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Reduction in Global Warming due to Fuel Economy Improvements and Emissions Control of Criteria Pollutants: New U.S. Light-Duty Vehicles (1968-1991)

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ABSTRACT

This paper explores the impact of U.S. emission controls and fuel economy improvements on the global warming potential (GWP) of new light-duty vehicles. Fuel economy improvements have reduced the GWP of both passenger cars and light-duty trucks by lowering the per mile emissions of carbon dioxide (CO_2). Further GWP reductions have been achieved by emission standards for criteria pollutants: carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x).

The GWP of a criteria pollutant was calculated by multiplying the emission rate by a relative global warming factor to obtain a CO_2 equivalent emission rate Both CO_2 and criteria pollutant emission rates per vehicle have decreased substantially for new light-duty vehicles over the period from 1968 to 1991. Over that period, the GWP from CO_2 was reduced by almost 50% in new vehicles by improving fuel economy. In that same time period, the GWP from criteria pollutants from new vehicles was reduced with emission controls by from 80% to 90%, depending on the global warming time frame of interest. Consequently, total reductions in the GWP of new passenger cars and light-duty trucks have been on the order of 55 to 75 percent compared to precontrol (before 1968) new vehicles.

However, the reduction in GWP caused by emission control of criteria pollutants has been larger than the reduction caused by improved fuel economy (i.e., reduced CO_2). The contribution of criteria pollutants to the GWP of precontrol new vehicles was substantial, but their contribution has been reduced significantly due to U.S. emission controls. As a result, the contribution of criteria pollutants to global warming is now much less than the contribution of CO_2 from fuel consumption.

INTRODUCTION

In the United States, careful evaluation of the global warming caused by motor vehicle emissions is being undertaken. This paper studies the federal emission controls on light-duty vehicles (which represent a major fraction of the total motor vehicles in the U.S.) with regards to the per vehicle global warming reduction that was accomplished due to these standards for the period from 1968 to 1991. We concentrate on the global warming potential caused by carbon dioxide (CO_2) and three criteria pollutants -- carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x) -- from light-duty vehicles (both passenger cars and light-duty trucks) run on gasoline.

The burning of fossil fuels definitely contributes to increased levels of greenhouse gases in the atmosphere. This fact and the results of a study of greenhouse gases emitted by developed countries indicate that the Unites States should be particularly concerned about issues of global warming since it is estimated to be next to the former East Germany with the highest CO_2 emissions per capita [1].

One of the main reasons for high levels of CO_2 emissions in the U.S. is the large per capita consumption of gasoline for domestic transportation. However, the motor vehicle emission standards in the U.S. are more restrictive than those of other nations, and CO_2 emissions from motor vehicles account for only a fraction of the global warming problem. On a worldwide basis, highway vehicles contribute only 7% of the total CO_2 emissions, and this represents less than 4% of all greenhouse gases [2]. But in the U.S., highway vehicles contribute about 25% of the total CO_2 emissions. Thus, making improvements in vehicle fuel efficiencies (the source of CO_2 emissions from gasoline and diesel fueled motor vehicles) provides a partial reduction in the overall greenhouse gas emission levels, but reducing the global warming caused by vehicle emissions must also include other pollutants besides CO_2.

The impact of these other greenhouse gases on global climate change is magnified by their increased heat absorbing capacities compared to carbon dioxide. The Intergovernmental Panel on Climate Change (IPCC) has developed a preliminary estimate of the global warming potential of the various greenhouse gases relative to carbon dioxide, expressed on a mass basis. Most of the greenhouse gases which are of concern to us with respect to global warming go through a series of physical or chemical transformations faster than carbon-dioxide. Subsequently, their warming effects generally diminish over long periods of time compared to carbon-dioxide (whose lifetime is considered to be very long). Table 1 is a list of motor vehicle related greenhouse gases and their relative global warming potentials over integration time horizons of 20 years, 100 years, and 500 years [3]. The global warming factor (GWF) of any particular gas is the non-dimensional ratio of the global warming potential of one gram of that gas to the global warming potential of one gram of CO_2. The standard of comparison is CO_2, thus its GWF is equal to one.

All of the gases in this list are emitted from motor vehicle tailpipes except chlorofluorocarbon-12 (CFC-12) which is used as a refrigerant in air conditioners. Exhaust emissions of criteria pollutants (HC, CO, and NO_x) are regulated in the U.S. through standards which limit emissions on a "grams per mile" basis. Methane (CH_4) emissions are regulated under the exhaust hydrocarbons standard, since the standard is for total hydrocarbons, including methane. Another source of hydrocarbon emissions is from fuel evaporation, which is regulated in the U.S. with a "grams per test" evaporative standard. Nitrous oxide (NO) emissions are not currently regulated in the U.S.; nor are CFC's except that their use is being phased out as a result of the Montreal Protocol. Carbon dioxide emissions are not regulated except indirectly through the Corporate Average Fuel Economy (CAFE) standards, since CO_2 emissions are directly related to fuel consumption.

TABLE 1 Relative Global Warming Potential of Selected Greenhouse Gases

	Global Warming Factor		
	Integration Time Horizon		
Greenhouse Gas	20 Years	100 Years	500 Years
CO_2 - Carbon Dioxide	1	1	1
CO - Carbon Monoxide	7	3	2
NMHC - Non-Methane Hydrocarbons	31	11	6
CH_4 - Methane	63	21	9
NO_x - Nitrogen Oxides	150	40	14
N_2O - Nitrous Oxide	270	290	190
CFC-12	7100	7300	4500

Source: Cristofaro, 1990 [3]

METHODOLOGY

Several steps were taken to estimate the global warming potential of emissions from light-duty vehicles. First, emission rates for the criteria pollutants were estimated from the emission standards for each year. Second, CO_2 emission rates were calculated from the fuel economy values for each year. Finally, the global warming potential was estimated by multiplying the emission rates by the appropriate global warming factor and adding the components together. These steps are described below in more detail.

CRITERIA POLLUTANT EMISSIONS - Tables 2 and 3 list the historical values of U.S. emission standards for the criteria pollutants: exhaust hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), and evaporative hydrocarbons (Evap. HC) [4-11]. These emission levels have been used in the analysis that follows for new passenger cars and light-duty trucks for the period 1968-91. Several different Federal Test Procedures (FTP's) were used during the period 1968-91, and a 2 gram/mile emission level from one FTP was not equal to a 2 gram/mile emission level of the same pollutant from another FTP. For exhaust HC, CO, and NO_x, the unit used in this paper for emission levels is grams per mile according to the U.S.-1975 Federal Test Procedures. In other words, the emission rate estimates are "standardized" to the 1975 FTP. The Sealed Housing for Evaporative Determination (SHED) method, which gives emission rates in grams per test, is the base FTP for evaporative hydrocarbons. The evaporative rates in grams per test were converted to grams per mile rates by estimating the diurnal and hot soak fractions, multiplying the hot soak fraction by three trips per day, and dividing the total by 30 miles per day.

The values for emission levels of some pollutants were estimated when there was no federal standard or reliable information for those pollutants during certain periods (e.g., no federal standard existed for NO_x before 1973, although some sources [9,10,12] do give a "national" standard which we have used for the period before 1973). In calculating the reduction in global warming over the period 1968-91, it would not be justifiable to ignore those pollutants just because there was no federal standard.

TABLE 2 Emission Rates for New Passenger Cars

	Criteria Pollutant Standards (1975 FTP-Equivalent)			
Model Year	HC (g/mi)	CO (g/mi)	NO_x (g/mi)	Evap. HC (g/mi)
Precontrol	8.7	87.0	3.5	3.0
1968-71	4.1	34.0	3.5	3.0
1972-74	3.0	28.0	3.1	1.0
1975-76	1.5	15.0	3.1	1.0
1977	1.5	15.0	2.0	1.0
1978-79	1.5	15.0	2.0	0.3
1980	0.4	7.0	2.0	0.3
1981-91	0.4	3.4	1.0	0.1

TABLE 3 Emission Rates for New Light Trucks

	Criteria Pollutant Standards (1975 FTP-Equivalent)			
Model Year	HC (g/mi)	CO (g/mi)	NO_x (g/mi)	Evap. HC (g/mi)
Precontrol	8.7	87.0	3.5	3.0
1968-71	4.1	34.0	3.5	3.0
1972-74	3.0	28.0	3.1	1.0
1975-77	2.0	20.0	3.1	1.0
1978	2.0	20.0	3.1	0.3
1979-80	1.7	18.0	2.3	0.3
1981-83	1.7	18.0	2.3	0.1
1984-87	0.8	10.0	2.3	0.1
1988-91	0.8	10.0	1.2	0.1

FUEL ECONOMY AND CO_2 EMISSIONS - Figure 1 shows the fuel economy values for passenger cars and light-duty trucks that were used to estimate the CO_2 emission levels [6,8,13,14,15]. Included are values for combined driving (a weighted combination of city and highway) for new vehicles and the on-road average for all vehicles (the fleet) for the period 1968-91.

The combined values for new trucks for the period 1968-74 were estimated. We have attempted to construct estimates for the full period, recognizing that the estimates of global warming reduction are less reliable for 1968-75 than thereafter. Nevertheless, it will be shown that the 1968-75 reductions are the most significant, because most of the reductions of motor vehicle emissions were achieved during this period, compared to the period where data quality and test procedures were more reliable (post-1975).

Figure 1 illustrates that the estimated fuel economy for new vehicles under test conditions is not the same as for the entire fleet of vehicles that actually operate on the road. In the first place, the on-road fuel efficiency is generally lower than the EPA test efficiency. In the second place, since only a small proportion of the fleet is replaced by new vehicles each year, improvements in new vehicles take many years to be reflected in fleet averages. These differences also apply to the estimates of CO_2 emission rates discussed below. Also, note that new car and new truck fuel efficiency dropped in the last few years, but the efficiency of the fleet continues to climb because the fuel efficiency of new vehicles remains well above old vehicles. Just as past increases in fuel efficiency of cars and trucks will continue to benefit the fleet for years to come, the past reductions in emissions of criteria pollutants will also continue to benefit the fleet for years to come.

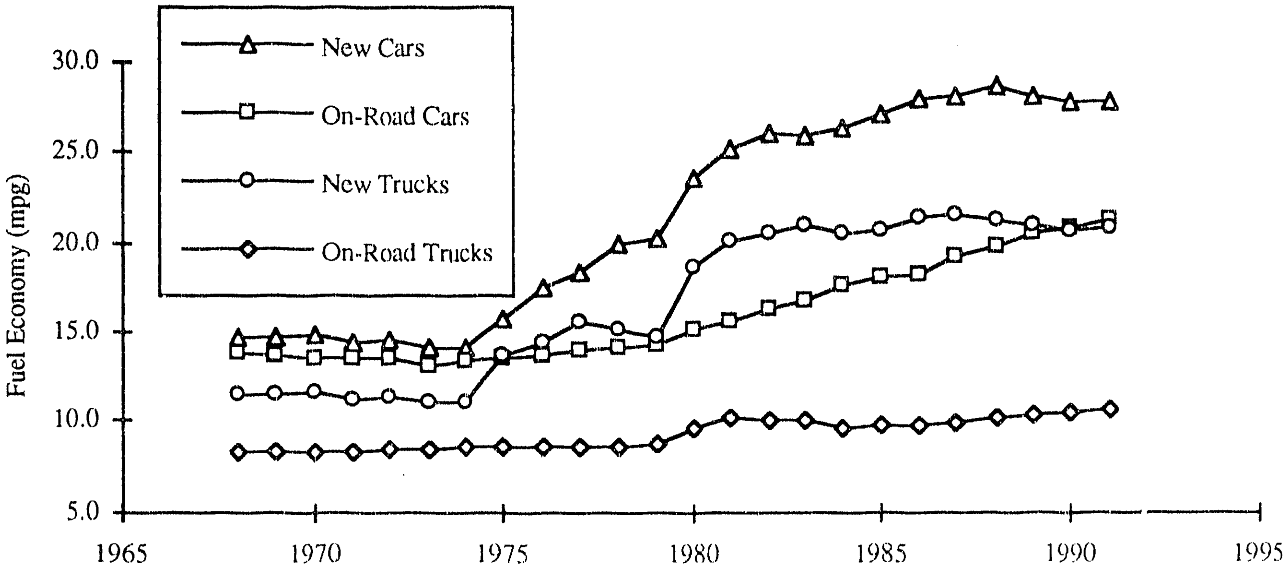

FIGURE 1 Car and light truck fuel economies for years 1968-1991.

To calculate the carbon dioxide (CO_2) emission rates for each year, we used the fuel economy values in Figure 1. Amann [16] gives the CO_2 emission index of gasoline as 8855 grams of CO_2 per gallon of fuel. The CO_2 emission index of a fuel depends on its carbon content, because burning a specific amount of fuel generates a specific amount of CO_2 when the carbon in the fuel reacts with the oxygen in the air. By using the CO_2 emission index and the fuel economy (in miles/gallon) we can obtain the CO_2 emissions from the tailpipe of a vehicle. For example: a vehicle with a fuel economy of 30 mpg would emit 8855/30 = 295 grams of CO_2 per mile. This procedure can be used to calculate CO_2 emissions for either new vehicles (combined driving conditions) or the on-road fleet average.

GLOBAL WARMING CALCULATIONS - The global warming capacity of the criteria pollutants (HC, CO, NO_x, and Evap. HC) is obtained by multiplying the emission rate estimates with the appropriate global warming factor (GWF) from Table 1. For example: to calculate the global warming capacity of a 2 gm/mi CO emission level over a 20 year integration time horizon, multiply the 2 gm/mi rate by the global warming factor of 7 (the 20 year value for CO from Table 1) to get a CO_2 equivalent rate of 14 gm/mi.

This can be done for each of the three integration time horizons. The global warming factor for non-methane hydrocarbons (NMHC) is used for both the exhaust and evaporative HC emission rates, because the fraction of methane in these components is relatively small. This could lead to a slight underestimation of the global warming capacity of a given HC emission rate, because the GWF of methane is higher than the GWF of NMHC. For new vehicles, we estimate the emission rates by assuming that the standards (from Tables 2 and 3) are just met.

Finally, the total global warming capacity in terms of CO_2 equivalent grams/mile for a particular year is obtained by adding the total CO_2 equivalent grams/mile obtained from criteria pollutants (HC, CO, NO_x, and Evap. HC) to the grams of CO_2 per mile obtained from fuel economy estimates. The emission rates for criteria pollutants in Tables 2 and 3 are assumed to be appropriate for new vehicles in combined driving conditions, thus they are used in conjunction with the CO_2 emission rates derived from the new vehicle combined fuel economy values from Figure 1.

RESULTS

In this study, we present estimates of the global warming potential (GWP) from new vehicles only, for combined city and highway driving conditions. We have not estimated the average values for the on-road vehicle fleet, nor have we multiplied the emission rates by the vehicle miles travelled (VMT) to get the actual mass of pollutants emitted. We present results for trucks and cars separately, because no sales or VMT weighted average for the two has been developed at this time. Note that these estimates count only the effect of criteria pollutants and CO_2. The effect of CFC's and nitrous oxide are not included.

NEW LIGHT-DUTY TRUCKS - For new light-duty trucks, Figures 2 and 3 provide a comparison of the estimates of total warming effect due to criteria pollutant and carbon dioxide emissions. The bottom two lines in the figures allow comparison of the separate totals for criteria pollutant GWP and CO_2 GWP. For the 20 year integration time horizon (ITH), the GWP contribution of criteria pollutants in 1968 was far greater than for the emissions of carbon dioxide. By the 1991 model year, the carbon dioxide emissions from new trucks were greater than the 20 year CO_2 equivalent emissions for criteria pollutants, but criteria pollutants still accounted for about one third of the total 20 year GWP for new trucks.

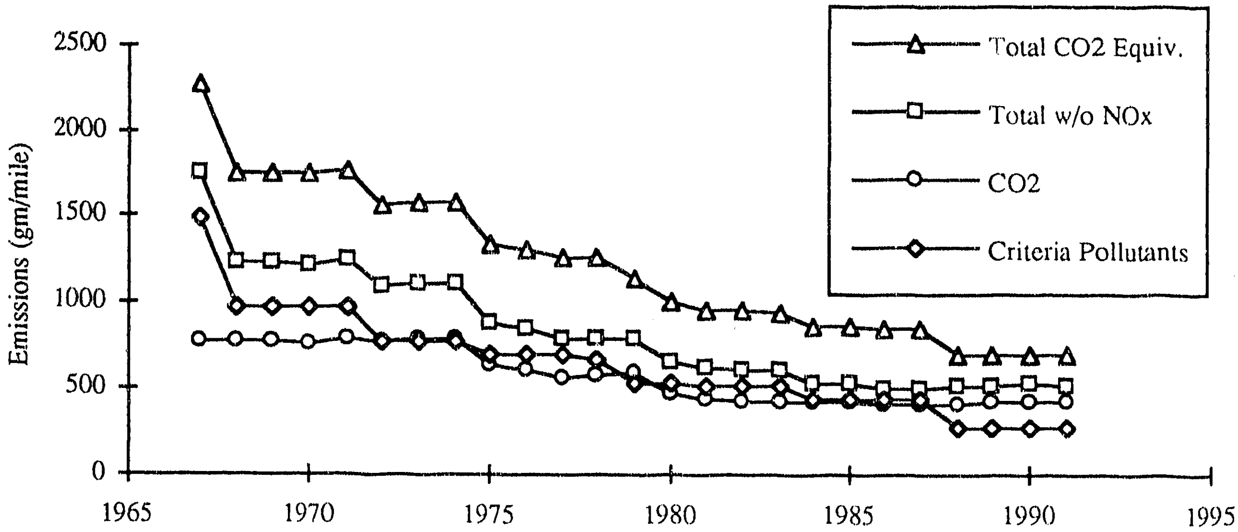

FIGURE 2 CO_2 **equivalent emissions for new light trucks - 20 year ITH.**

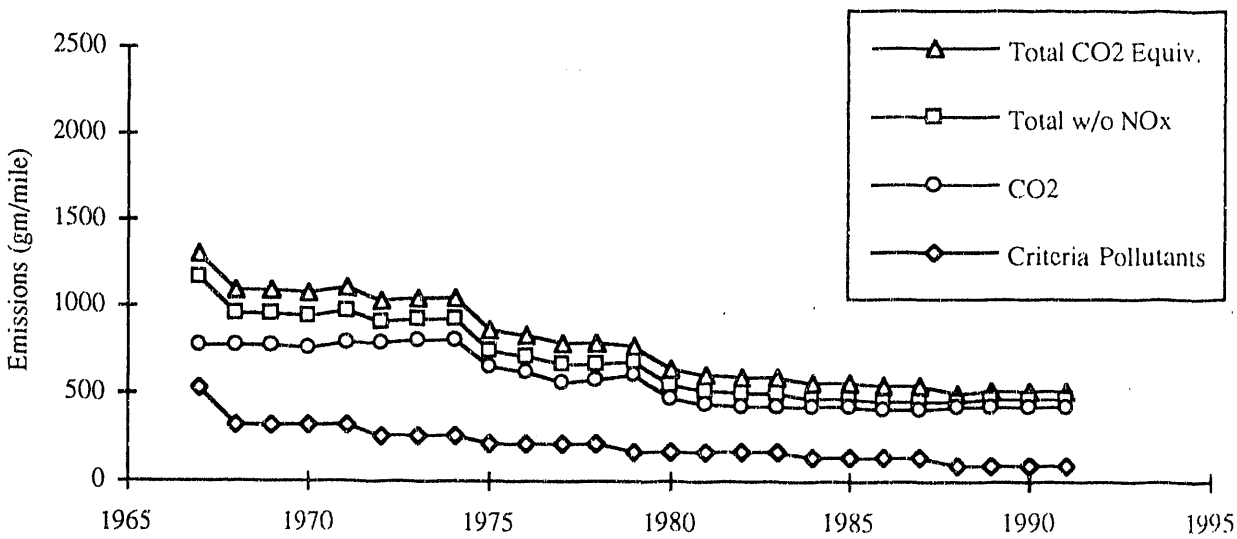

FIGURE 3 CO_2 **equivalent emissions for new light trucks - 100 year ITH.**

In terms of reductions achieved, the IPCC factors from Table 1 lead to an estimate that the 1968-91 reduction in GWP achieved by control of criteria pollutant emissions from new light trucks were over 3.5 times as great as the reductions from improved light truck fuel efficiency. Out of the total 20 year GWP reduction, almost 80 percent came from control of criteria pollutants. Even if nitrogen oxides, whose warming effect is more controversial [17], were to be eliminated from the calculation, over 70 percent of the total reduction in CO_2 equivalent emissions from light trucks would be due to control of criteria pollutants. It is important to recognize that there has been a reduction in 20 year CO_2 equivalent emissions from criteria pollutants emitted by new light-duty trucks of over 80 percent since 1968. If criteria pollutant emissions from new light-duty trucks were totally eliminated, the 20 year CO_2 equivalent emissions of these trucks would be further reduced by nearly 40 percent. In this historical study we have not estimated the reductions that will be achieved due to the Clean Air Act Amendments of 1990, but one could argue that additional control of criteria pollutants might actually be more effective than increased corporate average fuel economy (CAFE) standards.

The 20 year ITH values may be regarded as being at one end of the scale of concern to this generation and its descendents. The 100 year ITH values are at the other end of that scale. Over a century's time the emissions of criteria pollutants can be expected to be only about one third as significant (relative to CO_2 emissions) as over two decades. Even if the 100 year ITH is used, the emissions of criteria pollutants remain important to the global warming effects of new light-duty trucks.

For light-duty trucks built before 1968, the 100 year GWP of the criteria pollutants emitted from those trucks is about two thirds as large as from the carbon dioxide that was emitted during the life of those trucks. (Figure 3). Thus, one can say that the warming effect legacy of criteria pollutant emissions from those vehicles is almost as important as that of their CO_2 emissions. The 100 year GWP for 1988-91 model year trucks was reduced by over 80 percent compared to the uncontrolled trucks of the 1960's. Over the next century, the GWP of emissions from new 1991 light-duty trucks due to criteria pollutants should be about 20 percent of that caused by CO_2 emissions. This percentage will drop further for future model years, as the 1990 Clean Air Act Amendments cause additional criteria pollutant emissions reductions.

Figures 2 and 3 illustrate, for new trucks, the fact that the reduction of criteria pollutants through emission controls has led to a far sharper reduction of short-term global warming effects (those over a few decades) than long-term global warming effects (those over a century). The figures also illustrate that the most pronounced gains came in the first decade of emissions control, and that, as a percentage of post-1968 GWP reductions originally possible, most has already been achieved through control of criteria pollutants.

Whether the time period considered is two decades or a century, it is clear that the control of criteria pollutants emissions from new light-duty trucks represents a major contribution to the reduction of GWP. If one uses a 20 year time horizon, it is estimated that the U.S. has reduced its GWP of an average new light-duty truck by about 70 percent. If one uses a 100 year time horizon, it is estimated that the reduction is about 60 percent.

NEW PASSENGER CARS - Controls of criteria pollutant emissions from passenger cars have been tighter than those for trucks since 1975. Given our estimate that trucks and cars had equivalent emissions rates in the late 1960's, this means that our estimates of criteria pollutant reductions are greater for cars than for trucks. It is also true that the fuel economy standards imposed on cars have required greater percentage improvements than for trucks. Accordingly, our estimates of 1968-91 CO_2 equivalent emissions reductions for new cars are greater than for trucks. Even so, the general patterns of change for new cars and trucks are very similar, as shown in Figures 4 and 5. Thus, as in the case of light trucks, out of the potential GWP reductions achievable for new cars through criteria pollutant emissions controls, most has already been achieved.

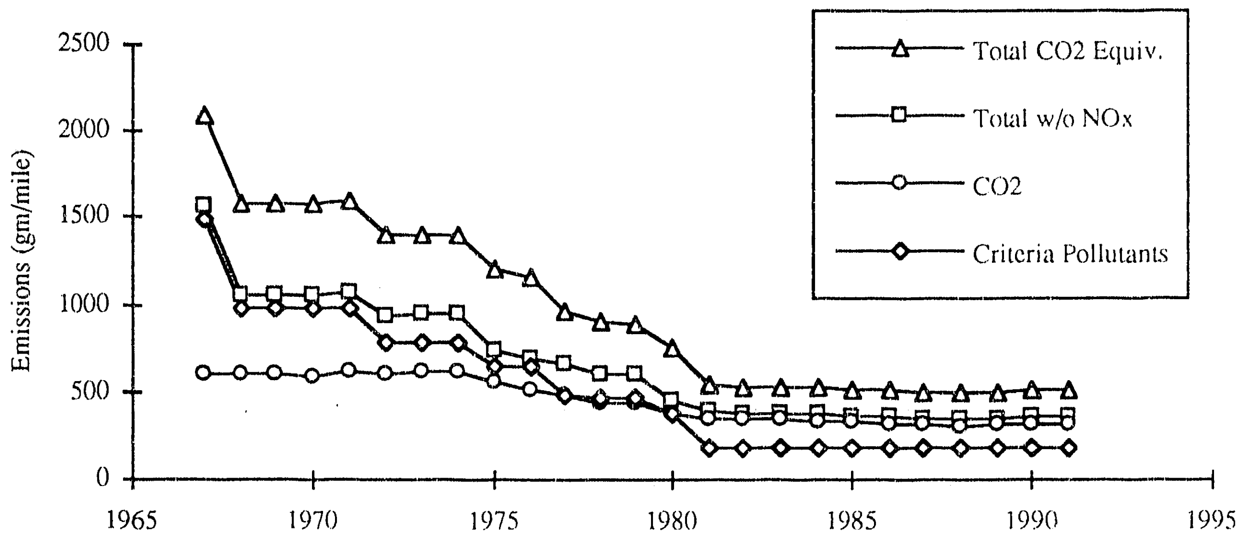

FIGURE 4 CO_2 equivalent emissions for new passenger cars - 20 year ITH.

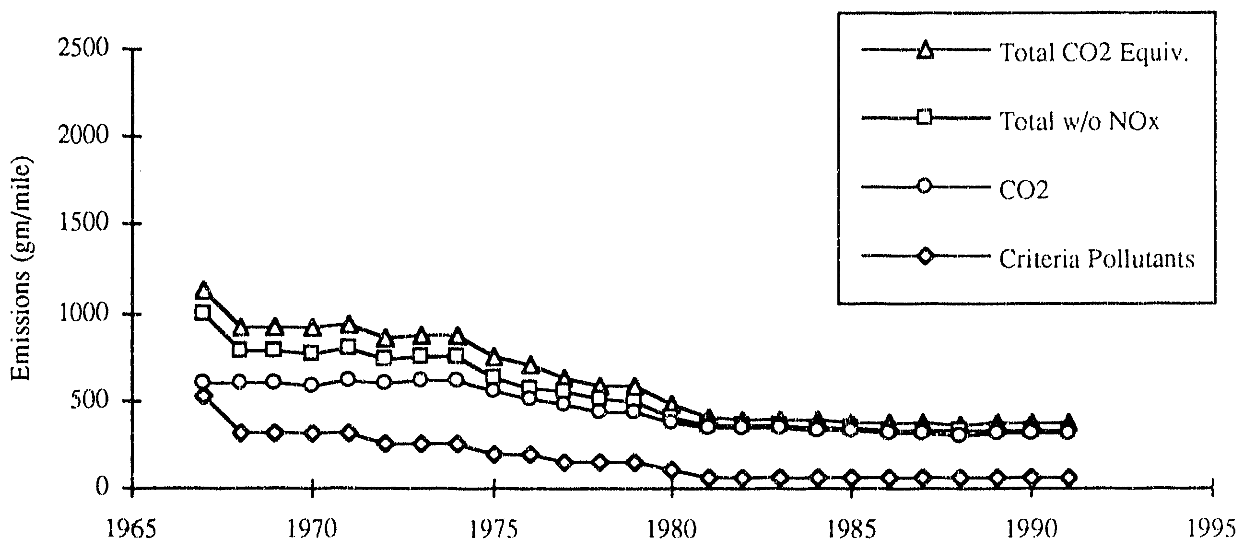

FIGURE 5 CO_2 equivalent emissions for new passenger cars - 100 year ITH.

Since cars are more fuel efficient than trucks, the identical precontrol criteria pollutant emission rate estimates we use for cars and trucks lead to an estimate that the precontrol emissions of criteria pollutants from cars contributed a higher percentage of the new car GWP than for new trucks. The criteria pollutant GWP for a precontrol new car is estimated to be 2.5 times as large as the contribution from CO_2 if a 20 year ITH is used (Figure 4) and 0.9 times as large if a 100 year ITH is used (Figure 5).

Since precontrol new cars emitted less CO_2 than precontrol new trucks, it turns out that the total CO_2 equivalent gram per mile reduction (in the 20 year horizon case) is almost the same as for new trucks, even though the percentage reduction is greater for cars. Also, the estimated contribution which is due to reduction of criteria pollutants is larger, representing over 80 percent of the estimated total reduction. Even if nitrogen oxides were to be eliminated from the calculation, over 75 percent of the total reduction in CO_2 equivalent emissions from new cars would be due to control of criteria pollutants. For the 20 year ITH, the GWP due to criteria pollutant emissions from cars has been reduced by almost 90 percent, compared to an uncontrolled vehicle. Nevertheless, criteria pollutants of new 1991 cars still have a 20 year GWP about 60 percent as large as the 20 year GWP due to their CO_2 emissions.

However, over the next century (the 100 year ITH), the GWP of criteria pollutant emissions from 1991 cars will only be about 20 percent as large as the GWP from CO_2 emissions (Figure 5), down from almost 90 percent for precontrol cars. As in the case of trucks, whether the time period considered is 20 years or a century, control of criteria pollutant emissions represents a major contribution to reduction of GWP. If one uses a 20 year time horizon, it is estimated that the U.S. has reduced the GWP of an average car by over 75 percent. If one uses a 100 year time horizon, it is estimated that the reduction is about 67 percent. These reductions should easily offset the doubling of passenger car miles travelled from 1968-91.

CONCLUSION

This study uses the Intergovernmental Panel on Climate Change's recently developed indexes of global warming potential (GWP) created by various greenhouse gases to estimate the amount of aggregate GWP that should now be (and should have been) attributed to emissions of criteria pollutants (CO, NO_x, and HC) from light-duty motor vehicles. The study examines the implications of using the 20 year and 100 year integration time horizons of the IPCC. It is shown that the IPCC numbers implicate criteria pollutants as major contributors to the GWP of light-duty vehicles - especially if those vehicles have little or no emissions control. The estimates imply that the U.S. has reduced the GWP of its new light-duty vehicles between 55 and 75 percent since 1968 (ignoring CFC's and nitrous oxide). The role of criteria pollutants in global warming is quite significant, as shown in this historical analysis for the U.S.

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