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Energy Use Impacts of the Mobile Source Provisions of the Clean Air Act Amendments of 1990 *

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INTRODUCTION

The Clean Air Act Amendments (CAAA) of 1990 will have a profound, positive impact on air quality. At the same time, they will affect the use of energy in various sectors of the U.S. economy. Given the continued reliance of the U.S. on imported petroleum, the impact of the CAAA on petroleum use is of particular interest. Various provisions of the CAAA are expected to lead to a reduction in its use (e.g., the addition of oxygenates to gasoline to meet oxygen content requirements and a switch from fuel oil to natural gas to achieve sulfur dioxide [SO2] reductions). Alternatively, other provisions will lead to increased petroleum consumption (e.g., the cold temperature carbon monoxide [CO] standards for light-duty vehicles [LDVs]). The net overall effect appears to be a reduction in oil use (1). However, the extent of that reduction is not clear-cut. It will be determined by technological developments as well as industry and consumer behavior.

In this paper, we present estimates of the impact on petroleum use of the mobile source provisions of the CAAA. These provisions may provide the largest oil displacement potential of the CAAA (1). As will be shown, however, the variety of assumptions required concerning technological developments and market response results in a wide range of estimates. In the future, reductions in the uncertainties associated with these developments and responses will allow for more definitive estimates of CAAA mobile source oil displacement.

SCOPE OF ANALYSIS

Figure 1 illustrates the mobile source provisions addressed in this analysis. We focus on fuel switching and fuel consumption impacts. The provisions which result in fuel switching, either to alternative fuels or to gasoline with a lower petroleum content, and the fuel economy implications of the vehicle emission standards, have been evaluated. Fuel standards are addressed in the context of the use of the revised fuel formulations by vehicles meeting new emission standards. There are other mobile source provisions in the CAAA, but they are generally expected to have negligible impacts on vehicle petroleum use and thus are excluded from analysis. We have not specifically addressed the implications of any of these provisions on refinery energy consumption.

The focus of the analysis is the year 2010 when relatively full implementation of the CAAA will be in effect. In the following sections, we detail as needed our assumptions regarding vehicle fuel economy, mileage, population, and mix as well as baseline petroleum fuel consumption.

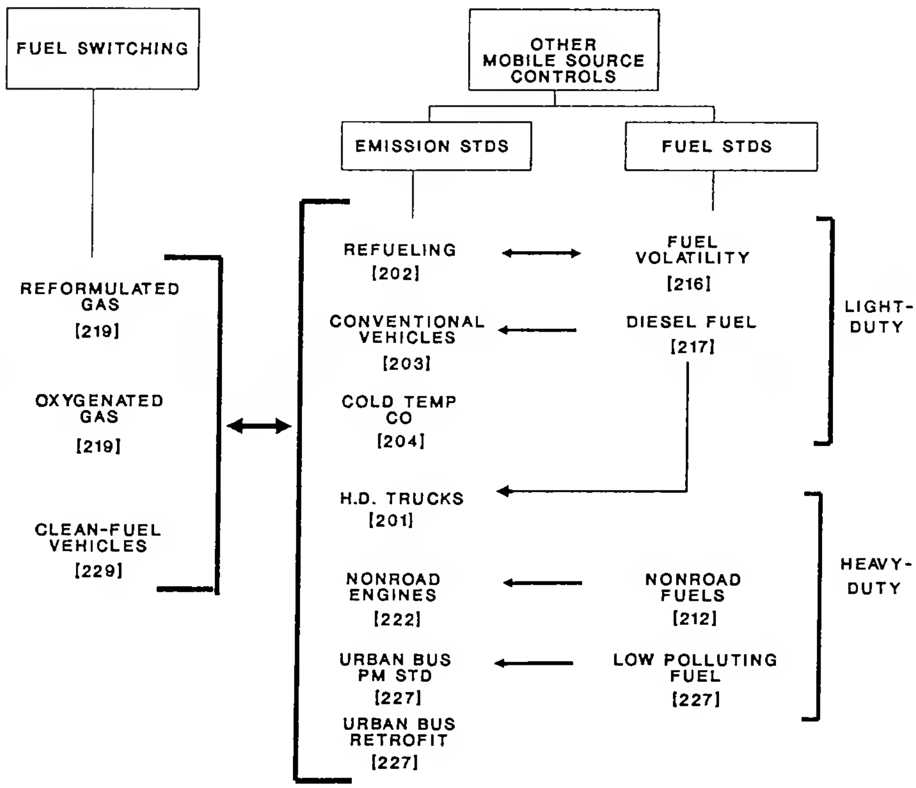

Figure 1 Scope of energy use impact analysis.

ENERGY USE IMPACT ANALYSIS

Fuel Switching

Reformulated Gasoline and Oxygenated Gasoline (Sec. 219). The oxygen content requirements of the reformulated gasoline and oxygenated gasoline provisions of the CAAA can lead to substantial oil displacement. The CAAA require that all gasoline sold throughout the year in the 9 worst ozone nonattainment areas (with a 1980 population of 250,000 or more) be reformulated beginning in 1995. Several content and/or performance-based standards must be met, but the key one for oil displacement is a required oxygen content level of 2.0% by weight. Oxygenates such as methyl tertiary-butyl ether (MTBE) and ethanol will be used to achieve this standard.

In addition to this requirement, all CO nonattainment areas with a CO level greater than 9.5 ppm are also required to use oxygenated fuels during the portion of the year (winter) when their areas are prone to high ambient concentrations of CO. These fuels must be used a minimum of 4 months, but the time period can be longer. The fuel must contain no less than 2.7% oxygen by weight. This program starts in 1992. The oxygen level may be raised to 3.1% in CO areas classified as "Serious" in 2001.

A wide range of oil displacement estimates for these programs is possible. The reformulated gasoline program specifically applies to 9 cities. Assuming that population is representative of gasoline use, the 9-city program will result in 22% of total U.S. gasoline being reformulated. However, all other ozone nonattainment areas may opt-in to the program effective in 1995 or later. Insufficient domestic capacity to produce this gasoline may lead to delays of up to 3 years in the use of this fuel in these opt-in areas, but the capacity issue will not affect the year 2010 estimates presented here. With maximum opt-in, 55% of U.S. gasoline could be reformulated.

Additionally, given the logistics of gasoline distribution, it may be assumed that spillover of the sales and use of reformulated and oxygenated gasoline will probably occur. Reformulated gasoline will probably be marketed in areas not mandated to use it, but adjacent to those areas and part of the distribution system to them (2). EPA has estimated that the spillover could be as great as 15% with the 9-city program (3). If all ozone areas opt-in to the use of reformulated gasoline and spillover occurs, it is possible that the oil industry would find it simplest to reformulate all gasoline in the U.S.

Not only are there several potential reformulated and oxygenated gasoline consumption levels, the choice of oxygenates also affects oil displacement. Both ethanol and MTBE negatively affect fuel economy because their use to increase the oxygen content of the fuel lowers the fuel's total energy content. To achieve a 2.0% oxygen level, MTBE must replace 11% of the gasoline volume while that volume rises to 15% to meet the 2.7% oxygen level. While tax credit exists for gasoline that is 10% ethanol, with the marketable oxygen credits in nonattainment areas included in the CAAA, the average ethanol content in a given area will be 8% to meet the 2.0% requirement and 9% to meet the 2.7% requirement. Additionally, production of grain-based ethanol utilizes petroleum. The ethers used in MTBE may be produced from petroleum as well as non-petroleum sources.

Given the above considerations, we have developed the oil displacement estimates shown in Table 1.

Table 1 Reformulated and oxygenated gasoline displacement in 2010 (thousands b/d)

Breadth of Program	Displacement
9 city only/no spillover/MTBE and ethanol	205
9 city only/15% spillover/MTBE and ethanol	235
Maximum opt-in/ no spillover/MTBE only	386
100% gasoline/ MTBE only	680

The "9 city only/no spillover/MTBE and ethanol" program assumes that reformulated gasoline will be used only in the 9 worst ozone nonattainment areas. As required, oxygenated fuel will be used in 44 CO nonattainment areas (based on 1988 nonattainment data). No spillover is expected. Ethanol is assumed to be used in those areas which are CO nonattainment, but which do not also require the use of reformulated gasoline for ozone attainment purposes. While the impact of ethanol blends on ozone levels is not clear cut, we have assumed here that it is unlikely that ethanol will capture much of the oxygenate market in the summertime in ozone nonattainment areas because it increases gasoline volatility and subsequently increases evaporative HC emissions (4). Seventeen percent of the U.S. population resides in such CO-only areas, while 22% reside in areas requiring reformulated gasoline. MTBE will be used in these latter areas.

The oxygenated gasoline in CO nonattainment areas will be required for "not less than 4 months". We have assumed that on average this gasoline will contain oxygenates 6 months of the year. One-half month's supply on both sides of the time period will be needed to provide buildup and to finish stock off. Some areas will need to use oxygenates for longer than 4 months. We do not estimate any increased use of oxygenates to meet the 3.1% oxygen requirement which may exist in several cities in 2001.

MTBE is produced from approximately 1/3 (wt) methanol and 2/3 (wt) isobutylene. We assume that 67% of the isobutylene will be produced from nonpetroleum sources. This is the current proportion of butanes and isobutanes supplied from natural gas (5). Estimates of the amount of petroleum required in the production of corn-based ethanol vary; we assume 0.09 gals petroleum per gallon of ethanol (6). A 1% fuel economy penalty is assumed with MTBE whether or not the MTBE is 11% or 15% of the fuel, while a 2% penalty is assumed with ethanol.

The "9 city only/15% spillover/MTBE and ethanol" program makes all of the same assumptions as above except that it assumes a 15% spillover of both reformulated gasoline and oxygenated gasoline due to distribution logistics. The "maximum opt-in/no spillover/MTBE only" assumes that all areas which can opt-in to the use of reformulated gasoline do. The estimate assumes no spillover to surrounding areas. Other assumptions remain constant. Including the CO-only areas, approximately 55% of the population is covered. We evaluate the use of MTBE-only to limit the number of scenarios examined. Whatever level of ethanol use may be assumed in these areas, oil displacement will be lower. (For example, if MTBE were substituted for all ethanol use in the "9 city only/15% spillover/MTBE and ethanol" scenario, oil displacement would increase by 37,000 barrels/day [b/d].) The "100% gasoline/MTBE only" program replaces conventional gasoline with reformulated gasoline throughout the country and raises its oxygen content to 2.7% in the CO nonattainment areas. Again, other assumptions remain constant.

<u>Clean Fuel Centrally Fueled Fleets (Sec. 229)</u>. In certain nonattainment areas, vehicles in fleets of 10 or more that are centrally refueled or capable of being centrally refueled must be clean fuel vehicles. The program applies in ozone and CO nonattainment areas with ozone and CO design values of 16 ppm or higher and which have a population of 250,000 or more. Some vehicles are exempt: i.e., rental fleet vehicles, and law

enforcement and other emergency vehicles. The standards for LDVs and light-duty trucks (LDTs) are equivalent to California's low-emitting vehicle (LEV) exhaust standards: 0.075 g/mi non-methane organic gas (NMOG), 3.4 g/mi CO, and 0.2 g/mi NOx. Standards are also set for heavy-duty vehicles (HDVs) up to 26,000 lbs. The program begins in 1998; by model year (MY) 2000, 70% of all new vehicles in the fleets covered by the program must be clean fuel. The program can be delayed to 2001 if vehicles meeting these standards are not being sold in California in 1998.

It is possible that these LEV standards may be met by light-duty gasoline-powered vehicles equipped with pre-heated catalysts and other advanced emission control equipment, and using reformulated gasoline (7). Alternatively, alternative fuels may be used. Because the CAAA provides that the HDV standards may be modified so that HDVs operating on clean-diesel fuel may achieve them, it is assumed that, in fact, the HDV standards will be met with clean diesel fuel, not alternative fuels. Oil displacement from the use of clean diesel fuel is not anticipated.

Two oil displacement estimates are possible. Where it is assumed that gasoline-powered vehicles will meet the LEV standards, oil will be displaced from the use of reformulated gasoline. The fleet program applies in the same 9 cities in which use of reformulated gasoline is required; fleet vehicle use of this gasoline should not be doublecounted. The fleet program also applies in another 17 cities with 8% of the U.S. population. 14 of these 17 cities (with 7% of the U.S. population) are already included in the "maximum opt-in" reformulated gasoline estimate derived above. Many of the 17 will probably receive reformulated gasoline as part of the spillover associated with distribution of reformulated gasoline to the 9 cities requiring it. Therefore, we estimate that in effect, if gasoline-powered vehicles are used to meet these standards, no additional oil displacement will be achieved by the program beyond that which is achieved by the reformulated gasoline program itself.

Alternatively, we estimate if alternative fuels are used, the fleet program will lead to an oil displacement in 2010 of 55,000 b/d. This estimate assumes the following:

- The program starts in 1998.

- Nationwide there are approximately 5.1 million cars and 2.1 million LDTs in fleets of 10 or more covered by the program. Daily rental fleets and police vehicles are not included. Federal, state, and local fleets are included as are other business fleets. These totals will grow at the rate of 1.5% annually. 30% of them operate in areas covered by the program. 50% are or can be centrally-refueled.

- The fuel economy of these vehicles is 23.8 mpg for cars and 17.9 for LDTs throughout the time period covered.

- Car fleets turnover every 30 months and LDTs every 5 years.

- The alternative fueled vehicles (AFVs) are all dedicated vehicles (using the alternative fuel 100% of the time).

The business fleets displace 51,000 b/d while the government fleets displace 4,000 b/d.

California Pilot Test Program (Sec. 229). The CAAA California pilot program requires the production and sale of clean fuel vehicles in California beginning with the 1996 MY. In the first three years of the program 150,000 new clean fuel LDVs and LDTs must be sold annually; beginning in 1999, 300,000 must be sold annually. The clean fuel vehicle standards are to be phased in: by 2001, these vehicles must meet California LEV standards. As in the national fleet program, these vehicles may be able to meet LEV standards with reformulated gasoline and advanced emission control strategies. If not, alternative fuels will be used. The voluntary opt-in to the program by other states is also provided for in the CAAA.

As with the centrally-refueled fleet program, it is possible that gasoline-powered vehicles equipped with pre-heated catalysts and other advanced emission control equipment, and using reformulated gasoline may be used in the California pilot program. If that is the case, then we again estimate that there will be no additional savings due to the use of reformulated gasoline beyond what we have estimated for that program alone. The pilot program was established by the CAAA "to demonstrate the effectiveness of clean-fuel vehicles in controlling air pollution in ozone nonattainment areas". Therefore we expect many of these vehicles to operate in the areas for which we have already developed estimates of reformulated gasoline use.

Alternatively, we estimate that the California pilot program can displace 101,000 b/d by 2010 if alternative fuels are used. This estimate assumes the following:

- Vehicle scrappage follows the national trend for cars for the time period 1978-1989 (8);

- The fuel economies of the vehicles displaced are the same as those assumed for the fleet vehicle program described above;

- Approximately 70% of the vehicles are cars and the remainder LDTs;

- The AFVs are all dedicated vehicles (using the alternative fuel 100% of the time).

No opt-in by other states is estimated since other states are not allowed to mandate sales of AFVs.

A potential overlap exists between this program and the centrally-refueled fleet program. Some of the vehicles in the pilot program will probably be fleet vehicles. Sale of the pilot program vehicles to fleets is specifically allowed for in the CAAA. We estimate that 25% of the population covered by the centrally-refueled fleet program resides in California. Therefore, we estimate that 25% of the oil displacement that can be achieved by the fleet program in 2010 will be achieved in California as a result of the pilot program. This overlap can be deducted from either program total. Here we deduct the overlap from the pilot program and estimate that its incremental oil displacement potential, if alternative fuels are use, is 87,000 b/d.

Low Polluting Fuel Requirement for Urban Buses (Sec. 219). Beginning in MY 1994, all new urban buses are to meet a particulate matter (PM) standard representing at least a 30% reduction and up to a 50% reduction from the 0.1 g/bhph standard otherwise in effect then. EPA is to conduct a testing program to determine whether buses comply with this more stringent standard. If buses do not meet this standard over their full useful life, then EPA must implement a program requiring the use of low polluting fuels in urban buses in Metropolitan Statistical Areas (MSAs) or Consolidated MSAs (CMSAs) of 750,000 population or more. The buses will be required to operate exclusively on methanol, compressed natural gas (CNG), ethanol, propane or other low-polluting fuels. EPA may also extend this program to smaller urban areas for health benefits.

It is possible that urban buses requiring the use of alternative fuels will not be needed and thus will not displace any oil. However, if the buses are unable to meet the particulate standards for the life of the vehicle, then alternative fuels will be required. In that case, we estimate that this program, if applied only in areas of 750,000 or more population, can displace 32,000 b/d. This estimate is based on the following assumptions:

- There are approximately 58,000 transit buses currently in operation and they will increase in number to about 68,000 by 2010.

- These vehicles average 3.2 mpg and travel 33,000 miles/year. Fuel economy and vehicle miles traveled (VMT) will not change significantly over time.

- All transit buses are in urban areas and approximately 69% of them are in MSAs and CMSAs with a population of 750,000 or more.

- The program requiring the use of low polluting fuels will be phased in so that virtually all urban buses operating in these areas in 2010 will operate on low polluting fuels.

- The low polluting fuels will have no petroleum content.

The estimate above assumes 1) a relatively early determination that the buses will not meet the 0.07 g/bhph or 0.05 g/bhph standard over their useful life and 2) a seven year turnover in buses. If it takes more than 2-3 years to make the determination, then the displacement level for 2010 will be lower. However, the ultimate displacement level should be approximately 32,000 b/d if low polluting fuels are required.

Summary Estimate of the Oil Displacement Associated with the Use of Reformulated/Oxygenated Gasoline and Alternative Fuels. Table 2 presents a range of estimates of the oil displacement that can be achieved with reformulated and oxygenated gasoline and alternative fuels. We have used just two of the possible estimates shown in Table 1 for the reformulated/oxygenated gasoline program. If alternative fuels are used in the centrally-refueled fleet program and California pilot program, their use will reduce the amount of gasoline that needs to be reformulated and we have attempted to estimate that reduction. With the assumptions we have used, these three programs plus the use of low-polluting fuels in urban buses can lead to oil displacement levels ranging from 235,000 b/d to 547,00 b/d.

Table 2 Oil displaced from fuel switching in 2010, CAAA mobile source programs (thousand b/d).

Programs	Reformulated/ Oxy Gasoline	Central-ly Fueled Fleets	CA Program	Clean Bus	TOTAL
9 city reformulated/15% spillover/no alt fuels	235	0	0	0	235
9 city reformulated/15% spillover/ alt fuels in fleets and CA	222	55	87	32	396
Maximum opt-in reformulated/no alt fuels	386	0	0	0	386
Maximum opt-in reformulated/alt fuels in fleets and CA	373	55	87	32	547

Fuel Consumption, Light-duty Gasoline Vehicles

The tailpipe emission standards which are assumed to be in effect in 2010 are summarized in Table 3. Light-duty diesel vehicle assumptions are shown in Table 4. The impact of emission standards on light-duty diesel fuel economy is shown in Table 5. A summary of the findings for gasoline and diesel LDVs is presented in Table 6.

Light-duty Vehicle Emission Standards (Sec. 203). The fuel consumption impact of Phase I was evaluated by assuming all gasoline-fueled LDVs are equipped with multipoint fuel injection (MPI) with 3-way, adaptive learning catalytic converter technology, as of 1996. In addition, the impact of normal temperature (75° F) Phase II CO emission standards for gasoline LDVs ≤3750 lbs gross vehicle weight (GVW) was evaluated. The Phase II standards are effective in MY 2003 (at the earliest) if EPA determines further emissions reductions are required to attain or maintain the national ambient air quality standards. The influence of the Phase II NOx and non-methane hydrocarbon (NMHC) standards were not assessed. In practice, fuel consumption would probably be higher than presented here because as NOx is reduced, fuel consumption, CO, and NMHC increases. It has been suggested that the Phase II standards would require alternative fuels for most vehicles. This possibility was not addressed. We assumed CO emissions are not affected by fuel oxygen content, since some studies indicated that this had a negligible impact on emissions from vehicles with MPI/3-way adaptive learning catalytic converters (8,9).

For Phase I, we assume 10% of LDVs are not so equipped by 1996. This estimate is consistent with current rate of adoption of MPI (10). We assume a 3% fuel economy improvement is possible by converting from port-fuel injection (PFI) to MPI (11), and that the average fuel economy for PFI-equipped cars is 27.7 mpg, representing the 1990 fleet average. Fuel consumption is expected to be reduced in the 1996-2003 production vehicles operating in 2010 by 6,300 b/d in 2010. (This ignores the fact that MPI is also being introduced for improved performance, fuel economy, and driveability and the impact of adding this technology cannot be attributed solely to emissions reduction.)

A Phase II standard for CO of 1.7 g/mi at normal temperatures is pending, effective in MY 2003, for LDVs ≤3750 lbs GVW. (As mentioned, only the CO standard was evaluated.) Based on the emission levels reported by Most (8), at least another 50% reduction in emissions over engines with MPI with adaptive learning 3-way catalyst technology is required. We assume the electrically heated catalytic converter is required for compliance, and that fuel consumption is affected by this technology only. It can be argued that some fuel consumption credit be given for installation of MPI systems. However, based on current rates of market penetration, it is likely that vehicles will have these systems regardless of the Phase II CO standard. Because the converter is heated electrically prior to a cold engine startup (typically 40 seconds [s]), fuel energy is required to recharge the battery to a state of charge that existed before the heating cycle. Since the delivered thermal energy to the converter and exhaust gas represents only about 50% of the power available at the battery (12), one normal ambient temperature converter heating cycle requires about 0.015 gallons of gasoline, based on typical charging efficiencies and fuel economy.

The total vehicle startups occurring above 20° F were estimated to estimate the impact on fuel consumption nationally. EPA estimates (13) that 92% of all vehicle miles traveled occurs at temperatures over 20° F. Assuming an average trip length of 17 miles (that is, the electrically heated converter is activated every 17 miles), about 2.58×10^{10} converter activations are required, nationally, per year, at temperatures above 20° F. This increases fuel consumption by 29,000 b/d by 2010. This estimate includes vehicles potentially affected by the clean fuel centrally fueled fleet program and the California pilot test program. These programs will affect 2.8 million passenger cars and 1.2 million LDTs. Assuming alternative fuel use in these programs, fuel consumption for Phase II CO control is reduced by 1,000 b/d to yield at total of 28,000 b/d.

Carbon Monoxide Emissions at Cold Temperatures (Sec. 204). It is assumed that MPI with adaptive learning, 3-way catalyst technology will be adopted to achieve the 10 g/mi cold temperature (20° F) CO standard, phased in by 1996. The fuel benefit attributable to this standard is accounted for in the discussion of Phase I emission standards above.

The Phase II cold temperature standard of (3.4 g/mi for LDVs, 4.4 g/mi for LDTs), effective from MY 2002, is applicable if, as of 1997, 6 or more nonattainment areas have a CO design value of 9.5 ppm or greater. The analysis is similar to that of the Phase II normal ambient temperature CO emission standard discussed above, since both standards may require the use of electrically heated converters. It is estimated that a 90 s heating cycle, consisting of 10 s of pre-crank heating and 80 s of post-crank heating would be required (8,10). The additional gasoline required for recharging the battery and for running the heater during engine operation is estimated to be about 0.03 gallons, based on typical charging efficiencies and passenger car fuel economy.

EPA estimates (13) that 8% of all vehicle miles traveled occurs at temperatures at 20° F or below, resulting in 2.2×10^9 converter activations at cold temperature nationally, per year. The energy consumption in MY 2003 and newer LDVs amounts to 5,000 b/d. Assuming full implementation of alternative fuel use in the California pilot test and centrally fueled fleet programs, the energy consumption for CO control is reduced by 300 b/d, to 4700 b/d.

Refueling Control and Fuel Volatility (Secs. 202 and 216). We have not developed our own estimates of energy changes due to new requirements for vehicle refueling emission controls or the effect on fuel economy of the Phase I and II fuel volatility requirements. These changes may be substantial and therefore we include EPA's estimates (1) in our summary table for light-duty vehicles. It appears that the EPA estimates shown here exclude energy changes in the refinery.

Table 3 Potential tailpipe emission standards for light-duty vehicles, 2010. (g/mi)

Class	Pollutant		Emission Standard
Vehicles, trucks ≤ 3750 lbs (Phase II stds.)	NMHC		0.125
	CO	(ambient)	1.7
		(cold temp)	3.4
	NOX		0.2
	PM		0.08
Trucks 3751-5750 lbs (MY 1996+)	NMHC		0.46
	CO	(ambient)	6.4
		(cold temp)	4.4
	NOX		0.98
	PM		0.10
Trucks > 5750 lbs (MY 1996+)	NMHC		0.56
	CO	(ambient)	7.3
	NOX		1.53
	PM		0.12

Assumes:
--Phase II standards implemented in 2003
--Useful life for ≤3750 lbs class is 10 years, 100,000 miles
--Standards for other vehicles are those cited for 5-year, 50,000 mile useful life.

Fuel Consumption, Light-duty Diesel Vehicles

Phase I (1996) Standards (Sec. 203). The assumptions affecting Phase I analysis are summarized in Tables 4 and 5 (14,15,16,17,18,19,20). Phase I light-duty diesel emission standards are phased in and are applicable to all LDVs and LDTs produced from MY 1996. We assume that half of the diesels sold in 1996-2002 are of the indirect-injection (IDI) type and half are of the direct-injection (DI) type; this is relatively optimistic since DI diesels are just emerging for light-duty application (14). DI diesel fuel economy is generally 10% to 15% greater than that of IDI diesel engines (15). Therefore, given a slower market penetration of DI engines than assumed here, the fuel penalties associated with compliance with Phase I standards would be greater. We assumed a NOx/PM relationship for DI engines which correspond to "conventional technology" as described by Needham et. al. (16). This technology includes combustion modifications for NOx control and catalytic traps to control PM. Typical trap backpressure required to achieve a PM reduction was calculated, assuming compliance with the NOx standard. Next, relationships between fuel economy, trap backpressure and NOx were used to estimate overall fuel economy changes for each light-duty vehicle class. The impact of NMHC and CO emission controls was not assessed. However, CO emissions are typically low in diesel engines and particulate traps would help reduce NMHC emissions as well.

A greater number of diesels are predicted here than in other sources (21,22), primarily because we assume advanced, 3-cylinder, fuel efficient DI engines become available. We estimate diesel passenger car sales in 2010 are equal to the 1981 sales level, and that the same replacement rates are the same as those for gasoline vehicles. This results in an estimate of 7.4 LDVs in 2010, consisting of 4.3 million vehicles which comply with the Phase II standards, and 3.1 million vehicles built between 1996 and 2003, which comply with the Phase I standards.

We went beyond the requirements in Section 217 (Diesel Fuel Sulfur Content) by assuming that a fuel comparable to diesel fuel sold in California ("California" fuel) (23) is available nationally before 2010. It is generally felt that improving diesel fuel quality is critical in reducing emissions. The 10% aromatics limit for California fuel is in most cases more stringent than the Federal specification of a minimum cetane index of 40 (24,25).

Given these assumptions, we estimate about 18,600 b/d of additional diesel fuel will be consumed by MY 1996-2002 diesel passenger cars and 10,100 b/d for MY 1996+ diesel LDTs as a result of the Phase I standards, in 2010.

Phase II Standards (Section 203). The impact of the Phase II standards were evaluated in a similar manner. The Phase II standards are applicable to LDVs (cars and trucks) $\leq$ 3750 lbs GVW. The effect on fuel consumption was estimated by assuming that all diesel vehicles in this class produced after MY 2002 have DI. We assume that the NOx standard can be met by modifying the engine, and that catalytic traps would be required to meet the particulate standard. The NOx/PM tradeoffs corresponding to the "advanced technology" relationship described by Needham et. al. (16) were used. Advanced technology assumes the utilization of high pressure fuel injection, rematched combustion system, and light load timing advance. This represents optimistic and currently unproven engine technology which is assumed to be available by 2003. (It should be noted that given our assumption of advanced diesel technology and some market penetration of lightweight, 3-cylinder diesels, light-duty diesel fleet fuel economy is significantly higher than that for the current IDI fleet.) We estimate the additional diesel fuel consumed by diesel passenger cars and diesel LDTs built between 2003 and 2010 to be 9,900 b/d.

Table 4 Light-duty diesel vehicle assumptions.

Class	Engine Size, Type	Fuel Economy (mpg)	NOx/PM relationship [a]
Passenger Cars <3750			
	2.4 L, IDI	36	FSPM [b] = 8.43*(0.90) ^{FSNOX}
	1.3 L, DI	57	PM = -0.12*NOx + 0.92 (conv. tech)
	2.4 L, DI	41	PM = -0.04*NOx + 0.42 (adv. tech)
Light-Duty Trucks			
≤ 3750	2.4 L, DI	41	PM = -0.04*NOx + 0.42 (adv. tech)
3750-5750	2.4 L, DI	34	PM = -0.04*NOx + 0.42 (adv. tech)
>5750	>2.4 L, DI	24	PM = -0.04*NOx + 0.42 (adv. tech)

Fuel Effect on Emissions

Diesel Fuel	Sulfur (wt%)	Aromatics (vol%)	Percent Reduction [b]	
			NOx	PM
Pre-1994	0.28	29	n/a	n/a
Post-1994, Federal	0.05	29	0%	$4.6x10^{-3}$% of fuel consumed
California spec.	0.05	10	11%	25%

Effect of NOx and PM control on fuel economy

NOx control $y = (1.05)*(0.98)^{x}$

PM control $y = 1 + 0.0456*\ln(1-z)$

y = fraction of baseline fuel economy

x = NOx emissions in g/Bhph

z = average PM collection efficiency over the FTP cycle (as fraction)

References: (14,15,16,17,18,19,20)

[a] NOx/PM relationships for DI engines were adapted from Fig. 9, ref. 16, and test results on advanced DI engines in ref. 15. "Conventional technology" as used here is represented by the trend shown in the uppermost curve in Fig. 9, ref. 16, *adjusted* for the emission data given in ref. 15. The "advanced technology" relationship was estimated in a similar manner using the next uppermost curve in Fig. 9, ref. 16. Heavy-duty emissions trends were extrapolated to lower emission levels. It was assumed heavy-duty diesel NOX/PM relationship approximates light-duty diesel emissions. Emissions relationships for IDI engines were adapted from the average trend shown in ref. 17, Fig. 1.

[b] fuel specific [c] relative to pre-1994 diesel fuel

Table 5 Impact of emission standards on light-duty diesel fuel economy.

Class	Change in fuel consumption, %	
	Phase I[a]	Phase II[b]
≤3750 lbs	+12	+11
3750-5750 lbs	+14	n/a
≥5750-8500 lbs	+13	n/a

[a] Assumptions:
- -- 50% of fleet is DI, (balance is IDI) for ≤3750 lb class
- -- 100% of fleet is DI for other classes
- -- PM traps on all classes
- -- Conventional technology NOx/PM trends and post-1994 Federal fuel (relationships shown in Table 4).

[b] Change relative to pre-Phase I emission standards. Assumptions:
- -- 100% of fleet is DI
- -- Advanced technology NOx/PM trends and California specification fuel (relationships shown in Table 4).

Table 6 Fuel consumption changes in 2010 from light-duty vehicle emission standards (thousand b/d).

	Base	Excluding CA pilot and central fueled fleets
Conventional Motor Vehicles (Sec. 203)		
Gasoline		
Phase I (1996 stds)	- 6.3	- 6.3
Phase II (CO only)	+29.0	+28.0
Diesel		
Phase I (1996 stds)		
Cars	+18.6 (diesel)	+18.6 (diesel)
Trucks	+10.1 (diesel)	+10.1 (diesel)
Phase II		
Cars, Trucks (≤3750 lbs)	+9.9 (diesel)	+9.9 (diesel)
Sec. 203 Subtotal	+61.3	+60.3
Cold Temperature CO (Sec. 204)		
Phase I	n/a	n/a
Phase II	+5.0	+4.7
Refueling control (Sec. 202)--EPA est	-11.9	-11.2 [a]
Fuel Volatility (Sec. 216)--EPA est		
Phase I	-33.9	-32.0 [a]
Phase II	-39.0	-36.9 [a]
Sec. 216 Subtotal	-72.9	-68.9
Total, light-duty vehicles	**-18.5**	**-15.1**

Assumptions:
--Base case: all vehicles are gasoline fueled, including LEVs for centrally-fueled fleets, and clean fuel vehicles in the California pilot test program;
--Gasoline vehicles are equipped with MPI, 3-way, adaptive learning by 1996 and electrically heated catalytic converters in 2003;
--Diesels are equipped with catalytic particulate traps.
[a] Calculated by excluding alternative fueled vehicle fleet assuming full implementation.

Fuel Consumption, Heavy-duty Diesels

The overall methodology to estimate fuel use impact on heavy-duty diesels is similar to that used in the analysis of diesel LDVs. (The fuel use impact on gasoline HDVs and light-duty nonroad gasoline engines was not assessed.) We used heavy-duty diesel fleet projections and fuel consumption from Energy and Environmental Analysis, Inc. (21). Unlike the light-duty diesel analysis, we did not assume an increase in fuel economy attributable to nonemissions related engine/vehicle redesign. The generalized NOx/PM trends from Needham et. al. (16), and trap backpressure and NOx impacts on fuel economy were used to arrive at the changes in fuel consumption.

<u>Heavy-duty Diesel Truck Standards (Sec. 201).</u> Effective from MY 1998, NOx emissions from heavy-duty trucks (>8500 lbs GVW) are limited to 4.0 g/bhph. The PM standard remains at 0.10 g/bhph. In addition, rebuilding practices will be studied by EPA to determine the feasibility of retrofit emission control, presumably on pre-1998 engines. We assumed that the fleet is converted to meet the 1998 emission standards. It is estimated that truck fuel consumption will rise by an average of 3%. Fuel consumption attributable to this standard is estimated to increase by 52,000 b/d.

<u>Nonroad Engines and Vehicles (Sec. 222).</u> Within 12 months of enactment of the CAAA, EPA will complete a study of emissions from nonroad engines and vehicles (other than locomotives). If emissions of CO, NOx, and volatile organic compounds (VOCs) from the nonroad sources are significant contributors to ozone or CO concentrations in areas which have failed the national ambient air quality standards for these pollutants, EPA is to promulgate standards to control these emissions. Within 5 years of enactment of the Amendments, EPA is directed to promulgate emission regulations for new locomotives and locomotive engines.

An important criterion for determining emission standards is the requirement that EPA first consider standards <u>equivalent in stringency</u> to standards for comparable motor vehicles regulated under Section 203 of the Amendments. We interpret "equivalent stringency" as requiring the nonroad engine to achieve the same percent reduction in emissions as its onroad counterpart, tested at its typical duty cycle. The difference in NOx and PM emissions between a conventional and advanced heavy-duty diesel technologies (as defined by Needham et. al. [16]) burning California specification fuel was used. By ignoring the fuel effect of emission reductions, only the impact on engine technology is assessed. Fleet size is assumed to be constant, at the level estimated by Weaver (26). Effect on diesels for construction, high and low speed marine, locomotive, farm, and mobile refrigeration applications were assessed. It is assumed all nonroad diesel sources are controlled in 2010, and that traps are required to meet PM standards.

As a result, a fuel consumption increase of 11%, or 84,000 b/d, is predicted in

2010. The largest increase in fuel consumption is expected from locomotives (25,500 b/d) and farm engines (21,000 b/d).

Urban Bus Standards (Sec. 227). Nonfuel related portions of this section address: 1) potential PM reduction requirements over the 0.1 g/bhph requirement and 2) retrofitting engines with emission controls. Our assumptions are discussed in the section on low polluting fuel requirements, above. An increase in diesel fuel consumption is expected if the 30% PM reduction standard is promulgated as a result of an increase in required collection efficiency of existing traps. We assume a 30%, not 50%, reduction will be promulgated, otherwise all buses would have to be alternative fueled. Assuming the retrofit standards are promulgated by 2000, it is assumed all buses are equipped with improved traps to achieve the 30% reduction, and that all engines have "advanced technology" as defined above.

Using the methodology described in the section on light-duty diesels, a 1% increase in fuel consumption for the typical urban bus is expected from lowering PM from 0.1 g/bhph to 0.07 g/bhph. The increase in fuel consumption is relatively small because we assume particulate traps have been previously installed to meet the 4.0 g/bhph NOx and 0.1 g/bhph PM standard. Additional fuel is consumed primarily from the increase in backpressure required to achieve a higher collection efficiency. Given an urban bus fleet of 68,000, it is estimated about 700 b/d additional fuel will be consumed to comply with the standard. If, instead, low polluting fuels are required in buses operating in areas of 750,000 population or more, then fuel consumption in the remaining 31% of the bus fleet that is not alternative fueled will be 200 b/d.

Table 7 Diesel fuel consumption changes from CAAA heavy-duty vehicle emission standards (thousand b/d, diesel fuel).

Heavy-duty trucks (Sec. 201)		+52.0
Nonroad Engines and Vehicles--Diesel only (Sec. 222)		
Farm	+21.1	
Construction	+20.8	
Marine	+13.2	
Locomotive	+25.6	
Mobile refrigeration	+ 3.5	
Total		+84.1
Urban Bus (Sec. 227)		+0.7 (+0.2 min)
Total, heavy-duty diesel vehicles		**+136.8**

CONCLUSIONS

Table 8 presents a summary of the oil displacement and increased fuel consumption that may occur as a result of the mobile source provisions of the CAAA of 1990. The estimate ranges from 116,000 b/d to 425,000 b/d oil displaced. Use of reformulated and oxygenated gasoline leads to the greatest oil displacement of all the measures discussed. However, the potential displacement achieved with these gasolines varies widely depending upon the degree of spillover which occurs due to distribution logistics. The particular oxygenates used and the petroleum required to produce them also lead to variation in potential displacement.

Alternative fuels may or may not be used to meet the centrally-refueled fleet program, California pilot program, and low-polluting bus requirements of the CAAA. If pre-heated catalysts and reformulated gasoline can be used to meet California's LEV standards, alternative fuels need not be used in the fleet or pilot programs. It is unclear at this time whether urban buses will be able to meet their useful standards which allow them to continue with the use of diesel fuel. If alternative fuels are used in these three programs, they could make a substantial contribution to oil displacement.

Compared to the fuel switching provisions, of the CAAA, light-duty vehicle emission standards have a relatively small impact on oil displacement. However, this represents a direct energy penalty, whereas the fuel switching provisions apply to displacement and do not necessarily imply reduced energy conversion efficiency. EPA's reported (1) fuel volatility controls provide the greatest energy savings in the light-duty vehicle class. We estimated the impact of the Phase II CO standards only, and it is likely that the energy impact of all the provisions within Phase II would further reduce energy efficiency. A relatively large energy penalty is estimated for light-duty diesels assuming tailpipe controls are required in 1996.

Emission standards for nonroad diesel engines and vehicles are predicted to significantly increase fuel consumption. This is not totally unexpected since nonroad sources are not currently regulated. We did not assess the impact on gasoline nonroad engines and vehicles, but we expect similar increases in fuel consumption. The further tightening of the heavy-duty truck standards is also seen to increase fuel consumption. The urban bus particulate standards and retrofit standards are not seen to contribute much to fuel consumption.

Table 8 Oil displaced in 2010 from fuel switching and fuel consumption changes as a result of the CAAA (thousand b/d).

Provision	Max. [a]	Min. [a]
Fuel Switching:		
Reformulated/oxy gas	386	222
Alternative fuel	174	0
Fuel consumption [a]:		
Light-duty stds. (Phase I and Phase II CO only)	18	15
Heavy-duty stds. (Diesel only)	-137	-137
Composite [b] total	425	116

[a] Negative values indicate increase in fuel consumption
[b] Not additive since some scenarios are mutually exclusive.

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