5
No. of vehicles that are identified by RSD, and fail IM240 test	9,719	12,496	4,339
Failing vehicles as a % of number of vehicles read by RSD	1.1%	1.4%	.4%
Emissions reductions HC	305	392	136
Emissions reductions CO	4,259	5,475	1,901
	Costs		
Total cost ($/year)	$3.5 million	$2.8 million	$3.9 million
Cost-Effectiveness ($/year)			
Cost per ton ozone precursors	$9,413	$5,818	$23,034
Cost per ton CO	$831	$514	$2,034

[1] Costs and emissions reductions from vehicles leaving the area not included here.

Another critical issue for the potential of a RSD high emitter program is that it be enforced effectively. If it is not enforced, for instance by suspending or revoking vehicle registration, some motorists will not bring in identified high emitting vehicles for an I/M test, and others will not repair vehicles that have failed the IM240 test. Such a program would look like our pessimistic scenario.

Another issue is that the contract to run the RSD program should be designed to result in the most cost-effective outcome. Most recent RSD contracts specify a fixed payment for some number of vehicles identified. In Texas, the contractor is paid for the number of unique vehicles identified over a period of time. This gives the contractor the incentive to use RSD units to find as many different vehicles as possible. If the goal is to have vehicles fail at least twice before being recruited for further testing, a different payment design would be required. Setting up the contract to provide the right incentive is a key element in program design. Finally, some regions are considering linking a profiling analysis with an RSD high emitter identification program which could also improve cost-effectiveness.

8.3.2 Combined RSD High Emitter Identification and Scrap Program

The other alternative we examined is a combination of a RSD high emitter identification (HEI) program (like the one described above) with an old vehicle scrap program. As shown in Figure 8-1 above, 45 percent of the highest emitting vehicles are in the model years 1984 to 1987. The more recent model year vehicles tend to be cleaner and are likely to stay cleaner throughout their useful lives. The RSD program requires that high emitting vehicles come in for further testing, and then get repaired if necessary. However, there is some evidence that some of these high emitters are difficult to repair effectively so that emissions reductions are lasting. Many vehicles that receive repairs in the AIR program and eventually pass the test in that cycle, fail again in the next test cycle. Figure 8-2 shows that the failure rate in the Denver program for vehicles that failed on their previous test is much higher than for vehicles that passed on their previous test for all model years except the most recent. In addition, 25 percent of the highest emitters did not pass a subsequent I/M retest. Therefore, a policy to remove some of these older, highest emitting vehicles from the fleet and replace them with cleaner vehicles has promise to make the program more cost-effective.[6]

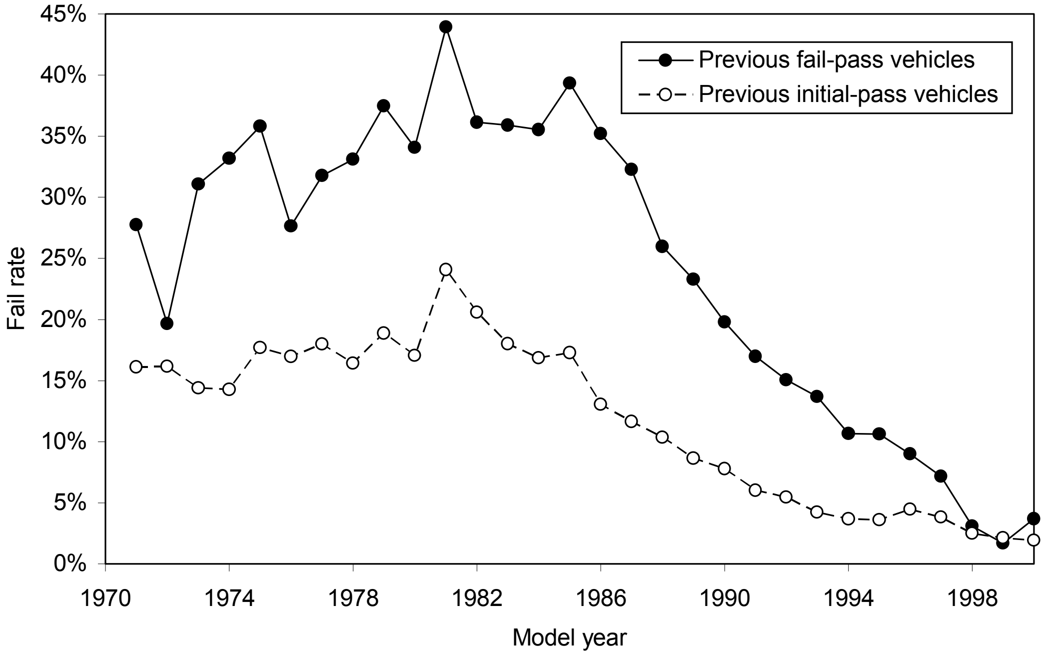

Figure 8-2. Failure rate on next test for vehicles tested in 1990 or 2000, by model year and previous I/M result.

We propose a policy to encourage motorists to scrap older vehicles as a component of the mandatory RSD HEI program described above. Because there are some possible negative incentives with scrap programs, our suggestion is that there should be several short-term programs over a period of time to identify and scrap some of the highest emitting vehicles. If vehicle owners know that there is an opportunity to receive a lump sum payment for an old polluting vehicle, they may attempt to participate by driving their old vehicles more or somehow make their older vehicles more polluting. A short-term program with little advance notice and relatively low monetary incentives should reduce this possibility, and result in overall emissions reductions because some vehicles are scrapped. Such short-term scrap programs can be run periodically, with the monetary incentives increased as necessary. Also, a scrap program can be combined with a scrap/repair subsidy program if the latter proves more cost-effective or more politically acceptable.

The program analyzed here would add a scrap offer to owners whose vehicles are identified as high emitters by RSD. An owner of such a vehicle would have the option of repairing the vehicle or taking the offer to scrap it for $1,000. We chose $1,000 because that is roughly the

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[6] For more information about old vehicle scrap programs and implementation issues, see Eastern Research Group study on scrappage, ERG (2002)

average trade-in value of older vehicles if they were to be sold outside the region. There is a good deal of uncertainty about how many vehicle owners would elect to accept the scrap offer, rather than repair the vehicle at this scrap price. In the analysis below, we looked at the sensitivity of the results to different proportions of motorists who decide to scrap. From an early study of the Delaware Vehicle Retirement Study (Alberini et al., 1994), we have an estimate that about 30 percent of older eligible vehicles would be scrapped at an offer price of $1,000. Because that scrap program was run approximately 10 years ago and had an intensive recruitment effort, we assumed that the proportion who respond would be lower in the Denver area. We examined a range of acceptance rates from 5 to 20 percent in the analysis below; details are provided for a range of scenarios in Appendix 8A. The acceptance rate is tied to the incentive offered; the higher the incentive, the higher the acceptance rate.

In our analysis of this program, we also assumed that when a vehicle is scrapped, it is replaced by a vehicle that represents an average vehicle in the fleet in terms of emissions rates. This assumption reflects the fact that no matter how the individual motorist decides to replace his or her scrapped vehicle, the effect of that decision cycles through the fleet. The motorist who sold a vehicle to someone who scrapped his vehicle will likely then purchase another vehicle, and the owner from whom he or she purchased will then purchase a different one, etc. In the absence of information about exactly how these used vehicle markets will be affected, it is a reasonable assumption that the replacement vehicle has the average emissions of the I/M fleet. Those emissions rates are 0.8 grams/mile for HC and 8 grams/mile for CO. We assumed that each scrapped vehicle would have been driven for at least a year if it was not scrapped; however, all scrap programs are subject to the "free rider" phenomenon, in which a motorist submits a vehicle that was not being driven or would have been scrapped any way without the program.

The results of the RSD/scrap combination program for a 10 percent and a 20 percent acceptance rate are shown in Table 8-4. Figure 8-3 shows the cost effectiveness of different scrap offer acceptance rates. Appendix 8A provides more detail on the results of the RSD and scrap program.

Table 8-4. RSD high emitter identification with scrap program $1,000 scrap offer.

	10% accept scrap offer	**20% accept scrap offer**
Total cost of RSD plus scrap ($/year)	$3.9 million	$4.0 million
	Number of vehicles	
Number of vehicles scrapped	972	1,944
Number of vehicles repaired	8,747	7,775
	Tons Reduced	
Total Tons reduced HC	340	376
Total tons reduced CO	4,689	5,119
	Cost-Effectiveness	
Total costs/ton Ozone precursors	$9,380	$8,598
Total cost/ton CO	$837	$774

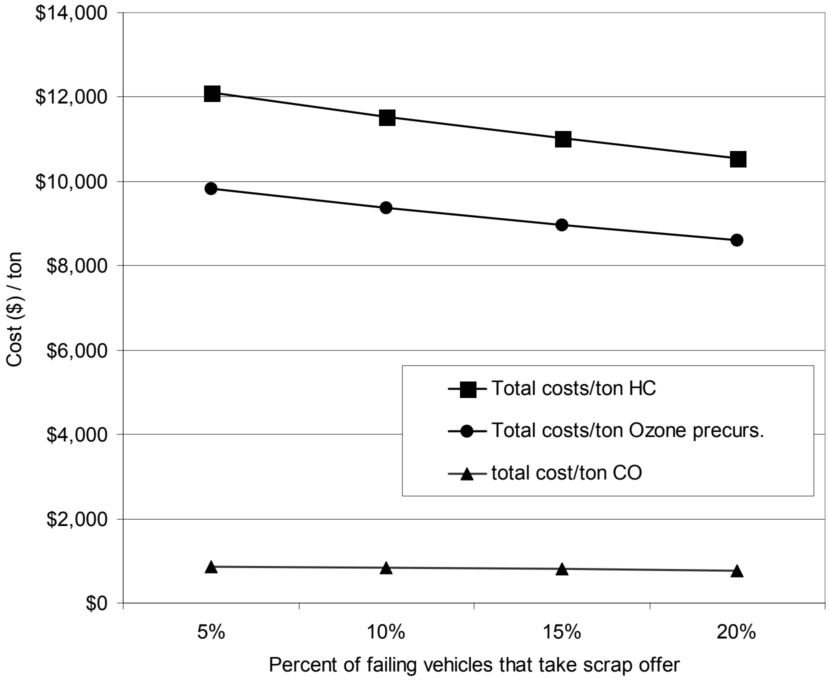

Figure 8-3. Cost-effectiveness of joint RSD and scrap program with different scrappage acceptance rates.

The RSD program with the scrap component is somewhat more cost-effective than the stand-alone RSD program. We found slightly improved cost-effectiveness both in terms of ozone precursors and CO, no matter how many vehicles take the offer. Vehicles that are scrapped reduce emissions by more than if they are repaired in this analysis, but there is also some increase in costs because the vehicles must be purchased and retired. The offer price of $1,000 per vehicle is offset by the fact that all of the vehicles scrapped had value to their owners of less than $1,000 (otherwise, the owner would not have taken the offer). Therefore, the net cost is the $1,000 minus the increase in value to vehicle owners who take the offer. In our analysis, we assumed that the average value of vehicles scrapped is $500, so the net cost per vehicle scrapped is also $500. All of the fuel economy benefits for both repair and scrap were taken into account. Higher acceptance rates mean more vehicles must be paid for, but they also bring larger emissions reductions. The emissions reductions are greater with higher acceptance rates and the cost-effectiveness is slightly improved at higher acceptance rates.

Overall, the scrap program added to the RSD high-emitter identification program offers promise for more emissions reductions and cost-effective reductions. However, there are several caveats to this analysis:

- As in the RSD program above, we did not account for the deterrent or incentive effects of these programs. The addition of the scrap program may induce some owners to bring their dirty vehicles in for testing, when, under the RSD alone program, they might have sold the vehicle outside the region to avoid the hassle and expense of further testing and repair. This would make emissions reductions of the joint RSD-scrap program lower and would make the program less cost-effective. On the other hand, some vehicles owners would have been in violation of the RSD stand alone program and would not come in for testing after their vehicles had been identified. Some of those owners might be induced to scrap if the scrap component is added. This would make emissions reductions of the joint program higher and cost-effectiveness better than in our analysis above.

- Another important point is that the analysis here may understate the benefits of including the scrap program for HC emissions. Older vehicles tend to have high evaporative HC emissions. When these vehicles are removed and replaced with relatively new vehicles, evaporative emissions decline. We have not taken into account reductions in evaporative HC emissions in this, or any other, aspect of our analysis.

9.0 ALTERNATIVE CONTROL MEASURES

This section discusses alternative control measures that could be implemented in addition to, or instead of the current AIR Program.

9.1 SUMMARY

The primary focus of air quality managers in the Denver area in the near future is going to be on controlling ozone levels. Because ozone is formed in the atmosphere via a complex set of nonlinear reactions of VOCs and NOx, effective ozone control programs must achieve a balance of VOC and NOx emission reductions appropriate to local conditions. Current evidence suggests that peak ozone levels in Denver are likely to respond most effectively to measures that emphasize VOC controls rather than NOx controls. Some of these measures include:

- Expanding public awareness of and response to the Ozone Action Alert Program via educational and other outreach campaigns.
- Significantly expanding public transit.
- Increasing alternative fuel use.
- Introducing low sulfur gasoline.
- Increasing the use of low emission portable gasoline containers.
- Reducing emissions at refineries.
- Instituting controls on gas field condensation tanks to reduce flash emissions.

For these and other measures, we have provided an estimate of the cost-effectiveness from another area of the country where these measures have been studied extensively. Control program alternatives and costs in the Denver area are not yet available.

Air quality management agencies in Denver as in other major cities can reduce or limit the future growth of emissions in many different ways. As discussed in Section 2, the primary focus of air quality managers in Denver in the near future is going to be on controlling ozone levels. Current management practices have resulted in attainment of the CO and PM10 standards and there does not appear to be any immediate danger of non-attainment with respect to PM2.5 although there is potential for heightened concerns about fine particulate matter in the future.

Projections of future on-road mobile source VOC, NOx, and CO emissions with and without continuation of the current I/M program were discussed in Section 6. These figures show that emissions of all three pollutants are projected to decline, which should produce continued improvements in CO, PM and ozone air quality. However, since ozone is formed in the atmosphere via a complex set of nonlinear reactions of VOCs and NOx, effective ozone control programs must achieve a balance of VOC and NOx emission reductions appropriate to local conditions. Similarly, the response of secondary PM to changes in the precursor mix can also be quite complex. As discussed in Section 2, current evidence, although quite limited, suggests that peak ozone levels in Denver are likely to respond most effectively to measures that emphasize VOC controls rather than NOx controls. However, further inventory development and atmospheric modeling will be needed to better understand the effect of future emission changes on ambient ozone and PM levels.

VOC emission reduction benefits of the I/M program and associated costs are described in Sections 4 and 7, respectively. Costs for alternatives to and modifications of the current I/M program are described in Section 8. To provide a context for the cost effectiveness of the I/M program in terms of VOC reductions, we present here a brief summary of readily available information on the formulation and cost effectiveness of other VOC control measures. Project resource limitations precluded development of a detailed analysis of potential control measures specifically tailored to the Denver area for this report. Instead, we summarized information previously developed for other metropolitan areas, including areas that, like Denver, have entered into ozone early action compacts with the EPA. A number of these measures have been discussed by Denver area stakeholders in connection with the ozone Early Action Compact (EAC). A list of these control measures along with estimates of their cost effectiveness expressed in $/ton of VOC reduction is presented in Table 9-1. For the reasons noted above, only the VOC cost effectiveness is considered here, although many of these measures will also result in reduced NOx and PM emissions.

VOC control measures listed in Table 9-1 were culled from lists of measures compiled in connection with recent ozone State Implementation Plan development efforts in Sacramento, Dallas, Houston, Las Vegas, Phoenix, and Los Angeles. Cost effectiveness estimates shown in Table 9-1 were specifically obtained from information compiled for SIP development efforts in Sacramento since this represented the only comprehensive, consistent, and readily available source of cost effectiveness data for use in this study. *As a result, the cost effectiveness estimates shown in Table 9-1 are very rough estimates tailored to the specific features of the proposed emission reduction measures, as they would be applied to Sacramento. As such, these values may not be representative of actual costs in Denver, but are presented here for purposes of comparison, as specific estimates for Denver have not yet been developed.* Cost effectiveness estimates are based on a mixture of fixed and marginal costs and the relative contributions of these two cost elements will differ from city to city. Some of the measures listed in Table 9-1 may not be applicable in Denver or may require modification if they were to be applied to Denver but we have listed them here to provide a point of reference for comparison of the cost effectiveness of various strategies. Denver-specific measure formulations and associated cost effectiveness estimates will be developed for Denver in support of the 8-hour ozone EAC process.

A summary of VOC emissions in the Denver area was prepared as part of the recently approved ozone maintenance plan; this is reproduced in Table 9-2. As in other large metropolitan areas, on-road mobile sources represent a significant fraction of the total anthropogenic VOC inventory. However, stationary and area sources combined account for roughly 2/3 of all anthropogenic VOC emissions in Denver so there is opportunity for emission reductions in these sectors as well.

As shown in Table 9-1, a wide variety of VOC control measures are available for consideration by planners. Some of the stationary source measures listed may not be applicable (or feasible) because the level of the targeted activities may be too small in the Denver area to support the strategy. Detailed emission inventory data for Denver is currently limited and a comprehensive review of source categories was outside the scope of this analysis. In addition, some measures listed here may duplicate or overlap programs already in place in Denver. Again, a detailed review of existing regulations was beyond the scope of this analysis. The Regional Air Quality Council in Denver is currently developing emission reduction estimates specific to the Denver area for several control measures which have been identified as leading candidates for inclusion in the EAC. These estimates are expected to become available later this year (Ken Lloyd, personal communication, 2003).

On-road mobile sources are one of the single most significant VOC source categories. Colorado does not have jurisdiction over vehicle design requirements but there are a wide variety of transportation control measures available for consideration. Control measures representing modifications to the I/M program (including programs based on remote sensing) are not included here; these measures are described in Section 8. Of the other on-road mobile source control measures listed in Table 9-1, we find some, such as expanding public awareness of and response to the Ozone Action Alert program via educational and other outreach campaigns, are estimated to be more cost effective (i.e., cost less than about $10,000 per ton of VOC reduced) than the current I/M program.[1] Other on-road mobile source control measures such as significantly expanding public transit are estimated to be far less cost effective but may have other social benefits, which are not a part of this analysis. Several programs are currently under discussion as part of the RAQC stakeholder review process, including alternative fuel use, early introduction of low sulfur gasoline, and several voluntary and incentive based travel control measures.

Off-road mobile sources have come to be recognized as a significant contributor to the overall VOC emissions budget. Colorado does not have jurisdiction over design requirements for new equipment but can control what is sold or the manner in which it is used. Control measures aimed at off-road sources cover a wide range of cost effectiveness, with some measures having the potential to be at least as cost effective as the current I/M program. However, estimates for many measures are not currently available. At least one potential control measure for off-road and related sources has been discussed as part of the RAQC stakeholder process (voluntary or mandatory use of low emission portable gasoline containers).

Point source VOC controls focus on tightening requirements for existing or new large sources. Some of these measures may be fairly cost effective but many of the least cost approaches may actually already be in place. Controls that have been discussed as part of the RAQC stakeholder process include reductions at refineries and instituting controls on gas field condensation tanks to reduce flash emissions.

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[1] This comparison ignores the CO benefit contribution to the "HC+" benefit measure used in Table 7-4 as the cost effectiveness values in Table 9-1 are based on VOC reductions only.

Table 9-1. Summary of selected potential VOC control measures and associated cost effectiveness estimates which have been implemented or are being considered for implementation in other U.S. cities. This summary represents a compilation of information on strategies developed for consideration in Sacramento, Houston, Dallas, Las Vegas, Phoenix, and Los Angeles. Only selected measures are shown; this is not intended to be a comprehensive list. *Cost effectiveness estimates represent values specifically developed for Sacramento; values for Denver may differ significantly.*

Emissions Category	Source Category	Type	Strategy Title	Strategy Description	Cost Effectiveness ($/ton VOC)
Area	All	Consumer Products	New Consumer Products Evaporative Limits	New mass-based or reactivity-based limits on consumer products.	$800
Area	Industrial processes	Asphalt	Asphalt Paving/Roofing	Limit VOCs caused by emulsified and liquid asphalt in paving materials and paving and maintenance operations by requiring use of new/modified low emission kettles or limiting temperatures at which such kettles may operate.	$500 - $5,000
Area	Industrial processes	Cooking-Commercial	Cooking-Commercial	Control VOC emissions from commercial cooking and frying operations, including chain-driven and under fire commercial broilers. Could also include deep fat fryers and charbroilers	$4,600
Area	Waste Treatment & Recovery	Landfills/Wastewater Treatment works	Landfills & Other Waste Disposal/Treatment	Apply current and emerging technologies and rules and regulations for active landfills. This measure includes controls of ROG emissions from decomposition gases from sanitary landfills, from domestic sewage treatment, and from industrial wastewater treatment.	$10,000 - $22,000
Area	Refueling	Vapor Recovery	Stage II Vapor Recovery	Require installation of Stage II vapor recovery systems	
Area	Refueling	Equipment	Portable Fuel Containers	Replace conventional containers with vapor control models	$10,000
Area	Architectural Coatings	Product Reformulation	Low VOC Paints and Solvents	Replace high VOC paints and solvents with low VOC formulations	
Area	Surface Coating	Process Control	Auto Body Refinishing	Reduces VOC content of auto body paint, requires more efficient paint application and cleaning of spray guns	$2,000 - $77,000
Off-Road	Airport GSE	Fleet turnover	Pursue approaches to reduce emissions from Airport Ground Service Equipment and Ground Access Vehicle.	Pursue approaches to reduce emissions from Airport Ground Service Equipment and Ground Access Vehicle.	$270,300 - $462,400
Off-Road	All	Engine/ New Technology	Retrofit controls and 3-way catalyst for spark ignition engines	Clean up existing off-road gas equipment through retrofit controls (spark ignition engines 25 hp and greater)	$20,000
Off-Road	All	Engine/ New Technology	Lower emissions equipment, fuel neutral	Alternative fueled equipment (construction, Agriculture, etc)	Unknown
Off-Road	All	Engine/ New Technology	Applications where highway engines are or can be used	Find applications where highway engines are or can be used, so 1998 or better 2004+ engines can be included into future estimates	$47,000 - $95,000
Off-Road	All	Fuel, episodic	Raise fuel prices	Raise fuel prices during ozone season	$343,000
Off-Road	All	Misc.	Establish clean air labeling, energy conservation and public education programs	Establish clean air labeling program; Continue/enhance statewide energy conservation program and education/public outreach campaign for air quality.	Unknown

Emissions Category	Source Category	Type	Strategy Title	Strategy Description	Cost Effectiveness ($/ton VOC)
Off-Road	All	Restrict usage, episodic	Restrict use of portable and 2-stroke engines	Restrict use of portable engines on spare the air days and ban some activities such as use of 2-cycle engines	$1,932,000
Off-Road	All (portable)	Fleet turnover	Portable Engine and Generator Emissions Reduction	Implement portable engine emission reduction program; Lowering emissions from portable/standby electrical generating units by proposed 50% reduction in the existing standards and mandated use of Tier2 and tier 3 engines.	$12,000 - $112,000
Off-Road	Commercial & Industrial	Shift operations, episodic	Incentives to shift non construction offroad emissions to low ozone season	Incentives to shift commercial and industrial equipment operation other than those of construction and point/area sources to low ozone season	$3,597,000
Off-Road	Lawn & Garden	Fleet turnover	Replace standard gasoline powered mowers with electric ones	Incentive programs for replacement of gasoline powered residential mowers with electric mowers.	$2,000
Off-Road	Lawn & Garden	Indirect / Land Use	Xeriscaping - eliminate residential mowing	Reduce lawn coverage from residences and institutional grounds to eliminate the need for push behind and riding mowers.	$1,000,000
Off-Road	Lawn & Garden	Restrict usage, episodic	Mowing restrictions	Disincentives, such as fines if caught mowing during Ozone alerts and through the use of various incentives, the commercial mowing time would be restricted during ozone action days. All commercial mowing including parks, golf courses, and smaller commercial entities would voluntarily agree to not mow during ozone episodes.	$1,511,000
Off-Road	Recreational	Fleet turnover	Incentives for newer boats and engines	Two-stroke Outboard Motor Control or Exchange Program; Incentives to replace 2 cycle boat motors with 4 cycle; Get industry (manufacturer) to offer incentives for newer boat engines. Make up losses through higher volume.	$6,000
Off-Road	Recreational	Misc.	Increase registration fee on recreational vehicles	Increase registration fee on recreational (non-essential) vehicles, Including recreational marine and/or off-road vehicles.	$14,000
On-Road	All	Fleet Rule	Clean Fleet Requirements	Clean Fleet Requirements (alternative fuels and equipment)	$25,000 - $59,000
On-Road	All	Enhanced Fleet Turnover	Commercial vehicle fleet modernization	Fleet Modernization for older commercial vehicles	$50,000 - $500,000
On-Road	All	Repair Incentives	Automobile Maintenance Organization	An Automobile Maintenance Organization would function as an HMO for cars. Participating vehicles would be provided maintenance that would ensure emission benefits above and beyond the current I/M program	$89,000
On-Road	All	Transit	Secure Funding for Expanded Transit	Secure funding for expanded transit network that provides clean-fueled buses or light rail at 15-minute intervals to 80% of the region's population (those living within the urbanized areas) and 30-minute intervals between cities.	$3,524,000
On-Road	All	Fuel	Fuel RVP	Lower fuel RVP	
On-Road	All	Fuel	Early Low S Fuel	Early introduction of low sulfur fuel	
On-Road	All	Fuel	RFG	Introduce use of reformulated gasoline	

Emissions Category	Source Category	Type	Strategy Title	Strategy Description	Cost Effectiveness ($/ton VOC)
On-Road	Land Use	Indirect Source	Indirect Source Rule for existing development	Develop and adopt an Indirect Source Rule similar to that in Los Angeles basin to encourage mixed use development, increase in-fill development and affordable housing.	$27,000
On-Road	LDV, LDT, MDT	Indirect / Land Use	PremAir catalyst to reduce ozone.	Apply PremAir (TM) catalytic coating to air conditioners.	Unknown
On-Road	Light Duty	Engine/ Technology	Catalytic converter replacement program	Implement a program to replace the catalyst in light duty vehicles and truck including (SUVs) in order to reduce NOx and HC emissions. Implementation could include providing incentives	$3,900 - $6,500
On-Road	Light Duty	Engine/ Technology	Gas Cap Program	Expand gas cap checks and provide free replacement caps	$31,000 - $142,000
On-Road	Light Duty	Programs for new technology	Station Car Programs and electric vehicles	Provide/fund neighborhood low emission/electric vehicles for use. Individuals could use the vehicles for short trips instead of their cars.	$1,586,000
On-Road	On-Road Mobile	Transit	Focus on Buses rather than Light Rail	Bus Rapid Transit (BRT). Clean fuel (CNG/LNG) express bus rapid transit	Unknown
On-Road	TCM	Fees, episodic	Fee for Access to City Center and free public transit	Heavy Duty or LD vehicles pay fee to access city centers. Increased parking fees for LD and MD vehicles. Free public transit on spare the air days or provide free transit to particular events.	$186,200 - $678,700
On-Road	TCM	HOV lanes	Dedicated Bus Lanes	Incurouge transit use by providing exclusive lanes that are for public transit only on major arterials.	$107,100
On-Road	TCM	Parking	Parking Incentives and Fees	Limits on parking time, providing cash-outs on not using the employer provided parking. No incentives on busy parking days and at metered or free parking zones. Emission-based parking fees at all possible lots and change unlimited in/out privileges at city-owned garages.	$4,585,000
On-Road	TCM	Programs, episodic	Expand/enhance Ozone Action Program	Increase awareness of the goals of the “Ozone Action” program by expanding notification, recruiting higher levels of voluntary vehicle trip reduction during periods adverse for formation of ozone, and lowering the ozone threshold for declaring an “Ozone Action” day	$6,925 - $10,291
On-Road	TCM	Traffic Calming	Traffic Calming	Traffic speeds are set so they are safe for pedestrians and cyclists and encourage trips by cyclists and pedestrians. Traffic calming techniques are used to reduce motor vehicle speeds and volumes. Traffic circles help slow traffic and reduce vehicle stops/accelerations.	$44,000
On-Road	TCM	Transit	Discounts and Incentives for Employees	Increase use and advertisement of available transit discount programs.	$305,000 - $1,374,000
On-Road	TCM	Transit	Community-based shuttle system	Community based shuttle system that links into public transit.	$250,000 - $500,000
On-Road	TCM	Transit	Bus Traffic-Signal Pre-emption	Encourage transit use be providing signal pre-emption for buses to override traffic lights, etc.	$89,000 - $267,000
On-Road	TCM	Work-Commute	Work-Related Trip Reduction Program	Tie projects and target projects to peak v. off-peak time periods. For example, 25% emissions reduction for employers, they decide how to meet it (i.e. telecommute with rotating schedules, etc.)	Unknown

Emissions Category	Source Category	Type	Strategy Title	Strategy Description	Cost Effectiveness ($/ton VOC)
On-Road	TCM	Work-Commute	Regional alternative work schedules	Reduce commute trips by restructuring the workweek to 4 ten hour days per week (4/40 schedule).	Unknown
On-Road	TCM	Work-Commute	Traffic Information	Enhance real time traffic information so people can make better decisions about when and where to travel, thereby reducing congestion and peak period emissions.	$103,000
On-Road	TCM	Work-Commute controls, episodic	Reduce Work-Related Trips with regulations and controls	Develop agreements with companies requiring them to shutdown or reduce activity on Ozone Action days; implement driving restrictions like odd/even no-drive days; implement gross polluter controls and restrict use of 1985 and older vehicles on Ozone Action days. Restrict [on road] trucks to hauling at night unless equipped with low emission technology on these days.	$69,000 - $2,700,000
Stationary	All	Enhanced Compliance	Permit Exemptions	Assess opportunities for further emission reductions through changes to permit rules such as adjustment of exemption thresholds, increased efforts to locate unpermitted equipment, and improved permit conditions. Also review enforcement and compliance practices at stationary sources through use of compliance and enforcement audits.	$1,000 - $3,000
Stationary	Industrial processes	Breweries	Breweries	Apply VOC controls to brewery operations.	$14,000 - $42,000
Stationary	Industrial processes	Foam, plastic, formica	Foam Blowing, Plastic Products and Formica Manufacturing	Reduce VOC emissions from expandable polystyrene molding (foam blowing) and polyester resin operations via various control technologies.	>$12000
Stationary	Industrial processes	Emissions Trading	Cap and Trade Emissions Reduction Program	Implement a market driven emissions allocation program similar to the RECLAIM program in the Los Angeles basin.	Unknown
Stationary	Industrial processes	Metal Parts Coating/Cleaning	Solvent Use Restrictions	Regulates technology level and operation of machines used to clean metal parts (electronic components or auto parts)	$2,000 - $10,000
Stationary	Solvent Utilization	Wood	Wood Products & Coating	Establish limits for the solvent contents for various categories of coatings for wood products applied in manufacturing facilities; establish additional measures for control of VOC emissions from the manufacturing of wood and paper products in industrial operations.	$15,000
Stationary	Storage & Transport	Oil & Gas	Petroleum Production	Apply additional controls to limit fugitive losses of VOCs from Oil and Gas Production and from Petroleum Production such as natural gas transmission losses and fugitive emissions from natural gas production, including "flash" emissions from evaporative storage tanks.	>$10,000
Stationary	Petroleum Refining	Fugitives	Leak Detection and Repair	Enhance leak detection and repair programs and refineries and chemical manufacturing facilities	
Stationary	Petroleum Refining	Flares	Flares	Apply control technologies for flares and flare monitoring equipment that can limit input into flares.	Unknown

Table 9-2. Denver summer season VOC emission inventory (source: Dilley, 2002, 2003a,b).

		VOC Emissions (tons/day)
Area		
	Miscellaneous Non-industrial: Commercial Solvents	17.8
	Miscellaneous Non-industrial: Consumer Solvents	43.6
	Surface Coating	24.3
	Comm./Inst. Fuel use	0.1
	Residential Fuel*2	0.0
	StructureFires3	0.1
	ForestFires3	2.8
	Prescribed File	0.1
	TOTAL AREA	88.7
Off-Road		
	Aircraft	1.7
	Locomotive	0.3
	Agricultural Equipment	0.7
	Airport Equipment	0.7
	Commercial Equipment	6.1
	Construction Equipment	15.5
	Industrial Equipment	1.4
	L&G Commercial	37.1
	L&G Residential	7.9
	Pleasure Craft	0.4
	Recreational Equipment	1.1
	Oil Field	0.1
	Railroad Equipment	0.0
	TOTAL OFF-ROAD	72.9
On-Road[2]		
	Gas Exh	52.5
	Diesel Exh	8.1
	Gas Non-Exh	40.4
	TOTAL ON-ROAD	101.0
Point Sources		
	Points (includes refueling)	54.0
	Flash	65.9
	TOTAL POINTS	119.9
GRAND TOTAL		382.5

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[2] Total on-road emissions from Dilley, 2003 (MOBILE6 estimate); breakdown by exhaust/other from Dilley, 2002 (MOBILE5b estimates).

10.0 LEGAL ISSUES

In this section we discuss the legal issues surrounding the Clean Air Act requirements, as well as future year emissions projections relative to regulatory requirements. We also discuss issues related to the preparation of the State Implementation Plan (SIPs) and transportation conformity analyses.

10.1 SUMMARY

The Environmental Protection Agency (EPA) has redesignated the Denver area to "attainment" status for carbon monoxide (CO), 1-hour ozone, and PM10. The Clean Air Act requires redesignated areas to submit to the EPA a maintenance plan that ensures continued attainment of the relevant national standards for at least 10 years after a redesignation request is granted. Regional transportation plans must also demonstrate conformity with State Implementation Plan emissions budgets for 25 years after adoption of the plan. Colorado must meet three legal/regulatory requirements in relation to pollutants covered by the AIR Program: transportation conformity, maintenance of the national air quality standards, and (optional) early action on the 8-hour ozone standard.

Emission forecasts based on actual on-road and Program data indicate that Denver does not need an Inspection and Maintenance (I/M) program to remain in attainment of the CO standard. The latest draft revision to the carbon monoxide plan provides CO emissions projections based on MOBILE6, the computer model that is required by the Environmental Protection Agency for projecting on-road emissions. This plan shows MOBILE6 projected emissions to decline in the future, but results are provided only with continuation of the I/M program. Ozone forecasts are much more challenging, and forecasts must be made with complex photochemical models. Although we project reductions in on-road vehicle emissions that contribute to ozone formation, changes in other sources that contribute to ozone formation must be evaluated and modeled, and the effects of combinations of on-road and other control strategies can be assessed.

10.2 INTRODUCTION

The Denver metropolitan area (Denver) is in substantive attainment of all National Ambient Air Quality Standards (NAAQS) and EPA has redesignated Denver to "attainment" for carbon monoxide (CO), 1-hour ozone, and PM_{10}.[1] Our analysis of future light-duty vehicle emissions concluded, after accounting for DRCOG's projections for growth in total vehicle travel, that emissions of CO, VOC, and NOx would continue to decline through at least the year 2025, even without an I/M program (see Section 6). MOBILE6 also predicts declines in emissions without an I/M program. Nevertheless, although Colorado is now in attainment of air quality standards, 8-hour ozone levels are very close to the standard at some monitoring sites (see Section 2).

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[1] Citations and dates for the EPA redesignations are as follows: 1-hour ozone standard, September 11, 2001, 66 FR 47086; CO standard, December 14, 2001, 66 FR 64751; PM_{10} standard, May 23, 2002, 67 FR 36124.

Colorado has continued legal and regulatory obligations, both as an attainment/maintenance area for current air quality standards, and also based on the new 8-hour ozone standard, which EPA will implement in 2004 (EPA, 2003). Colorado will need to ensure continued attainment of EPA's new $PM_{2.5}$ standard. The Clean Air Act (CAA) requires redesignated areas to submit to EPA a maintenance plan that ensures continued attainment of the relevant NAAQS for at least 10 years after a redesignation request is granted.[2] Regional transportation plans must also demonstrate conformity with the State Implementation Plan (SIP) emissions budget for 25 years after adoption of the plan.[3] In addition, because Denver may violate the 8-hour ozone standard within the next few years, the region has entered into an "Early Action Compact" (EAC) with EPA. The EAC option was created to encourage areas redesignated to attainment for 1-hour ozone to take proactive steps to reduce 8-hour ozone levels. In exchange, if the area in question exceeds the 8-hour ozone standard, EPA agrees not to redesignate the area as non-attainment until at least January 2008 (EPA, 2003).

Current and projected future mobile-source emissions inventories for maintenance plans and conformity determinations must be based on the latest approved version of EPA's on-road mobile-source emissions model.[4] MOBILE6.2 is the current EPA-approved model for on-road emission inventories (hereafter referred to as MOBILE6) (EPA, 2002).

Colorado's contract with ESP for IM240 testing in the I/M program does not appear to create any constraints on the state's ability to modify or end the AIR program. The contract specifies that "The contractor assumes the risk of revision or repeal of the program or the implementing laws and regulations during the term of the contract. The contract does not grant a vested right to the continuation of the AIR program, a minimum number of inspections annually, the form or manner of the inspection, the classes of vehicles inspected, or otherwise limit the authority of the General Assembly or [Air Quality Control] Commission to revise or repeal the statutes and regulations governing the AIR program. The contractor shall not be entitled to compensation if, during the term of the contract, the State terminates the AIR program, in whole or in part, amends it to require fewer periodic inspections, or amends the regulatory requirements."[5] We therefore proceed on the assumption that the state's contract with ESP does not legally constrain Colorado's ability to modify or end the AIR program.

This section assesses the extent to which Clean Air Act SIP and conformity requirements could affect Colorado's ability to modify or end the AIR program and makes recommendations on how Colorado can maintain clean air and satisfy its Clean Air Act obligations, while also reducing the costs of air quality regulation for Colorado's citizens.

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[2] CAA Sec. 175A

[3] CAA Sec. 176(c)

[4] CAA Sec. 172 (c)(3) and 40 CFR 51.112(a)(1)

[5] Automobile Inspection and Readjustment contract between the CDPHE and Envirotest Systems Corporation, as amended February 28, 2003.

10.3 FUTURE EMISSIONS RELATIVE TO REGULATORY REQUIREMENTS

Colorado must meet three legal/regulatory requirements in relation to pollutants covered by the AIR program: transportation conformity, maintenance of the air quality NAAQS, and (optional) early action on the 8-hour NAAQS. These legal/regulatory obligations cover three pollutants: hydrocarbons (HC), nitrogen oxides (NO_X), and carbon monoxide (CO). HC and NO_X are of concern as ozone precursors, as there are no NAAQS specifically for HC, while Colorado complies with the NAAQS for NO_x.

Carbon Monoxide. On June 11, 2003, a draft revision to the CO maintenance plan for the Denver metro area (hereafter "revised CO plan") was released. The revised CO plan includes ton-per-day estimates and forecasts for mobile source CO emissions in 2001, 2006 and 2013, based on MOBILE6, along with "allowable" emissions in 2006 and 2013, based on the CY 2001 attainment inventory. The attainment inventory is 1,800 tons per day, including all CO sources, and is based on estimated emissions in 2001.

Table 10-1 compares the revised CO plan MOBILE6 CO inventory for 2001 and forecasts for 2006 and 2013 with our results based on I/M and remote sensing data. The RAQC projected CO emission levels are based on MOBILE6 modeling, assuming continuation of the I/M program. The four "ENVIRON AIR Audit" columns are our conservative scenarios, both with and without I/M.[6]

The absolute emission levels from the different estimation methods are not directly comparable for several reasons. First, our emissions estimates and forecasts are based on IM240 test data, idle test data, and remote sensing data, and do not include cold start emissions, but the MOBILE6 results do include the assumed contribution from cold starts. Second, our results are only for the light-duty vehicle fleet (i.e., cars, SUVs, minivans, and pickup trucks), while the RAQC results are for all on-road vehicles.[7] Third, comparisons of MOBILE6 predictions with actual emissions measured in tunnel studies suggest that MOBILE6 significantly overestimates actual CO emissions from gasoline vehicles (as discussed in Section 5). In order to more easily compare the results of the different estimation methods, Table 10-1 also provides the percent change in CO emissions from the CY 1996 and CY 2001 base years. Because the absolute tonnage estimates are different for each estimation method, looking at percentage changes provides a better comparison of the predicted emissions trend based on each method.

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[6] In all four Environ columns, estimates for CYs 1996 and 2001 are for the with I/M cases, since these programs were in place during those years.

[7] The remote sensing data actually do include those heavy-duty vehicles that have an exhaust pipe a few inches above the road level, such as some delivery trucks.

Table 10-1. CO emission estimates and forecasts (in tons per day).*

	RAQC Proposed CO Maintenance Plan Revision	ENVIRON, AIR Audit			
Year	**MOBILE6 (with I/M)**	**I/M-based forecast (without I/M)**	**RSD-based forecast (without I/M)**	**I/M-based forecast (with I/M)**	**RSD-based forecast (with I/M)**
1996		779	621	779	621
2001	1,638	489	480	489	480
2006	1,614	424	423	365	351
2013	1,125	343	336	200	279
Percent change from CY 1996 base					
2001		-37%	-23%	-37%	-23%
2006		-46%	-32%	-53%	-43%
2013		-56%	-46%	-74%	-55%
Percent change from CY 2001 base					
2006	- 1%	-13%	-12%	-25%	-27%
2013	- 31%	-30%	-30%	-59%	-42%

* The use of three significant figures in reporting ton-per-day estimates in the table should not be taken mean that the true CO inventory is known to the nearest ton per day. The true inventory is not known to even the nearest 100 tons per day. However, because MOBILE6 estimates emissions to the nearest ton, and the regulatory process demands this level of precision, we report all estimates to the nearest ton per day for comparison.

For all scenarios, estimates for CYs 1996 and 2001 are based on scenarios that include the I/M program, since the I/M program was actually in place during those years. Scenarios without I/M assume the program is removed only in future years. The I/M- and RSD-based forecasts are based on the conservative scenarios discussed in Section 6 of this report. The effect of oxyfuels is implicitly included in these scenarios, since the forecasts are based on CO data collected when oxyfuels were in use.

All of the forecasts predict substantial declines in CO emissions in 2013 when compared with the 2001 base year, and even more so relative to the 1996 base year in our estimates. This suggests that Denver will have no problem maintaining CO attainment in the long term, with or without an I/M program. The policy and regulatory question is whether phasing out the I/M program sooner could result in a violation of the CO standard during the next few years.

Based on our results, it seems unlikely that Denver will violate the CO standard at any time in the future, whether or not the I/M program is continued. Denver has been in attainment of the CO standard since 1995, so CO emissions from 1996 onward can be considered consistent with continued attainment of the standard. We estimate that light-duty tons-per-day CO emissions declined between 28 and 43 percent between 1996 and 2002 (based on remote sensing and I/M data, respectively). This suggests that CO emissions could increase by at least 39 percent above the level measured in 2002 without causing a violation of the CO standard.[8] Figures 6-15 and 6-16 show how much CO emissions would need to increase to return to mid-1990s levels. Our forecasts also project a 32 to 46 percent decline in CO emissions between 1996 and 2006 in the conservative, without I/M scenario, once again

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[8] This is based on the 28% reduction in CO emissions from 1996 to 2002 based on remote sensing (1/(1-0.28) = 1.39), meaning emissions would have to increase 39% above the 2002 level to return to the 1996 level, under similar meteorological conditions occurring during 2001-2002 (severe stagnation episodes can produce higher CO levels).

suggesting that CO emissions would continue to decline even without an I/M program (see Figures 6-15 and 6-16).

Our results also indicate that the oxyfuels program is not necessary for continued CO attainment. MOBILE6 projects that winter CO emissions would be about 10 percent higher without oxyfuels, which would result in CO emissions that are still much lower than emissions during the mid- to late-1990s (see Figure 6-19).

Our results differ substantially from the RAQC's forecasts based on MOBILE6. While we predict at least a 25 percent reduction in CO between 2001 and 2006 in our conservative, with-I/M scenario, MOBILE6 projects only a one percent decrease in CO emissions over the same period. It is implausible that differences between the MOBILE6 fleet and the light-duty fleet or the effect of cold starts could account for this difference, particularly because it is a difference in the rate of change in fleet emissions, rather than a difference in absolute emissions. For example, according to MOBILE 6, CO emissions of warmed-up light duty vehicles account for more than half of total on-road CO emissions. If we assume that these emissions decline 25 percent, then the only way to end up with roughly constant CO emissions overall would be for cold-start and heavy-duty emissions to increase by more than 25 percent.

A comparison of emission trends from 1996 to 2002 suggests that MOBILE6 does indeed underestimate the actual rate of decline in on-road CO emissions. As shown in Figure 6-19, MOBILE6 estimates that total CO emissions hardly changed from 1996 to 2001, even though both the I/M and on-road data show large reductions. Given that MOBILE6 is based on vehicle emissions data collected several years ago, along with many implicit assumptions of unknown validity that are hardwired into the model, it is seems likely that the problem is with MOBILE6, rather than with the on-road and I/M data, both of which would be expected to be more representative of the real world than the output of MOBILE6.

Another factor to consider is that the above forecasts of total emissions are somewhat misleading. CO levels in a given area depend mainly on local emissions rather than regional emissions. Thus, the key question for attainment is whether local emissions near any CO monitor will be high enough in the future to cause an exceedance of the CO standard. This depends mainly on future trends in traffic patterns and travel fractions in these locations, rather than on overall metropolitan growth. The CO monitors that register the highest CO readings tend to be in the more densely populated downtown area. Suburbanization in the outlying areas will increase regional VMT, thereby increasing the overall CO inventory, but this will affect CO levels in downtown areas only to the extent that traffic volumes and congestion increase in those areas. Thus, estimates of future CO levels are probably best attained through dispersion modeling in areas of concern, using realistic location-specific future emissions projections in those areas. Given ongoing reductions in CO emissions during the last few years, and continued improvement that we predict in coming years, future violation of the CO standard seems unlikely.

HC and NOx. The CDPHE has not yet released any HC and NO_x emissions forecasts based on MOBILE6, so we rely on our MOBILE6 runs for comparison with our forecasts based on I/M data. HC and NOx are of concern for their role as ozone and $PM_{2.5}$ precursors. This makes the situation more complicated than for CO, which is a local pollutant with a comparatively straightforward relationship between emissions and ambient levels. Ozone is also now a greater concern than CO for the Denver metro area, since ozone levels at some monitoring locations in the region are close to the 8-hour standard.

Ozone modeling is very complex and well beyond the scope of this study. We can only compare our forecasts based on I/M data with our MOBILE6 output, and raise key issues that Colorado should address in dealing with both the substantive and regulatory requirements relating to ozone attainment.

MOBILE6 predicts large HC reductions both in the short and long term. Our HC forecast is less sanguine, even with our optimistic scenario projecting greater emissions than MOBILE6. Nevertheless, even our conservative, without I/M scenario predicts that tailpipe HC emissions will decline both in the short and long term (see Figure 6-17). Both our forecasts and MOBILE6 project substantial declines in NOx both in the short and long term. However, on-road vehicle emissions are only a portion of the areawide HC and NOx emissions, and emissions from other sources may increase. Recent ambient data suggest that Denver runs a risk of violating the 8-hour ozone standard sometime within the next few years. Photochemical modeling will be necessary to understand the nature of the problem and to develop appropriate control programs.

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Appendix 4A

Conversion of Idle Emission Concentrations to IM240 grams per mile

The IM240 test measures CO, HC, and NOx emissions in grams per mile, and fuel economy in miles per gallon; however, the idle test measures only CO and HC emissions, in percent and parts per million (ppm) concentrations. In order to calculate mass emissions and emission reductions of vehicles given an idle test, we needed to convert the idle CO and HC emission concentrations to rough IM240 equivalents. In previous analyses, including the previous audit of the AIR program, researchers have converted idle emissions to IM240 or FTP equivalents based on correlation coefficients for a small number of vehicles tested on both types of tests (Sierra research, 1997; DeFries et al., 1999; AIR, 1999). There are several limitations with this approach, including the lack of data on a sample of Colorado vehicles tested on both types of test. Therefore, we compared the IM240 and idle test emissions trends by vehicle type and model year, and developed conversion factors that appeared to best "link" the trends of the two emission tests over model year 1971 to 2000 vehicles.

Figures 4A-1 through 4A-6 show how we developed six conversion factors to convert 2500 rpm idle test emissions to mass-based IM240 emissions. Each figure shows the initial test emissions by vehicle type and model year (in the figures 1966 is all 1966 and older vehicles). 2500 rpm idle emissions for 1981 and older vehicles are on the left scale, and IM240 emissions for 1982 and newer vehicles are on the right scale. The curved trendline is the polynomial fit of the IM240 emissions extended back to model year 1966. In each figure the right IM240 scale has been adjusted so that the idle and IM240 emissions trends by model year approximately line up; the resulting adjustment factors are listed on each figure. The dashed lines represent changes in I/M cut points by model year. One would expect that changes in cut points would not affect the trends in average initial emissions, but there do seem to be cases where a cut point change appears to affect the emission trend. Figures 4A-5 and 4A-6 show the method to estimate IM240 emissions for heavy trucks. Because no heavy-duty vehicles are given an IM240 test, we used the trend in light-duty truck IM240 emissions as a basis for developing the conversion factors for heavy-duty trucks.

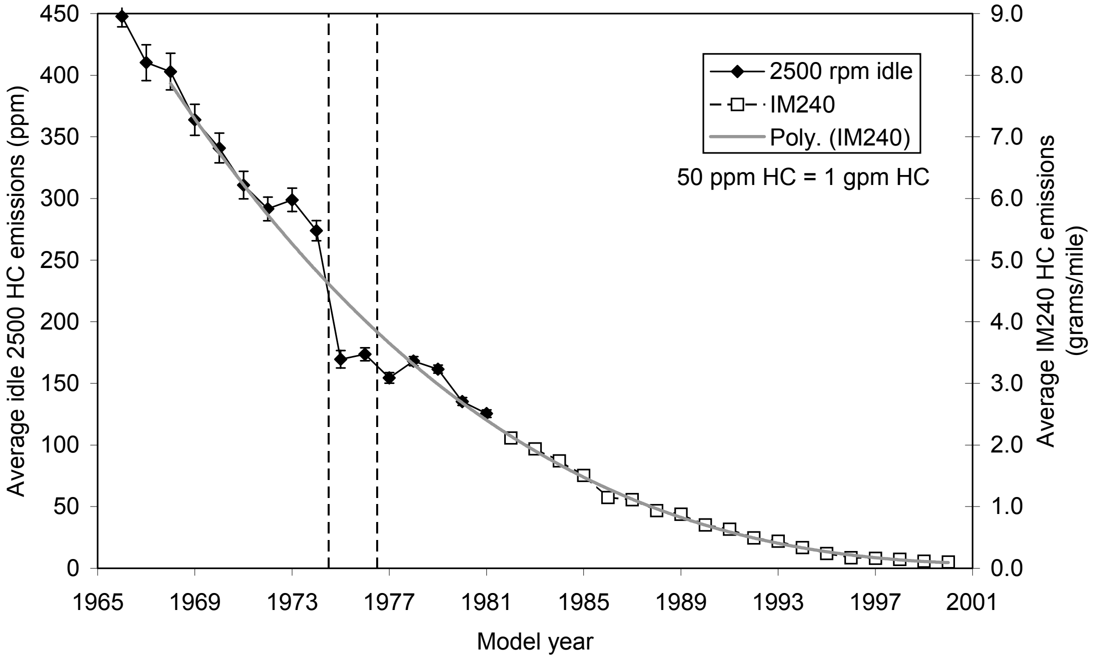

Figure 4A-1. Trend in initial car HC emissions by I/M test type and model. The factor used to convert car idle HC emissions to IM240 equivalents is shown.

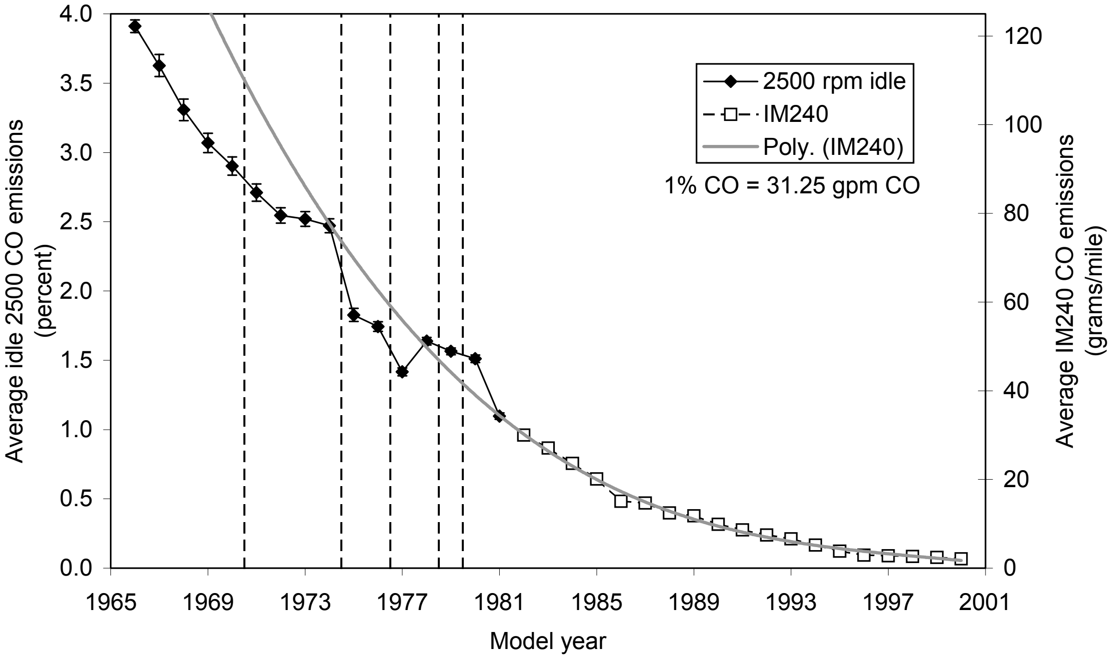

Figure 4A-2. Trend in initial car CO emissions by I/M test type and model. The factor used to convert car idle CO emissions to IM240 equivalents is shown.

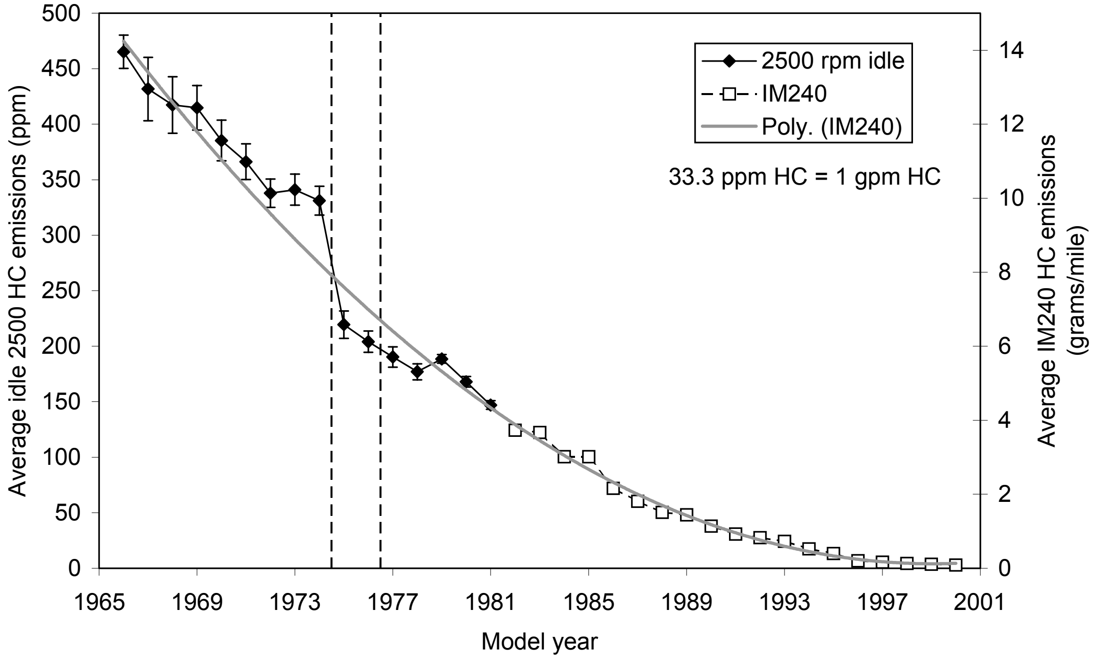

Figure 4A-3. Trend in initial light truck HC emissions by I/M test type and model. The factor used to convert light truck idle HC emissions to IM240 equivalents is shown.

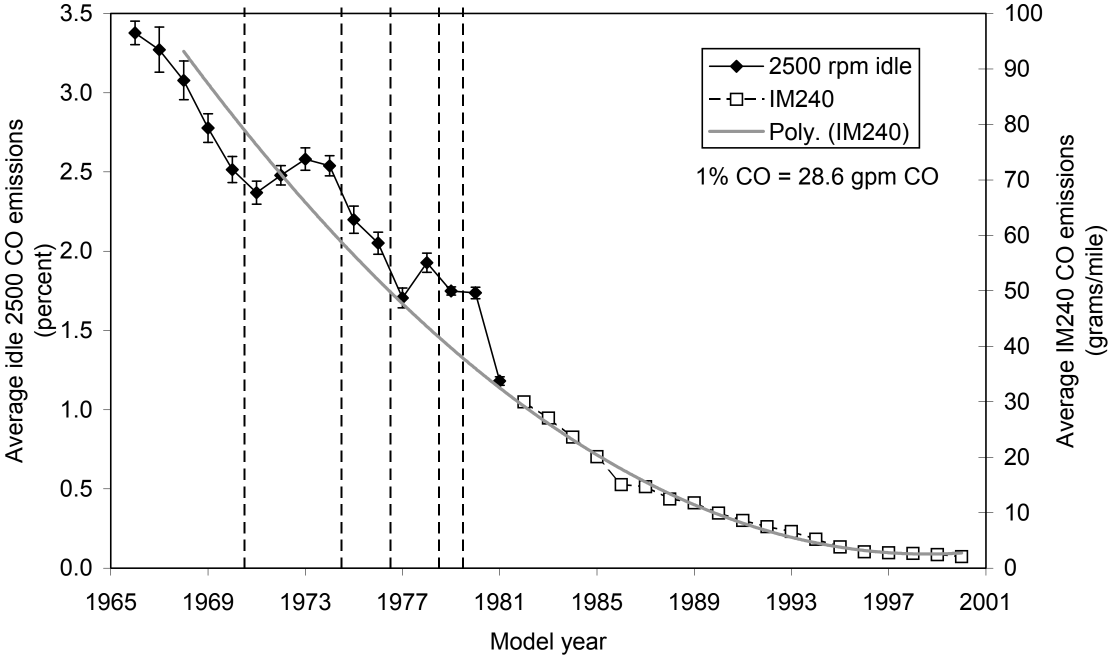

Figure 4A-4. Trend in initial light truck CO emissions by I/M test type and model. The factor used to convert light truck idle CO emissions to IM240 equivalents is shown.

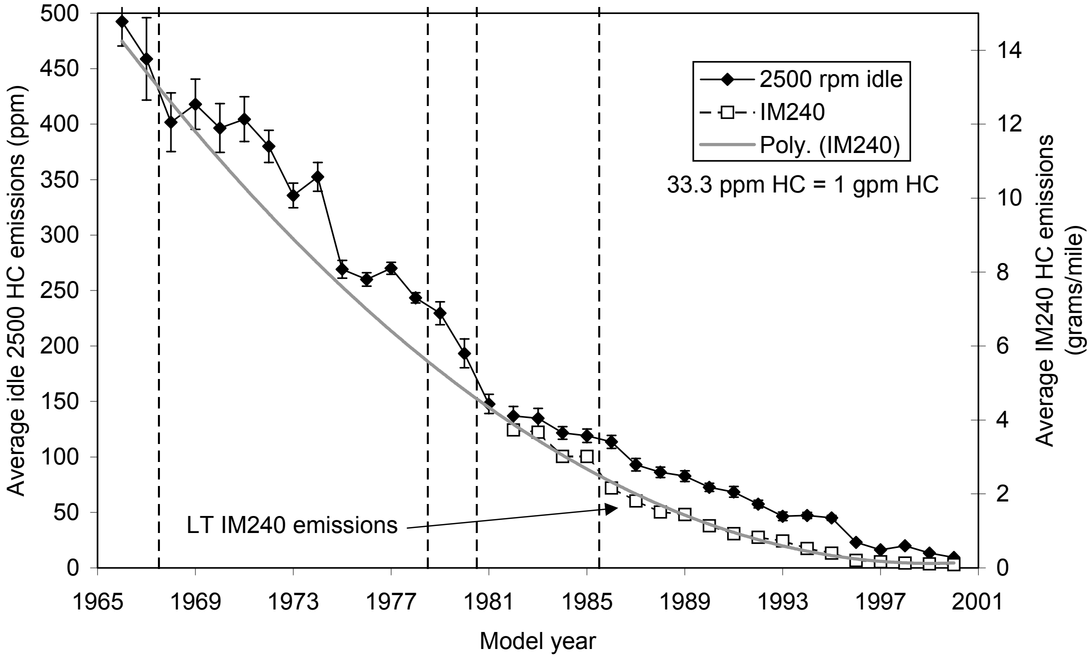

Figure 4A-5. Trend in initial heavy truck HC emissions by I/M test type and model. The factor used to convert heavy truck idle HC emissions to IM240 equivalents is shown.

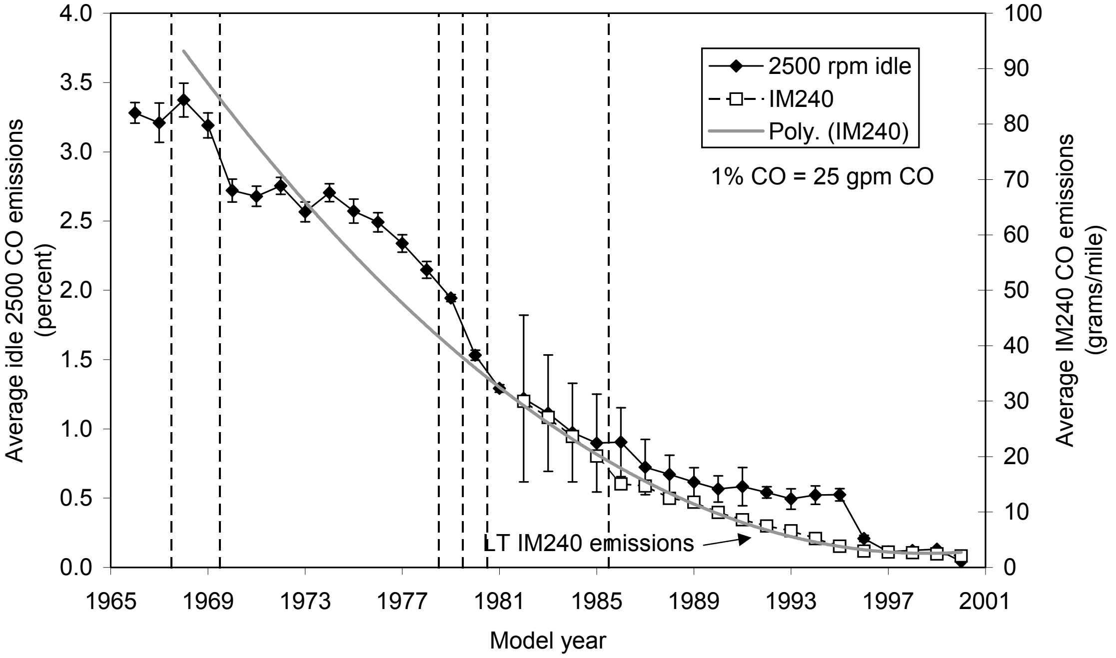

Figure 4A-6. Trend in initial heavy truck CO emissions, by I/M test type and model. The factor used to convert heavy truck idle CO emissions to IM240 equivalents is shown.

This method appears to be a reasonable approach to estimating the IM240 emissions of vehicles given an idle test. However, there are a few troubling aspects with the approach. First, note the large drop in CO idle emissions between model year 1980 and 1981 cars and trucks, which makes it difficult to line up the two emissions trends. The idle I/M cut points did not change between these two model years, and, although new vehicle certification standards were drastically reduced for model year 1980, there was no change for model year 1981 vehicles. Second, emissions appear to continue to increase with older technology. This is contrary to the conventional wisdom that at some age the emissions tend to level off, as the remaining older vehicles on the road are as well-built and –maintained as newer technology vehicles. However, the figures do not suggest a leveling off of emissions due to this vehicle "survivor" effect. This could be because the I/M data include vehicles that are driven very rarely, and are not measured in remote sensing studies or recruited in dynamometer testing studies that have suggested this indication of the survivor effect.

The six conversion factors we developed are shown in the figures. Each factor was applied to all idle emission rates for that pollutant and vehicle type, regardless of model year or I/M result. Because the six factors were applied to both initial and final emissions results, use of the factors will not affect the percent change in emissions from idle testing. However, they will affect the absolute level of emissions, and therefore the estimate ton per day benefit of the AIR program. Because the idle test does not measure NOx emissions, or emissions in terms of mass, we could not estimate changes in NOx emissions or fuel consumption for light-duty vehicles older than model year 1982, and all heavy-duty vehicles.

Appendix 4B

Assessment of Accuracy of ESP Method to Adjust Fast-Pass Emissions to Full IM240 Emissions

Clean vehicles can be passed after only 30 seconds of testing on the IM240. ESP has developed software to project what the emission rates of "fast-pass" vehicles would be if they were tested over a full IM240 test. The fast-pass feature was disabled for all vehicle tests conducted for a period of several months in early 1996. We compared the January 1996 measured full-test emissions of these vehicles with the projected full-test emissions of fast-pass vehicles, by vehicle type and model year, to assess the accuracy of the ESP projection. Figure 4B-1 shows the ratio of projected emissions of fast-pass cars to the measured emissions of passing cars given a full IM240 test; Figure 4B-2 shows the comparable ratios for light trucks. The figures indicate that the projected emissions from fast-pass results: consistently overstate measured full IM240 car CO emissions across all model years (ranging from 5% to 20%, for individual model years); consistently understate fuel economy (or overstate fuel use) by 25% to 30% for cars and light trucks; overstate CO emissions for older light trucks (by as much as 30%); and understate CO for newer light trucks (by as much as 20%). The projected emissions from fast-pass results tend to understate HC and NOx emissions for both car and light trucks, with the percent difference greater for newer model years.

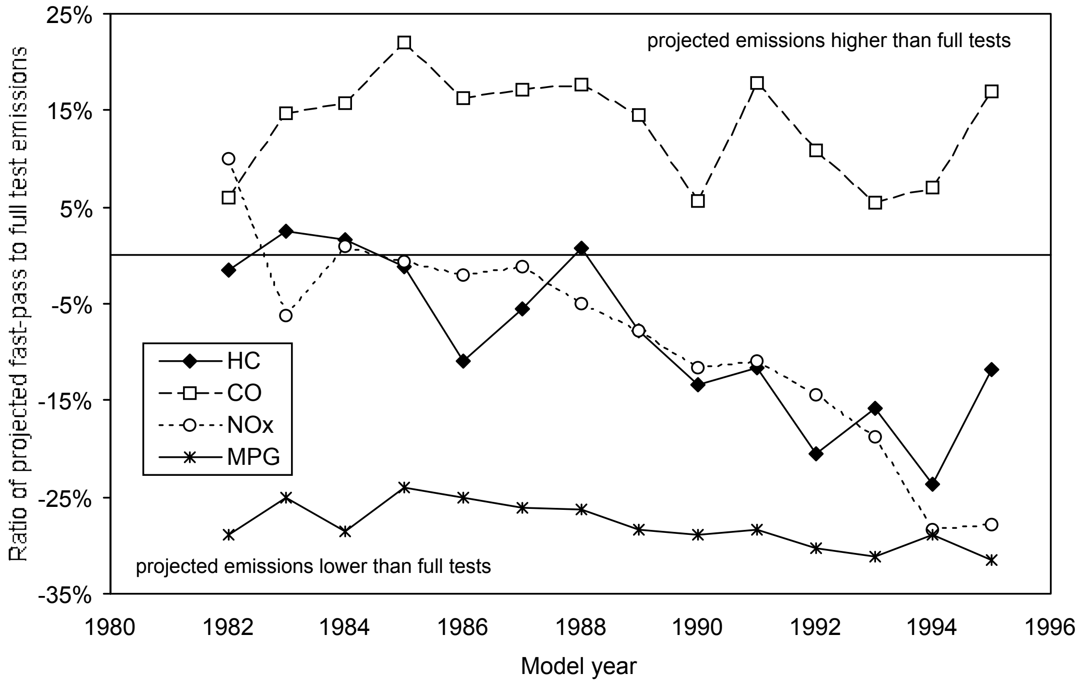

Figure 4B-1. Ratio of projected fast-pass emissions to full test emissions, passenger.

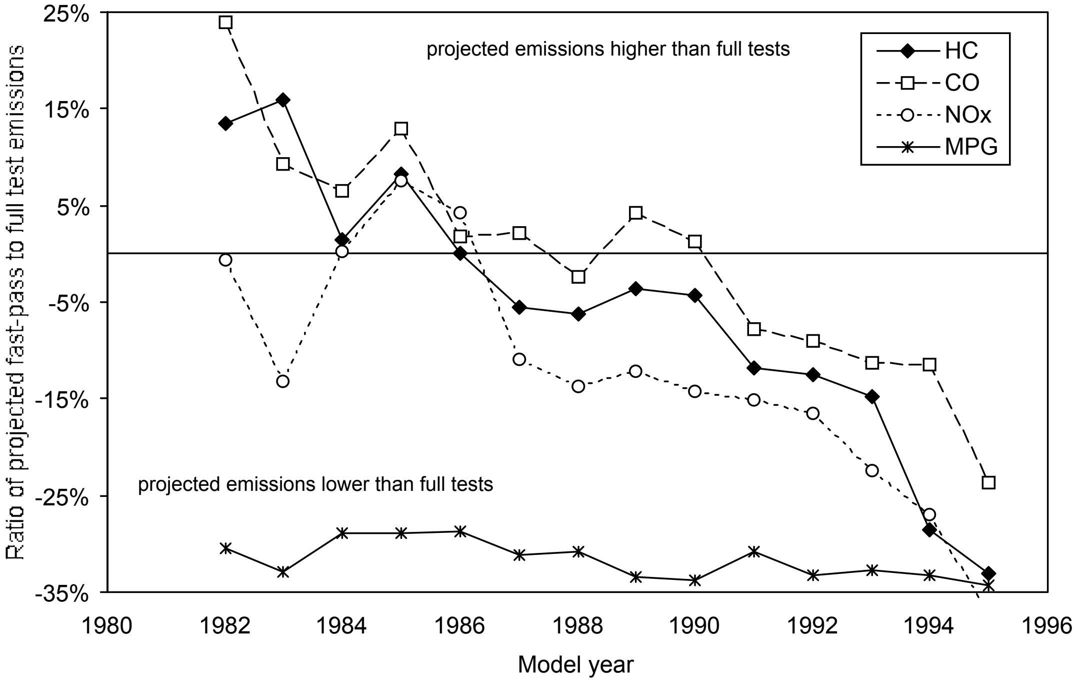

Figure 4B-2. Ratio of projected fast-pass emissions to full test emissions, light trucks.

Because all failing vehicles are tested over the full IM240 cycle, these inaccurate predictions based on fast-pass results are not causing vehicles to be falsely failed in the AIR program. However, if the pass/fail decision is based on the projected fast-pass emissions results, then the inaccuracy in the prediction could be resulting in the program falsely passing a number of vehicles with marginally high emissions. In addition, inaccurate predictions of the full test emissions of fail-pass vehicles, which account for most of the vehicles tested, will bias our estimates of the benefits of the I/M program. In particular, the consistently high over-prediction of car CO emissions suggests that our estimate of program benefits overstates the CO benefit from cars.

Appendix 4C

ESP vs. UD Remote Sensing Measurements of On-road Emissions

There currently are two major sources of remote sensing measurements in the Denver area: several years of measurements made by the University of Denver at two sites, and several years of measurements made by the I/M program contractor, ESP, at multiple sites in the Enhanced I/M area. The ESP measurements were requested by CDPHE to fulfill EPA's requirement that 0.5% of the Enhanced I/M on-road fleet be measured every year, and used to evaluate the effectiveness of the I/M program in reducing on-road emissions. (A planned remote sensing clean screen program in the enhanced I/M area has not yet been initiated.) We originally hoped to combine these existing data sets to obtain remote sensing measurements of enough vehicles to discern an impact of pre-inspection maintenance in the few weeks before a scheduled I/M test on on-road emissions. We compared remote sensing measurements made in 2000 by each source to determine if they were comparable, and could be combined for our analysis.

Figures 4C-1 through 4C-3 compare the remote sensing emissions measurements made by UD and ESP in 2000. The UD measurements were made in January 2000, while the ESP measurements were made throughout the year, so the vehicles of any given model year measured by ESP were on average five months older than the vehicles measured by UD. Therefore, one would expect the ESP measurements to be slightly higher than the UD measurements. The UD measurements were made at two sites, whereas the ESP measurements were made at several sites throughout the enhanced I/M area. Figure 4C-1 indicates that car CO emissions from the two sources are quite similar; however, ESP reports lower emissions for older cars, and higher emissions for newer cars, than UD. The differences in the emissions of new cars are statistically significant. Figures 4C-2 and 4C-3 indicate that the ESP HC emissions are substantially lower, and the ESP NOx emissions substantially higher, than the UD emissions. Figures 4C-4 through 4C-6 illustrate a similar comparison for light trucks. The figures suggest that the differences between measurement sources for trucks, although still substantial, are smaller than observed for cars.

UD has reported a drift in the HC channel of their remote sensing instrument that causes HC emissions to have a constant offset for each measurement on a particular day. The degree of offset differs by measurement day. UD has developed an approach to correct of this offset; however, performing such a correction was not feasible given the time constraints of this audit. Another possible explanation of the differences in emissions is that each organization uses a different technology to measure NOx emissions.

We decided to use the ESP emissions measurements to estimate the benefit from pre-inspection repairs, and the short-term deterioration of emissions after repair, simply because there were more ESP measurements available. However, we did separate analyses using the UD measurements as well; for the most part, the analyses utilizing the UD measurements obtained similar results to those using the ESP measurements. We did use the UD measurements to identify vehicles being driven in the enhanced I/M area, as part of our estimate of the fraction of no-final-pass vehicles that continued to be driven after failing their enhanced I/M test.

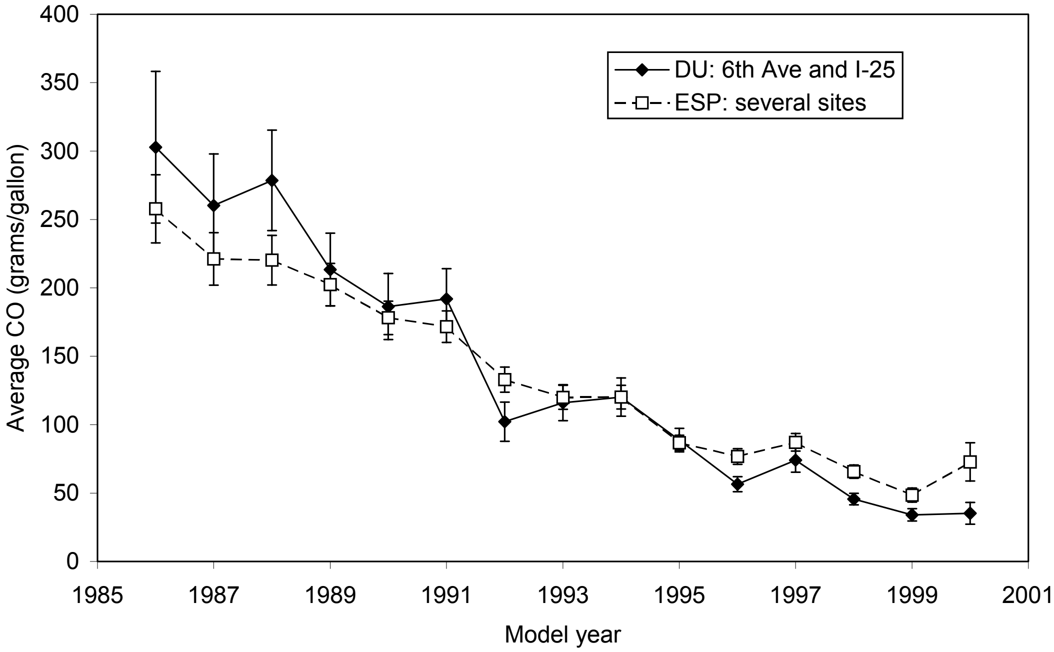

Figure 4C-1. Remote sensing CO emissions in 2000 by source and model year; cars with VSP 5 to 25 kw/tonne.

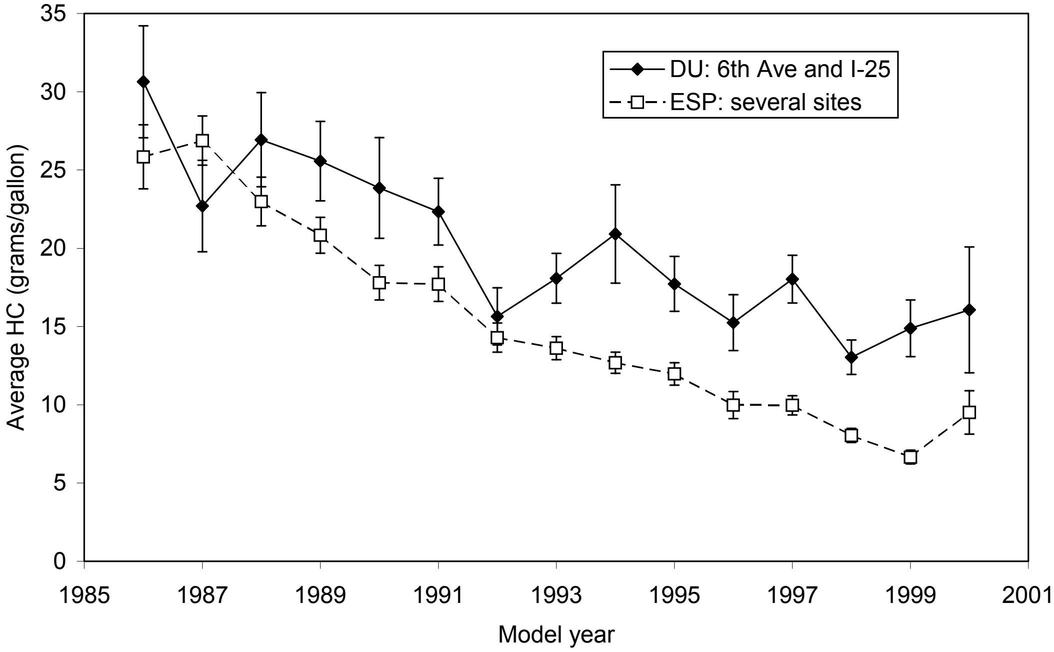

Figure 4C-2. Remote sensing HC emissions in 2000, by source and model year; cars with VSP 5 to 25 kw/tonne.

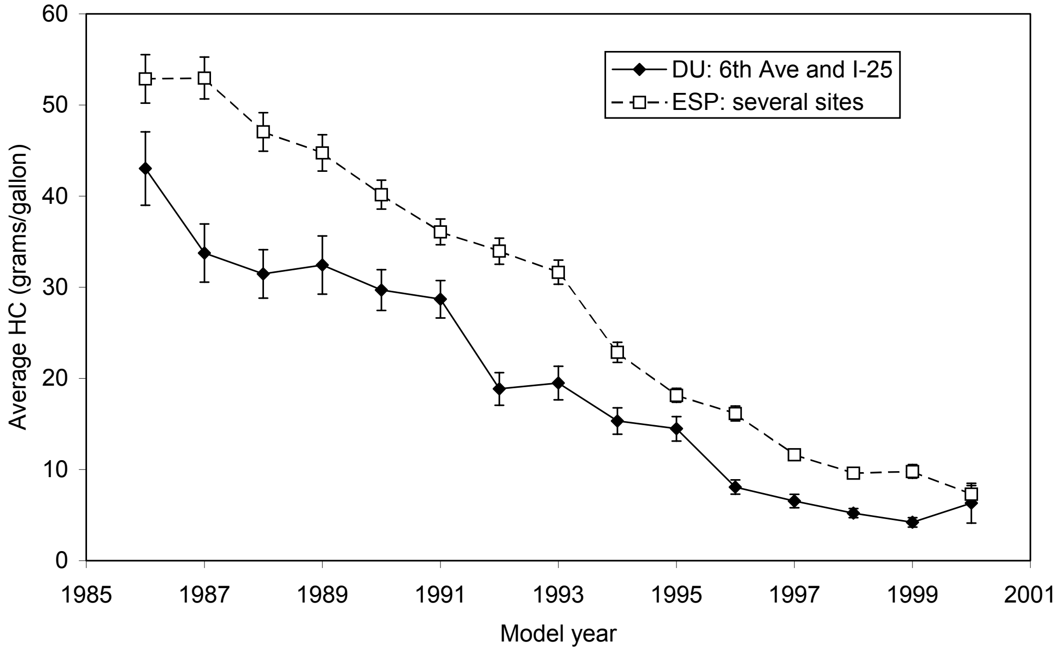

Figure 4C-3. Remote sensing NOx emissions in 2000, by source and model year; cars with VSP 5 to 25 kw/tonne.

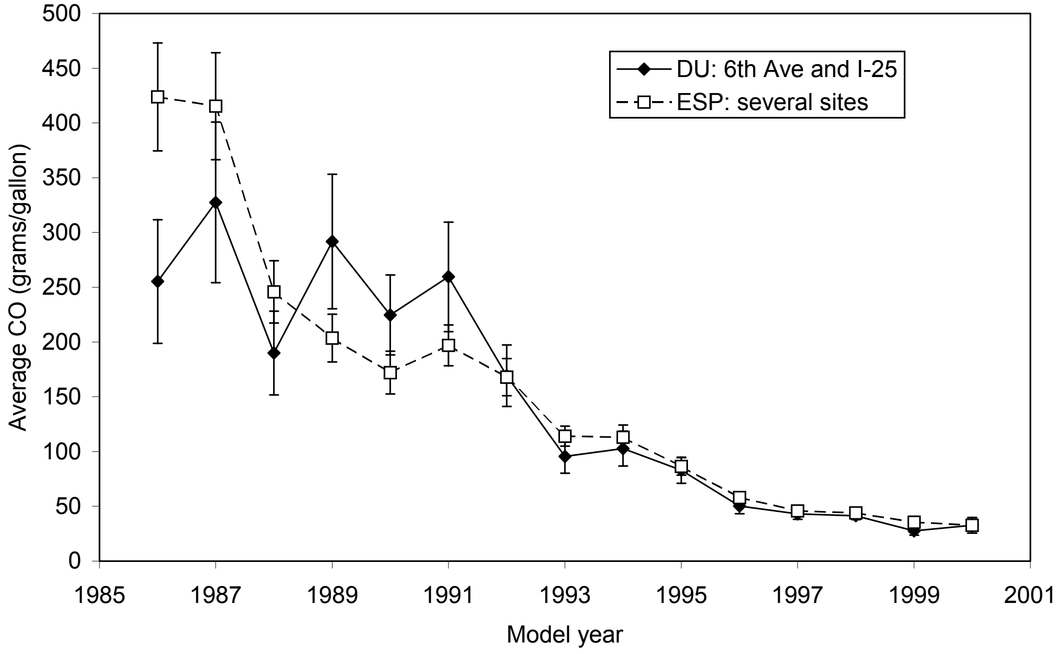

Figure 4C-4. Remote sensing CO emissions in 2000, by source and model year; light trucks with VSP 5 to 25 kw/tonne.

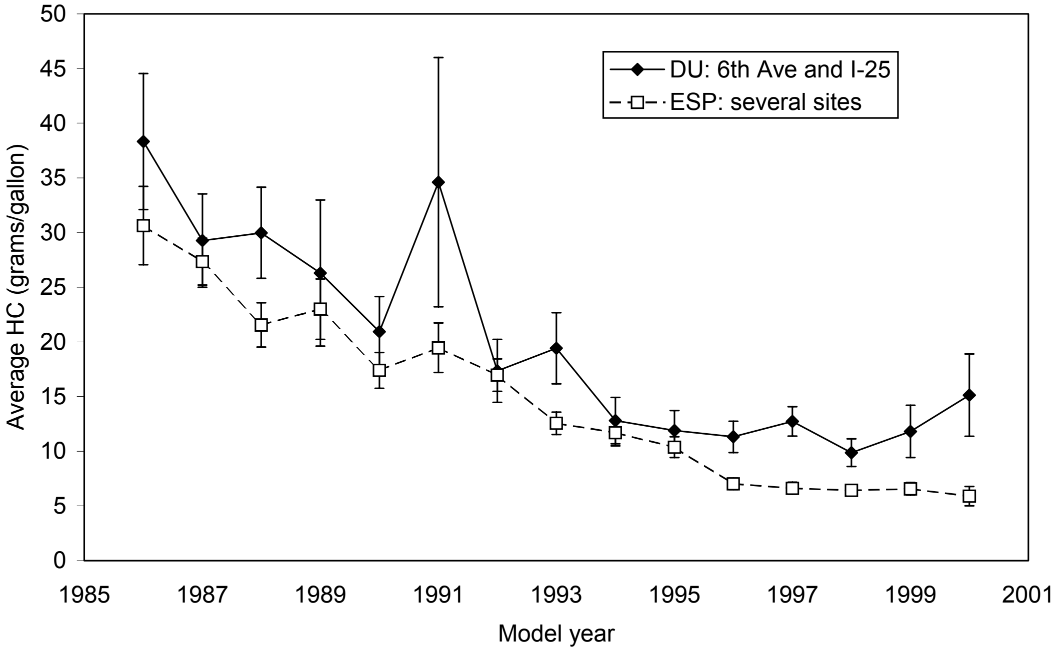

Figure 4C-5. Remote sensing HC emissions in 2000, by source and model year; light trucks with VSP 5 to 25 kw/tonne.

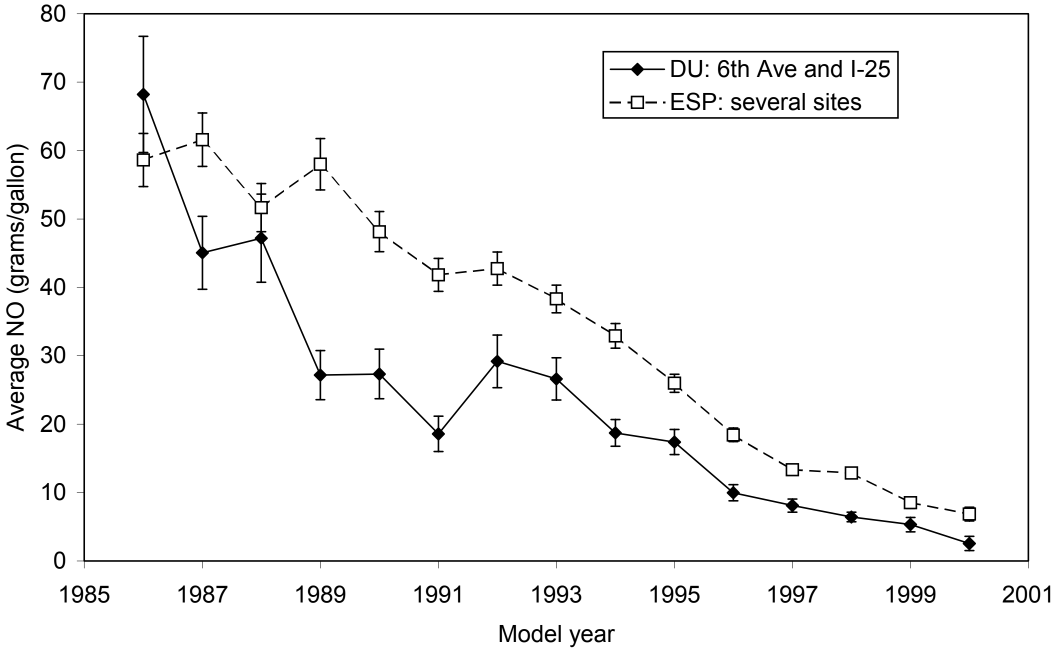

Figure 4C-6. Remote sensing NOx emissions in 2000, by source and model year; light trucks with VSP 5 to 25 kw/tonne.

Appendix 7A

Repair Costs

According the test records received from CDPHE, the total number of vehicles that failed the AIR test in 2000 was 79,779; of those 25,727 were tested and failed an idle test; 54,036 failed the IM240 test. All vehicles that failed and returned for retesting were required to turn in a form detailing repairs made and the associated costs. However, only 10% of vehicles retested turned in forms with cost information. Table 7A-1 shows the reporting rate for costs of repair by model year. It also shows the proportion of forms on which $0 costs were reported.

Summary of some findings from analysis of the repair cost dataset.

1. About 27% of repairs were done by owner. Reported costs are lower for repairs done by owner.
2. The repair form includes a box that allows owners/mechanics to check if any repairs were done under warranty. Repairs done under warranty should be at no cost to the motorist. However, of all 1999 and 2000 reported data from the forms, only 2.2 % report repairs done under warranty, and, of those, almost all report some costs.
3. Of all of the repair records in 2000 and 1999, about 10% report repair costs (see table 7A-1). Of those that report costs, about 17% are zero costs. Of the non-zero costs, about 2.6% have repair costs greater than $1,000, and about 85% have costs that are less than $450.
4. Some of the vehicles that never have a passing test record (the so-called "no final pass vehicles") do go through one or more rounds of repair and retesting. We examined the CO reductions reported for those vehicles, and find that virtually none occurred, so no emissions benefits are assumed for those vehicles. However, repair costs are reported, but they appear not have successfully reduced emissions. Repair costs on these vehicles are lower on average than they are on the vehicles that fail and then eventually pass the test.

Table 7A-1. Repair costs of Denver I/M Program, reporting frequency by model year.

Model Year	% Non-Reporting	Zero Costs as % of all Reporting
1966	95%	32%
1967	94%	28%
1968	96%	19%
1969	94%	32%
1970	96%	43%
1971	95%	30%
1972	95%	27%
1973	95%	17%
1974	94%	28%
1975	93%	34%
1976	94%	26%
1977	94%	37%
1978	95%	27%
1979	94%	31%
1980	94%	33%
1981	92%	29%
1982	87%	0%
1983	89%	0%
1984	87%	0%
1985	88%	0%

Model Year	% Non-Reporting	Zero Costs as % of all Reporting
1986	87%	0%
1987	88%	0%
1988	86%	0%
1989	88%	0%
1990	87%	0%
1991	88%	1%
1992	87%	0%
1993	89%	1%
1994	88%	0%
1995	89%	0%
1996	89%	0%
1997	93%	0%
1998	94%	0%
1999	95%	6%
2000	99%	0%
2001	100%	

Appendix 7B

Costs of Removed Vehicles

One of the important ways emissions are reduced in the AIR program is that some motorists with vehicles that fail the IM test, and cannot reduce emissions enough to pass without large repair expenditures, elect to sell the vehicle outside the enhanced IM region. In the emission reduction section in the text, we describe our estimate of the number of vehicles in 2000 for which this was true in the Denver region. There are costs associated with this loss in vehicles, as described in Chapter XX in the text. This Appendix provides more detail on the methods and data used to estimate those costs.

If a vehicle fails the IM test, the expenses required to enable the vehicle to pass may be greater than the value of the vehicle. In this case, the motorist may elect to sell the vehicle for what he can get for it, which we take to be, on average, the trade-in value at a dealership. The loss in value because of the I/M test is then the difference between the retail and trade-in value of the vehicle.

The "Black Book" provides estimates of used vehicle prices based on auction and market data. The Black Book includes estimates of both the trade-in and retail values of particular vehicles in excellent, average and rough condition for model years 1989 and newer for the Denver region. We used a number of specific vehicle types over five model years, 1989 - 1993, and found the retail and trade-in values for vehicles in rough condition. We thought it likely that vehicles failing their IM test and traded out of the region would fall into the "rough condition" category. The average difference is about $1100, as shown in Table 7B-1 for a sample of four different vehicles. The averages differences in values for light trucks were similar to those shown for passenger cars.[1]

We extrapolated these results back to earlier years using an exponential function, since on average older vehicles have lower value and thus a lower proportionate difference between retail and trade-in value (there was no data from Black Book before the 1989 model year). The function is shown in Figure 7B-1. These differences in value are multiplied by the number of vehicles estimated to be sold outside the region for each model year. We assume that none of the vehicles sold outside the region will be newer than 1992 model year.

Table 7B-1. Sample data from Black Book, for the Denver area – ZIP code 80202. http://www.cars.com/advice/advice_carprices.jhtml?aff=denver

Rough Condition		Cars			
MY	**Type**	**Mileage**	**Trade-In**	**Retail**	**Diff**
1989	Acura HB	130,000	450	1450	1000
1989	Buick Century	130,000	400	1475	1075
1989	Chevy Caprice	130,000	375	1525	1150
1989	Toyota Camry	130,000	250	1325	1075
1990	Acura HB	120,000	830	1900	1070
1990	Buick Century	120,000	425	1500	1075
1990	Chevy Caprice	120,000	450	1600	1150
1990	Toyota Camry	120,000	350	1425	1075
1991	Acura HB	110,000	1225	2375	1150

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[1] We were able to find no data on heavy trucks, so we had to use the same estimate per vehicle for them as for cars and light trucks.

Rough Condition		**Cars**			
MY	**Type**	**Mileage**	**Trade-In**	**Retail**	**Diff**
1991	Buick Century	110,000	585	1725	1140
1991	Chevy Caprice	110,000	780	2000	1220
1991	Toyota Camry	110,000	450	1525	1075
1992	Acura HB	110,000	1345	2500	1155
1992	Buick Century	110,000	780	1925	1145
1992	Chevy Caprice	110,000	1420	2725	1305
1992	Toyota Camry	110,000	1175	2400	1225

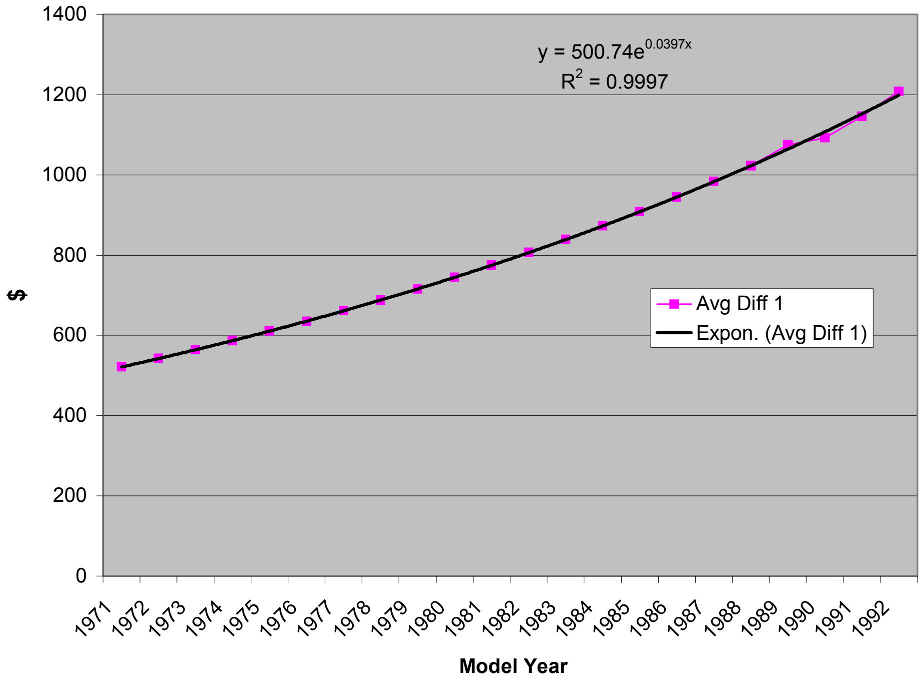

Figure 7B-1. Average difference in trade-in value and retail value – Cars.

Appendix 8A

Costs and Cost Effectiveness Estimates for Remote Sensing Based High Emitter Identification Programs under Different Assumptions

Table 8A-1. RSD HEI program under different assumptions; 50% coverage.

	Best	**Optimistic Estimate**	**Pessimistic Estimate**
No of Registered Vehicles = 1.7 M; 50% Coverage			
Needed number of readings to get 50% coverage – min. of 1 reading	2.2	2	3
Number of valid and matched readings needed	1,909,052	1,735,502	2,603,253
average % of readings that are valid and matched	50%	75%	40%
Total measurements needed	3,818,104	2,314,003	6,508,133
% of vehicles failing either HC or CO RSD cutpoints	2.00%	2.00%	2.00%
Number of vehicles failing RSD	17,355	17,355	17,355
Of RSD failing, number recruited for testing	12,149	13,884	8,678
Number of vehicles failing IM240 test	9,719	12,496	4,339
Emissions reduction, g/mile HC/veh	2.58	2.58	2.58
Emissions reduction g/mile CO/veh	36	36	36
Total tons HC reduced	305	392	136
Total tons CO reduced	4,259	5,475	1,901
Costs (1,000s except where indicated**)**			
Administration, notification, enforcement	$347	$278	$417
Total inspection costs	$304	$347	$304
Total motorists costs	$77	$88	$55
Total repair costs net of fuel savings	$1,093	$1,406	$488
Cost per valid and matched reading	$0.90	$0.50	$1.00
Total costs of obtaining readings	$1,718	$868	$2,603
Total cost ($/year)	$3,540	$2,813	$3,867
Cost-Effectiveness			
Cost per ton HC	$11,603	$7,172	$28,391
Cost per ton HC + CO/60	$9,413	$5,818	$23,034
Cost per ton CO	$831	$514	$2,034

Table 8A-2. Remote Sensing HEV Identification, with Scrap Program - Alternative to AIR Program. (Vehicle owners are offered $1,000 if they scrap their vehicle.)

Best RSD program assumed, 50% coverage	**5% scrap rate**	**10% scrap rate**	**20% scrap rate**
Costs			
No of Registered Vehicles	1,735,502	1,735,502	1,735,502
Coverage of X% of fleet	867,751	867,751	867,751
Needed number of readings to get X% coverage - min of 1 reading	2.2	2.2	2.2
Number of valid and matched readings needed	1,909,052	1,909,052	1,909,052
avg % of readings that are valid and matched	50%	50%	50%
Total measurements needed	3,818,104	3,818,104	3,818,104
Cost of administration	$694,201	$694,201	$694,201
Cost per valid and matched reading	$0.90	$0.90	$0.90
Total costs	$1,718,146.98	$1,718,146.98	$1,718,147
% of vehicles failing RSD cutpoints - HC or CO	2.00%	2.00%	2.00%
Number of vehicles failing RSD	17,355	17,355	17,355
Of RSD failing, number of vehicles brought in	12,149	12,149	12,149
Number of vehicles failing IM240	9,719	9,719	9,719
Of failing vehicles, % who elect to scrap	0.05	0.10	.020
Of failing vehicles, % who elect to repair	0.95	0.90	.80
Number of vehicles scrapped	486	972	1944
Number of vehicles repaired	9,233	8,747	7,775
Emissions reduction, repaired, g/mile HC/veh	2.58	2.58	2.58
Emissions reduction, repaired, g/mile CO/veh	36	36	36
Total tons HC – repair	290	275	244
Total tons CO – repair	4,046	3,833	3,407
Emissions reduction, scrapped vehicles, g/mile HC/veh	5.56	5.56	5.56
Emissions reduction, scrapped vehicles, g/mile CO/veh	72.35	72.35	72.35
Total tons HC – scrap	33	66	132
Total tons CO – scrap	428	856	1,712
Total cost of scrapped vehicles	242,975	485,941	971,900
Fuel economy savings due to scrap (232 gallons)	$169,111	$338,215	$676,442
Inspection costs	$25	$25	$25
Total inspection costs	$303,725	$303,713	$303,275
Total motorists costs	$77,268	$77,265	$77,268
Total Repair Costs net of fuel savings	$1,038,718	$984,030	$874,710
Total cost ($/year)	$3,905,923	$3,925,081	$3,963,508
Total Tons reduced HC	323	339	376
Total tons reduced CO	4,474	4,689	5,119
Total costs/ton HC	$12,104	$11,533	$10,552
Total costs/ton Ozone precurs.	$9,832	$9,379	$8,599
Total cost/ton CO	$873	$837	$774

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