Fuel-Based On-Road Motor Vehicle Emissions Inventory for the Denver Metropolitan Area

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ABSTRACT

Emission inventories from mobile sources have traditionally been obtained through computer modeling. This method, however, has intrinsic shortcomings in that ideal factors are included while real-world observations are left out. The model predictions have not correlated well with measurements from several studies. Recently, a fuel-based method of obtaining on-road emissions inventories has been developed. This technique calculates emission factors in grams of pollutant per unit of fuel used (kg, gallons or L) from remote sensing measurements. Combining these factors with fuel use data, available from tax records, yields a fuel based emission inventory. We have used this routine to calculate the CO, HC and NO on-road emissions inventories for the Denver Metropolitan area during several years when the enhanced I/M program has been in place. Our calculations indicate that the inventories are smaller than predicted by the MOBILE5b model and that emission reductions are not as extensive as modeled.

INTRODUCTION

In order better to monitor and control air pollution it is essential that one correctly designate the sources of pollution. An emission inventory does just that by assigning a specific quantity of pollutant to a source or set of sources. As of 1998, on-road vehicles were believed to be the single largest source for the major atmospheric pollutants, contributing 60% of the carbon monoxide (CO), 44% of the hydrocarbons (HC), and 31% of the oxides of nitrogen (NO_x) to the national emission inventory.[1] Thus, an assessment of emissions from motor vehicles is crucial to understanding the air quality of a given region.

Until recently, motor vehicle emission inventories have been travel-based; that is, they have been calculated from computational models that use vehicle activity data and mass per distance emissions factors from limited dynamometer testing. While the models may help obtain inventories rather quickly, their accuracy remains uncertain. The predictions from these models do not correlate well with on-road or ambient air data.[2] It has thus become imperative that a separate method be utilized to obtain independent assessments of emission inventories. The use of on-road remote sensing emissions data to obtain a fuel-based inventory is an ideal alternative. Such an assessment of the emission inventory would be based much more on data and less on model predictions.

Remote sensing involves measurement of emissions from a large, random sample of vehicles on the road. These qualities eliminate many of the biases seen with the travel-based approach. The vehicle sample is more representative with remote sensing because all types of vehicles that are on the roads are measured randomly. For example, with the travel-based approach, vehicle mileages are estimated from the registered fleet, and one can imagine that the dynamometer testing procedure would leave out many high-emitting vehicles which would not volunteer for emissions testing. In remote sensing data high emitting vehicles are weighted according to their presence on the road. Furthermore, remote sensing measures emissions of vehicles as they drive on the road; a range of speeds and loads is sampled and real-world emission measurements are obtained. Also with remote sensing, a proportionate picture of the relative activity of sub-sets of vehicles is obtained since the frequency of measurement is the frequency of travel. Finally, remote sensing is fuel-based in that emissions are measured in pollutant per amount of fuel. This type of measurement is less dependent on engine speed and load compared to a travel-based approach with measures in amount of pollutant per distance.[2,3]

Singer and Harley[2] have proposed a methodology for obtaining fuel-based emission inventories using remote sensing data. Emission rates for individual vehicles are obtained directly from remote sensing pollutant ratios. These grams of pollutant per gallon of fuel (or grams per kg) values are averaged for subgroups of vehicles to obtain emission factors for the subgroups. The factors for each subgroup are weighted by the fraction of total fuel used by that subgroup to obtain an overall fleet emission factor. This value is then multiplied by amount of fuel sold to obtain an emission inventory.

The remote sensor used in this study (FEAT) was developed at the University of Denver for measuring the pollutants in motor vehicle exhaust, and has previously been described in the literature.[4,5] The instrument consists of a non-dispersive infrared (IR) component for detecting carbon monoxide, carbon dioxide (CO_2), and hydrocarbons, and a dispersive ultraviolet (UV) spectrometer for measuring nitric oxide. The exhaust plume path length and density of the observed plume are highly variable from vehicle to vehicle, and are dependent upon, among other things, the height of the vehicle's exhaust pipe, wind, and turbulence behind the vehicle. For these reasons, the remote sensor can only directly measure ratios of CO, HC or NO to CO_2. The ratios of CO, HC, or NO to CO_2, termed Q, Q' and Q'' respectively, are constant for a given exhaust plume, and on their own are useful parameters for describing a hydrocarbon combustion system. The instrument reports measured emissions as %CO, %HC and %NO in the exhaust gas, corrected for water and excess oxygen not used in combustion. However, these percent emissions can be directly converted into mass emissions per gallon or kilogram of fuel used. We now prefer to use the g/kg of fuel conversion since they do not require any assumptions about the fuel density. These equations are:

$$
\begin{aligned}
\frac{gCO}{kgFUEL} &= \frac{28\times\frac{\%CO}{\%CO_2}}{\frac{\%CO}{\%CO_2}+1+(3\times\frac{\%HC}{\%CO_2})}\times(\frac{1}{0.014}) \\
\frac{gHC}{kgFUEL} &= \frac{44\times\frac{\%HC}{\%CO_2}}{\frac{\%CO}{\%CO_2}+1+(3\times\frac{\%HC}{\%CO_2})}\times(\frac{1}{0.014}) \qquad (1) \\
\frac{gNO}{kgFUEL} &= \frac{30\times\frac{\%NO}{\%CO_2}}{\frac{\%CO}{\%CO_2}+1+(3\times\frac{\%HC}{\%CO_2})}\times(\frac{1}{0.014})
\end{aligned}
$$

where the 28, 44 and 30 are grams/mole for CO, HC (as propane) and NO, respectively, and 0.014 is the kg of fuel per mole of carbon assuming gasoline is stoichiometrically CH_2. It turns out that g/kg of fuel calculations are very insensitive to the small changes observed in the carbon to hydrogen ratio because in all cases the majority of the fuel mass is the (measured) carbon component.

Studies sponsored by the California Air Resources Board and General Motors Research Laboratories have shown that the remote sensor is capable of CO measurements that are correct to within ±5% of the values reported by an on-board gas analyzer, and within ±15% for HC.[6,7] The NO channel used in this study has been extensively tested by the University of Denver, but we are still awaiting the opportunity to participate in an extensive blind study and instrument intercomparison to have it independently validated. Tests involving a late-model low-emitting vehicle indicate a detection limit (±3) of 25 ppm for NO, with an error measurement of ±5% of the reading at higher concentrations.

The remote sensor is accompanied by a video system to record a freeze-frame image of the license plate of each vehicle measured. The emissions information for the vehicle, together with a time and date stamp, are also recorded on the video image. The images are stored on videotape, so that license plate information may be incorporated into the emissions database during post-processing. A device to measure the speed and acceleration of vehicles driving past the remote sensor is also used.

Remote sensing has shown that a few very high-emitting vehicles dominate the fleet emissions.[8] Furthermore, it has been shown that emission rates are not necessarily a function of vehicle age but more a function of vehicle maintenance; an old model year car that has been well taken care of still emits as little as it did new, but a new vehicle whose oxygen sensor is broken may be high-emitting.[9] For these reasons it is important to accurately measure the emissions and fuel use of the high-emitters.

Harley et al. have used the fuel-based method to obtain inventories from several sources including a 1991[2] summertime inventory of running exhaust CO emissions for the South Coast Air Basin in California, a 1997[10] summertime inventory of emissions in the Los Angeles area, a heavy-duty diesel truck exhaust emission inventory of fine black carbon particles and NO_x,[11] and an assessment of off-road diesel engine emissions.[12]

In this study we have used a similar methodology to assess the on-road motor vehicle emission inventory for the Denver metropolitan area. This area consists of the six counties that participate in the enhanced Inspection and Maintenance program to reduce automobile emissions. These counties are Adams, Arapahoe, Boulder, Denver, Douglas and Jefferson. The Denver area was estimated to emit 1308 tons of CO per day in 1995 using the U.S. EPA's Mobile 5a model. To meet the standard, CO emissions would have to be reduced to 875 tons per day by 2001.[13] Carbon monoxide, hydrocarbons and nitric oxide are the pollutants being measured and quantified. Inventories for several years were conducted in order to assess progress in emission control.

METHOD

In a manner similar to Singer and Harley,[2] the fuel economy and measurement frequency of different model year car and truck subgroups are used to calculate relative fuel use by each of these subgroups. One can then combine the fuel use with emission factors for each of the subgroups to obtain an overall fleet emission factor. Mathematically, the process is as follows.

$$\mathrm{t}_{\mathrm{yv}} = \frac{\mathrm{n}_{\mathrm{yv}}}{\mathrm{N}} \qquad (2)$$

where

y = model year subgroup
v = vehicle type subgroup
t = fraction of travel of subgroup
n = number of measurements of subgroup
N = total number of measurements

In other words, given subgroups of model year *y* and vehicle types *v*, the fraction of travel of each subgroup (t_{yv}) is the number of measurements of that subgroup (n_{yv}) divided by the total number of measurements (N) during a remote sensing event.

The relative fuel use of each subgroup (f_{yv}) is then given by:

$$f_{yv} = \frac{(t_{yv}/E_{yv})}{\sum_{v=V_1}^{V_n}\sum_{y=Y_1}^{Y_n}(t_{yv}/E_{yv})} \qquad (3)$$

where

E_{yv} = fuel economy of model year subgroup y and vehicle type v
$Y_1 \ldots Y_n$ = various model years measured
$V_1 \ldots V_n$ = vehicle types measured

Finally, the overall emission factor is given by the product of relative fuel use and measured emission factor for each subgroup summed over all of the subgroups:

$$E = \sum_{v=V_1}^{V_n} \sum_{y=Y_1}^{Y_n} f_{yv} E_{yv} \tag{4}$$

This emission factor is then multiplied by total fuel use to obtain the emission inventory from gasoline.

RESULTS

For this study we have used the fuel economies given in Singer and Harley[10] for 1974 to 1997 cars and light-duty trucks. Pre-1974 vehicles were all assigned fuel economies of 5.0 km/L and model year 1998 and newer cars and trucks were assigned the economy of 1997 vehicles. The vehicles were divided into these two categories as designated by the Colorado DMV records (PAS and LTK as cars and trucks, respectively).

The first set of data analyzed was the measurements made in Denver during the winter of 1999-2000 under Coordinating Research Council (CRC) contract E-23. Measurements were conducted on 4 business days in late December of 1999 and early January of 2000 in Denver. The measurement site was the interchange ramp from northbound I-25 to westbound 6th Avenue in central Denver. A database was compiled containing 22,986 records for which the State of Colorado provided make and model year information. All of these records contained valid measurements for at least CO and CO_2, and 22,867 records contained valid measurements for HC and NO as well. The database, along with other FEAT remote sensing databases and reports, can be found at **www.feat.biochem.du.edu**.

When divided by model year and car/truck designation, each subgroup contained anywhere between 10 (1974 model year trucks) and 2000 (1999 model year cars) vehicles. From this data set, CO, HC and NO emission factors and the travel frequency were calculated for each model year and vehicle type subgroup. The emission factors were obtained by first converting the percent pollutant values measured by the FEAT system to grams of pollutant per kilogram of fuel using the equations given above. In the case of HC, the emission factor measured by remote sensors is somewhat less than 50% of the true volatile organic carbon factor in the exhaust. This is because remote sensors that measure absorption at 3.4 m report mostly alkanes but miss some of the unsaturated hydrocarbons measured by an FID detector.[14] Thus, the calculated HC emission factors are multiplied by 2.2. Next, these calculated values were averaged within each subgroup. Travel frequencies were obtained by dividing the number of measurements of vehicles in one subgroup by the total number of measurements. This procedure incorporates not only the relative number of vehicles from each subgroup in the fleet but also relatively how much each travels, since we are measuring their occurrence on-road.

The calculated travel frequencies and fuel economy data were combined using the equation above to obtain the fraction of fuel used by each subgroup. As indicated, this fraction was multiplied by its emission factor for each of the three pollutants measured. The products for each pollutant were summed, giving fleet emission factors. These factors were 59.3 g CO, 8.05 g HC and 7.24 g NO per kg of fuel. However, our measurements were conducted during a period in the yearly cycle when all of the gasoline fuel sold in the area is gasohol. Gasohol is a fuel designation for gasoline to which an oxygen-rich agent, such as ethanol, has been added in order to reduce on-road CO emissions. In order to obtain emission factors for vehicles burning non-oxygenated gasoline, the gasohol emission factors were scaled using a factor determined from IM240 data. We have previously looked at a year of I/M data and determined that, on average, oxygenated fuels cause emission decreases of 11% and 6% for CO and HC, respectively, while the oxygenation causes the NO emissions to increase by 10%.[15] We have scaled the respective emission factors determined from oxygenated fuel to reflect what the factors would be with normal gasoline. The two sets of factors, for gasoline and for gasohol, were then multiplied by the respective fuel use to determine two separate contributions to the overall inventory.

To determine fuel use in the Denver Metro area, the state fuel sales tax data were used. Such data can be obtained from the Colorado Department of Revenue – Office of Tax Analysis on a monthly basis.[16] The amount of gasoline sold in a fiscal year (July-June), minus the amount exported, was divided by the number of days in the year to obtain a value for fuel sold per day in Colorado. This yielded approximately 3.4 million gallons per day for the 1999-2000 fiscal year. Gallons were first converted to liters by using 3.785 L/gal. In the case of gasohol, 2.2 million gallons were sold per day.

To assess the percentage of the state fuel sales used in the project area, population and vehicle registration data were used. These statistics were taken from the Colorado Department of Local Affairs[17] and the Colorado Department of Motor Vehicles[18], respectively. Approximately 56% of the population lived in the Denver Metro area in July of 1999, and in the same year only 50% of the vehicles were registered in the area. Thus, it was assumed that 53% of the state transportation gasoline use occurred in the 6 county Denver Metro area. Assuming the density of gasoline to be 0.75 kg/L, gasoline use in the Denver area was calculated to be approximately 5.1 million kg per day. Multiplying this fuel use by the calculated emission factors gave the emission inventory from gasoline vehicles in the Denver metropolitan area: 369 tons/day CO, 48 tons/day HC, 37 tons/day NO. “Tons” are short tons, where 907185 grams equals a ton. Similarly, the contribution to the inventory from gasohol use was 220, 30 and 27 tons/day, respectively.

Diesel Emissions

So far only the gasoline and gasohol fuel use has been considered. A non-negligible fraction of total on-road fuel use, and of emissions, comes from diesel vehicles. Heavy-duty diesel trucks account for almost all of the diesel use. Though a certain number of diesel light-duty trucks and passenger cars exist, their fuel use is negligible compared to the commercial heavy-duty trucks. The contribution of the lighter diesel vehicles is well within the error discussed below.

Our group has measured emission factors for heavy-duty diesel trucks previously.[19] The measurements made during May of 1999 in Golden, Colorado are the most relevant as the fleet measured there is likely to be very similar to that in the Denver area. Furthermore, the altitude at the measurement site is well within the range found in the study area. The truck emission factors were 32 g CO, 7 g HC and 24 g NO per kg of fuel. Again in the case of HC, the remote sensor measurements need to be adjusted in order to obtain total VOC concentration. For diesel fuel the adjustment factor is 2.[14] Assuming the density of diesel to be 0.87 kg/L, the emission factors are then 28 g CO, 12 g HC and 21g NO per *liter* of diesel.

Diesel fuel sales for on-road vehicles in Colorado can also be obtained from the Department of Revenue.[16] The designation “special fuels” refers to all taxed fuels that are not gasoline, gasohol, aviation gas or aviation jet fuel. Thus, special fuel encompasses propane, kerosene and other fuels. 91.1% of the special fuel is diesel.[20] In the case of heavy duty trucks, population and vehicle registration data were supplemented with the Colorado Department of Transportation’s daily vehicle miles of travel[21] to apportion the total state diesel sales to the six county Denver metro area. Such an analysis allocates 36% of the heavy-duty truck travel, and thus diesel fuel use, to the Denver area. Thus, 1.7 million liters of diesel fuel per day are used in the area for on-road vehicle travel. Combining this fuel use with the emission factors above yields the following emission inventory from diesel trucks: 52 tons/day CO, 22 tons/day HC and 38 tons/day of NO.

Summation of the inventories from gasoline and diesel vehicles gives 642 tons CO, 100 tons HC and 102 tons NO per day. One potential emission contribution that has not been assessed explicitly is the impact of cold start vehicles. Singer and Harley suggest that cold starts may account for 16% to 18% of total CO emissions.[2] However, as will be discussed below, some of the sites where measurements were obtained to assess the range in emission factors contained a significant portion of cold start vehicles, since the sites were located in residential areas. Thus, the measurement of uncertainty in the emission factors obtained from these sites encompasses to some extent the presence of cold start vehicles.

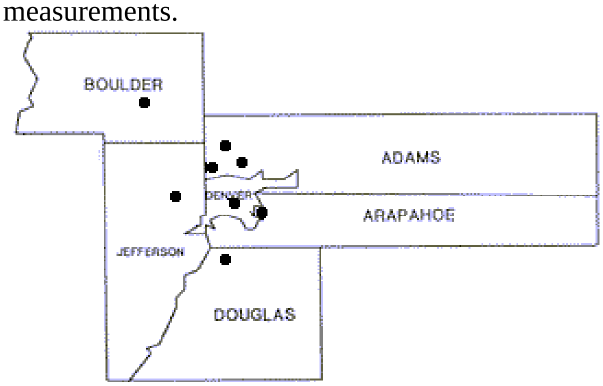
Measurement of Uncertainty

A major factor in extrapolating measurements of a fraction of a fleet to the entire fleet is that uncertainty is generated from various assumptions made in the process. Thus, it is imperative that an accurate uncertainty level be calculated for the fleet inventory. The first source of error arises in the emission factors. At least two mechanisms can contribute to the uncertainty in these factors: noise in the actual emission measurements and emission variability. Noise in the measurements may be caused by variability in the calibration factors. Since the instrument is not continuously calibrated, fluctuations in the ambient air quality can lead to imprecise readings. Though this uncertainty may be alleviated with frequent calibrations, it cannot be completely removed.

Emission variability, on the other hand, is a factor that cannot be alleviated since it is a property intrinsic to vehicle emissions. Broken vehicles in particular show very large emissions variability irrespective of how they are tested.[22] The rate of emissions of a vehicle depends on the state of the catalyst and other parts of the emission control technology, on the quality of the fuel, the quality of the air and the intake system, and a host of other variables. Measurement at one location limits the driving modes being sampled. In order to incorporate the whole profile of load on the vehicle several sites with varying speed, acceleration, grade, etc. must be sampled. Though we have used the measurements from one site to obtain the average inventory value, we have incorporated seven other sites in the Denver area to obtain the uncertainty in the emission factors.

These seven other sites were part of a Denver area emission study during the summer of 2000.[23,24] The sites were all within the Denver metropolitan area being studied here. In fact, each of six counties in the area is sampled. A map of the six county Denver area and the measurement locations, including the main measurement site in Denver County, are shown in Figure 1.

Figure 1. Map of the six county Denver metropolitan area. Dots indicate location of remote sensing measurements.



Besides encompassing a wide range of driving modes, these locations incorporate variances in other variables that affect vehicle emissions. As mentioned above, some of these sites, especially two of the three in Adams County, probably contain a fraction of cold start vehicles. At these locations the instrument was placed not on highway entrance and exit ramps but on residential roads. Many of the vehicles measured here, then, would have been in cold start mode as drivers had started their cold vehicles at home only moments before being measured. The multitude of measurement locations also aid in surveying vehicles from a wide range of socioeconomic backgrounds. It is well documented that socioeconomics plays an important role in the average age of the on-road fleet and, thus, its emissions.[2] The inclusion of measurements from several sites in assessing the uncertainty in the emission factors incorporates these and a number of other factors not mentioned here. Table 1 gives a listing of the measurement sites, their average emissions and their characteristics.

From these weeklong campaigns at the seven sites it is evident that emission rates vary. A statistical analysis of this data, along with the central set of Denver measurements, indicated the following 95% confidence intervals on the mean: 21% for CO and 27% for HC. The HC values had a further uncertainty due to the scaling factor used to convert remote sensing measurements at 3.4 m to an FID measurement, as mentioned above. Harley's group reported a 10% uncertainty in the factor,[14] and that is the value we have used to obtain an overall HC emission factor uncertainty of 29%. These seven other campaigns did not include NO measurements. The confidence interval for NO, then, was generated by sampling average values from various remote sensing campaigns conducted under sponsorship of the CRC. Three sets of measurements from Chicago and two sets each from Denver, LA and Phoenix were used. This analysis yielded a 95% confidence interval for NO of 16% of the mean.

Table 1. Measurement sites for the Smart Sign study and their characteristics.

Site	Start Date	Average CO/CO_2 (10^{-2})	Average HC/CO_2 (10^{-4})	Characteristics
6th Ave. and Kipling St., JEFFERSON	31-May-00	3.7	8.6	Uphill curved on-ramp from major arterial to freeway, moderate socioeconomics.
HW36 and Federal Blvd., ADAMS	27-Jun-00	4.3	12.9	Off highway loop, incline, moderate socioeconomics.
6th Ave. and I-225, ARAPAHOE	10-Jul-00	4.4	7.3	Long highway on-ramp, slight incline, accelerating, moderate-low socioeconomics.
Lincoln Ave. and I-25, DOUGLAS	17-Jul-00	1.8	4.3	Loop on-to highway, flat, upscale socio-economics, no residences within a mile.
Northglenn Town Hall, ADAMS	31-Jul-00	2.9	7.3	Residential-official, two-way road, flat, some slight acceleration.
112th Ave. and Colorado Blvd., ADAMS	3-Aug-00	4.1	9.6	Residential, two-way road, slight incline, moderate socioeconomics.
Table Mesa Dr. to Foothills Pkwy., BOULDER	14-Aug-00	3.3	5.7	One way loop between two transit roads, incline, somewhat upscale socioeconomics.

The other source of uncertainty is in the amount of fuel used in the study area. From the tax data the amount of gasoline and gasohol used in Colorado during the inventory year is quite certain. (There is the possibility of fuel being transferred in or out of the state. It is assumed, nevertheless, that the influx is equal to the outflow so that the net is equal to the tax records.) This statewide fuel use had to be then apportioned to the Denver area. To do so we looked at the fraction of the population (56%) and the fraction of the vehicle registrations (50%) in the metro area. It was thus assumed that 53% of the statewide fuel use occurred in the Denver metro area and that the uncertainty in this value was ±3%.

The uncertainty in the diesel emission factors was assumed to be the same as those in gasoline. This assumption most likely over estimates the uncertainty because heavy-duty diesel emissions are less skewed than gasoline-powered vehicle emissions.[19] There is expected to be additional uncertainty due to the variability in the percent of diesel in the "special fuels" designation. Using 91.1% of the Colorado Department of Revenue's "special fuels" value as the estimate, the uncertainty was set at 5% as suggested.[20] It is assumed that this uncertainty encompasses the relatively small amount of diesel used by light-duty trucks and cars.

Table 2. Inventory values and uncertainties for four separate years in the Denver Metropolitan area.

Year	CO (tons/day)	CO ±	HC (tons/day)	HC ±	NO (tons/day)	NO ±
2000	642	94	100	18	102	11
1999	653	109	79	15	106	12
1997	696	124	122	28	97	12
1996	700	119	117	25	125	14

Finally, to assess the uncertainty in apportionment of diesel use to the study area, heavy-duty truck registration data and daily heavy-duty truck vehicle miles traveled were used. Registration data suggests 41% of the fuel use in the area, while vehicle miles traveled data suggests 31%. Thus, an average value of 36±5% was used. Propagation of the errors led to overall uncertainties in tons of pollutant per day of 15% for CO, 18% for HC and 11% for NO.

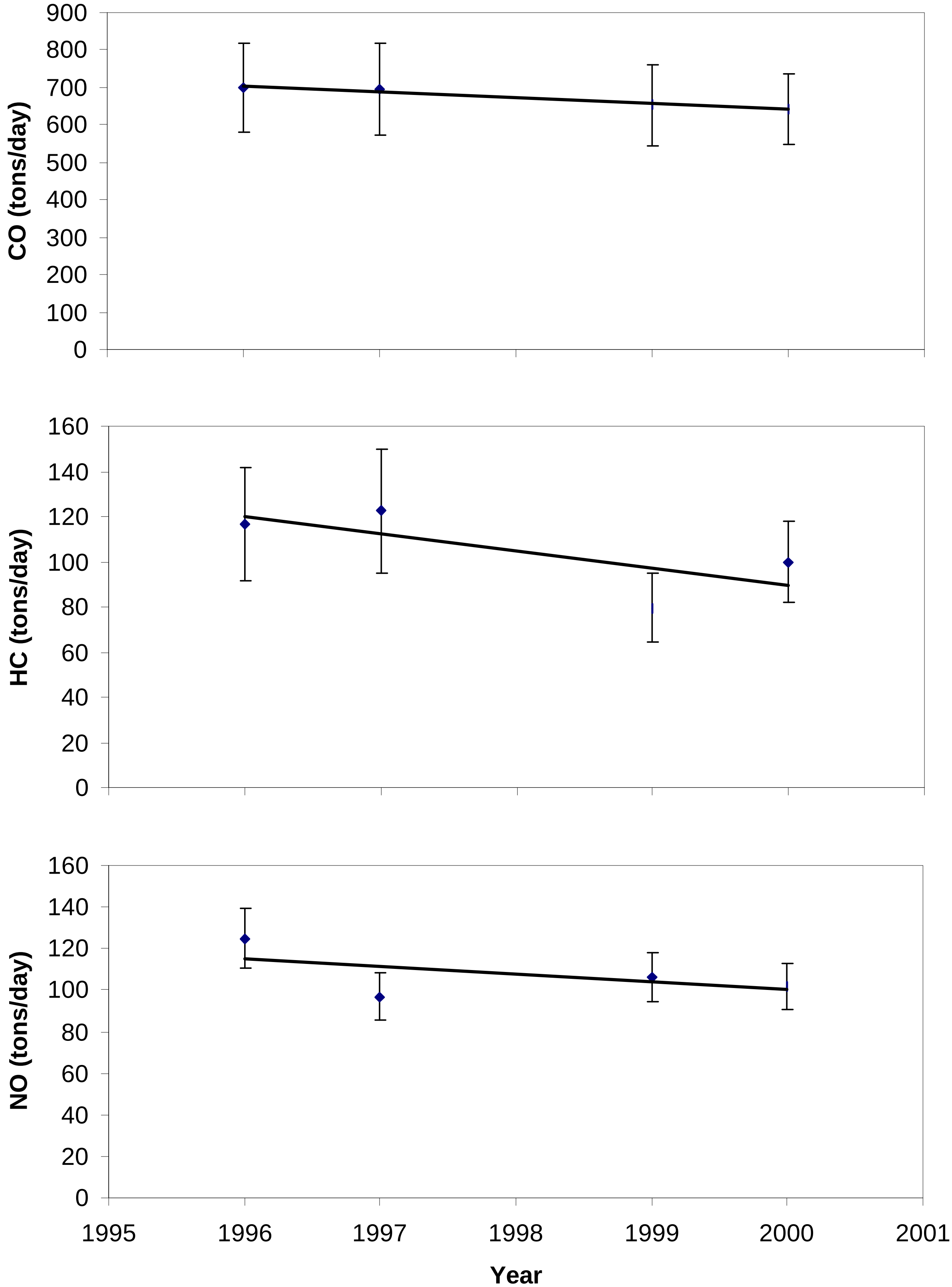
Trend Over Several Years

Measurements have been conducted at the 6th and I-25 site in Denver during several previous years. These data were used to obtain gasoline emission factors for those years of measurement. Heavy-duty diesel emissions were only measured in 1999 in the area so those diesel emission factors are used throughout. Fuel use data for those years were also available from the Colorado Department of Revenue. Population data were available from the Colorado Department of Local Affairs for previous years. During the five years, the percentage of the state population in the study area remained at 56%. Vehicle registration data were only obtained for calendar years 1996 and 1999; both years indicated 50% of the vehicle registrations in the six county Denver area. Thus, the average value of 53±3% was assigned to all the years of the study. Daily vehicle miles traveled data, for use with diesel emissions from heavy-duty trucks, was only available for the 1998 calendar year. It was assumed that the proportion of travel in the six county area (36±5%) was constant throughout the 5 years of study. The resulting emission inventories are given in Table 2 and illustrated in Figure 2. The fuel use and emission factor values for the four separate years are summarized in Table 3.

Table 3. Values used during the various years of study.

Year	State gasoline use (*10^4) (gal/day)	State gasohol use (*10^4) (gal/day	State diesel use (*10^4) (gal/day)	Gasohol CO emission factor (g/kg of fuel)	Gasohol HC emission factor (g/kg of fuel)	Gasohol NO emission factor (g/kg of fuel)
2000	340	225	125 ±6.3	59 ±15	8.1 ±2.4	7.2 ±1.4
1999	425	117	108 ±5.4	62 ±16	6.4 ±1.9	8.7 ±1.7
1997	427	83	97 ±4.8	72 ±18	12.1 ±3.6	9.2 ±1.8
1996	388	100	91 ±4.6	75 ±19	11.8 ±3.5	12.9 ±2.6

Figure 2. Plots of emission inventories for three pollutants during four years of study in the Denver area.



DISCUSSION

The trends seen in Figure 2 indicate decreasing emissions of all three pollutants from on-road vehicles during the years from 1996 to 2000. The general improvement in mobile source emissions over these years is predicted by emission models such as MOBILE5b and has been measured.[2] Such is the result of vehicle fleet turnover and emission control strategies. Even though on-road fuel use, and thus travel, is increasing (19% between 1996 and 2000) emission factors have been decreasing on a fuel basis (Table 3 – 24% for CO from gasohol). The emission factors have decreased enough so that the increased fuel use is more than offset.

Model calculations conducted by the Colorado Department of Public Health and Environment using the EPA's MOBILE5b model for CO[25,26] and HC and NO[27] also suggest reductions in the emission inventories. The magnitude of the reduction seen between 1996 and 2000 with the data-fuel based approach (8% for CO) is not as great as predicted by the model, which predicts a drop in CO from 1308 tons/day in 1995 to 875 tons/day by 2001[25] (20% decrease). The absolute values of the inventories also do not correlate perfectly. MOBILE5b predicts 783 tons/day CO[27], 84 tons/day HC and 115 tons/day NO_x[26] by the year 2006 in the Denver-Boulder non-attainment area. This area is completely encompassed in the six county boundary used in this study, with the rural eastern halves of Adams and Arapahoe counties being excluded from the non-attainment area. Even though the five-year time lag and, to some degree, the smaller geographical area would indicate that the model predictions be significantly less than our fuel-based approach, this is not true. In the cases of CO and NO_x the model predictions for 2006 are actually greater than the observations for 2000.

Part of the discrepancies in absolute inventory values may be the result of differences in the treatment of cold start vehicles between model and fuel-based calculation. The fuel-based approach assumes the cold start emissions are encompassed in the uncertainty. Cold start vehicles were measured at some of the sites which were used to obtain uncertainty in the emission factors. Furthermore, on a fuel basis cold starts do not contribute appreciably to the inventory since not much fuel is consumed during the short period of time when the vehicle is in "cold" mode. The models, on the other hand, lend significant weight to emission from cold-starts. Excessive weighting of emissions from cold start vehicles in the MOBILE5b model has been criticized previously.[28] However, an updated version of the MOBILE model (MOBILE6) is to be released soon, and will certainly improve the predictions.

It must be noted that this fuel-based assessment has treated each day during the year as being equivalent since the reported model estimates also do so. However, emission during weekend days would be expected to be lower than during weekdays. Emission factors have been measured during weekend days, and these are well within the uncertainty in the factors. Fuel use, on the other hand, should be less during the weekend. Thus, the reported daily inventories are a weighted average of weekdays and weekend days.

Another result of treating all days equivalently is that seasonal variations are not considered explicitly. Atmospheric conditions, such as temperature and humidity, have known effects on emission rates.[29] Again, however, emission measurements have been made during both winter and summer months to assess the uncertainty in the emission factors. Thus, seasonal variations are within the reported uncertainty.

CONCLUSIONS

A fuel-based approach has been used to calculate daily emission inventories for the Denver metropolitan area. The calculated values for the calendar year 2000 are 642±94 tons/day CO, 100±18 tons/day HC and 102±11 tons/day NO. These values are somewhat lower than predicted by the EPA's MOBILE5b model. Furthermore, calculation of fuel-based inventories for several previous years has shown that emission reductions are not as great as modeled. Further measurement of emission factors at various locations, especially for heavy-duty diesel trucks, would offer greater precision in the calculated factors and, consequently, the inventories.

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KEYWORD

Emission inventories
CO
HC
NO
Mobile source
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