Are Stringent Emission Standards for Heavy-Duty Trucks Worth the Cost?

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ABSTRACT

A study sponsored at Argonne National Laboratory (ANL) by the U.S. Department of Energy's Office of Environmental Analysis investigated the costs, benefits, and cost-effectiveness of requiring heavy-duty trucks to meet gaseous and particulate emission standards suggested or proposed by the U.S. Environmental Protection Agency (EPA) in 1981. The EPA and engine and truck manufacturers disagree over the feasibility of achieving these standards and the expenditure required. Moreover, EPA apparently did not include explicit computation of fuel economy losses in its draft regulatory analyses. The resulting incremental costs, presumably passed on to truck buyers both at time of sale and during the vehicle's lifetime, could be considerable. The greatest variation in cost estimates is related to trap oxidizer technology for heavy-duty diesel particulate control. Although the ANL study arrived at a quantitative estimate of cost-effectiveness in \$/ton of pollutant removed, the values are distributed over a wide range that reflects the continuing unresolved disagreements in control costs. The study also focused more specifically on the likely air quality benefits of the suggested standards in a case-study urban area with a history of nonattainment. While the proposed NO_x standard would result in a 45 percent reduction in total NO_x loading from the current standard, the corresponding reduction of short-term NO_x exposure in prototypical urban corridors of high heavy-truck vehicle-miles traveled would not exceed 35 percent. The resulting health benefits are unknown.

Section 202(a)(3)(A)(ii)-(iii) of the Clean Air Act as Amended 1977 stands as one of the signal manifestations of the egalitarian philosophy of the framers of the mobile-source-related facets of this historic legislation: what applies to cars will also apply (albeit with some delay) to trucks. Mandated in Subsection 202(a)(3)(A)(ii) were exhaust emission standards for the so-called Set II pollutants that

> . . . in the case of hydrocarbons and carbon monoxide . . . require a reduction of at least 90 percent, and . . . in the case of oxides of nitrogen . . . require a reduction of at least 75 percent, from the average of the actually measured emissions from heavy-duty gasoline-fueled vehicles or engines . . . manufactured during the baseline model year (of 1973).

These reduction targets, for trucks rated at gross weights of 8,500 lb and above, were to be met no later than the 1983 and 1985 model years, respectively. Moreover, the potential hazard posed by the particulate emissions from diesel-fueled vehicles did not escape the notice of the Congress, which in 202(a)(3)(A)(iii) called for exhaust particulate standards after model year 1981 that reflect

> . . . the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available for the model year to which such standards apply, giving appropriate consideration to the cost . . .

Thus the percentage reduction requirements for exhaust pollutants from heavy-duty trucks were brought into line with those for automobiles. The basis for particulate reduction was to be the best control technology reasonably available.

That the NO_x and particulate requirements in particular might turn out to be irreconcilable did not at that time occur to or influence the Congress--it was still the era of technology forcing. Nevertheless, the issue did not attain much prominence until EPA issued a Notice of Proposed Rulemaking (NPRM) for the heavy-duty engine particulate emission standard on January 7, 1981, and an Advance Notice of Proposed Rulemaking (ANPRM) for the NO_x exhaust emission limitation on January 19 of that same year (1,2). Each of these notices assigned numerical values to emission reductions previously expressed as a percentage difference from a baseline. The actual proposed value for NO_x in the ANPRM did not represent a 75 percent reduction from the calculated baseline of 6.8 grams per brake-horsepower hour (g/bhph) on the EPA steady-state test (a value that would have been 1.7 g/bhph), but rather a compromise value of 4.0 g/bhph. EPA considered this to be the lowest exhaust rate achievable by trucks using either (a) heavy-duty gasoline engines (HDGEs) without the requirement of control through unproven catalyst devices, or (b) heavy-duty diesel engines (HDDEs) without significant losses in fuel economy. The particulate standard of 0.25 g/bhph, applicable to all heavy-duty trucks but requiring control equipment only for HDDEs, was believed to reflect the best achievable performance of trap oxidizers (the apparent control technology of choice).

Despite this somewhat more lenient interpretation by EPA of the intent of the Congress, vehicle and engine manufacturers expressed dismay. In public testimony and comments submitted to the public docket on these proposals, the manufacturers indicated that

- Trap oxidizer technology for diesel vehicles was not near the degree of durability and reliability necessary for HDDE application.
- Even under an HDDE particulate standard of 0.6 to 0.7 g/bhph, roughly the average level then being achieved by new HDDEs, the lowest controlled noncatalyst (certifiable) emission level for NO_x that is achievable without significant fuel economy and other emission trade-offs was not below about 6.0 g/bhph.
- Any requirement for NO_x control to a level of 4.0 g/bhph or below would result in both substantial fuel consumption penalties in all heavy-duty trucks and, for HDGE, a substantial increase in emissions of HC, which were also to be the subject of rulemaking (3-10).

Thus, the battle lines were drawn.

In an effort to clarify many of the salient issues associated with these standards, the Center for Transportation Research at Argonne National Laboratory (ANL) (Argonne, Illinois) conducted independent analyses of (a) the technological issues associated with achieving the standards, (b) the cost and cost-effectiveness of the standards, and (c) the potential benefits of a 0.25-g/bhph particulate standard at the national level and a 4.0-g/bhph NO_x standard at both the national and local (site-specific) level. The standards were assumed to be in effect with the 1988 model year. Results of these analyses are presented in this paper; for a more detailed discussion, see Singh and Saricks (11).

TECHNOLOGICAL ISSUES

Heavy-Duty Diesel Engines

To meet the proposed NO_x and particulate standards, significant changes in HDDE emission control technology will be required. HDDEs generally do not employ emission control systems to comply with existing federal emission standards, although emission requirements are taken into consideration in HDDE design (12 and July 1983 letter and comments from D.C. Dowdall of Caterpillar Tractor Co. to M.K. Singh). The range of NO_x emissions from current production HDDEs outside California is 6 to 10 g/bhph on the steady-state cycle (13). The range of particulate emissions from national current production engines is 0.3 to 0.8 g/bhph, but the rate generally averages about 0.6 g/bhph.

Technologies under consideration to control HDDE NO_x to 4.0 g/bhph include injection timing retardation, aftercooling, exhaust gas recirculation (EGR), electronic engine control, turbocompounding, and modification of engine design (e.g., modifications to the compression ratio, combustion chamber shape, and spray tip design). Not all of these technologies work equally well on all diesel engines and therefore a variety of emission control systems is likely. Further, some of these technologies require additional development before they can be employed. While injection timing retardation, aftercooling, and turbocharging are essentially developed technologies, development is still under way on EGR and electronic engine controls. Many manufacturers anticipate that electronic engine controls (e.g., to provide more flexible and precise timing of fuel injection) will be available later in this decade (14). In contrast, considerable debate exists within the industry concerning the feasibility of using EGR to reduce NO_x substantially. However, the National Research Council (NRC), in an assessment of technologies available for NO_x control, estimated that EGR would be available by 1990, assuming use of electronic controls (13).

TABLE 1 Trade-Offs Between NO_x Emissions and Particulate Emissions, Hydrocarbon Emissions, and Fuel Consumption *(13)*

Emissions (g/bhph)			Fuel Consumption Penalty (%)
NO_x	Particulates[a]	Hydrocarbons	
8	0.4-0.5	0.6-0.8	0
6	0.5-0.7	0.7-1.4	2.5-4
4	0.6-1.0	0.8-1.7	7-12
2	–[b]	–[b]	15-20

Note: Data are for low-mileage emission levels, as measured by the transient test procedures. Data on NO_x emissions and fuel consumption are from the steady state test procedures for this purpose, the two tests are assumed equivalent.

[a]Particulate trap not included.
[b]Unknown; too few data are available to permit realistic estimates.

Associated with many of these NO_x control technologies are trade-offs in fuel economy and hydrocarbon emissions. Table 1 gives hydrocarbon and particulate emission levels and fuel consumption penalties that should be achievable in the mid-1980s at various NO_x emission levels. These estimates were developed in the NRC study (13) and are generally supported by the manufacturers (3-6). Only low-mileage targets are given in the table, and thus the estimates do not account for deterioration in emissions control with increasing use. Insufficient information is available for determining the appropriate standard. If appropriate deterioration factors and margins to accommodate engine-to-engine variability (based on data from current production engines) are assumed, the standards that could be met would be 1.2 to 1.4 times the low-mileage values given in the table. Only modest additional NO_x control can be achieved without fuel economy penalties or HC and particulate emission levels higher than those currently being achieved (13). In other words, a 4.0-g/bhph NO_x standard could not be achieved for HDDEs without (a) particulate traps to meet the 0.25-g/bhph particulate standard, (b) risking exceedence of the 1/3-g/bhph HC standard, and (c) a substantial fuel economy penalty. Finally, there are no data that show the technical feasibility of achieving the 1.7-g/bhph NO_x standard (13).

Unlike the case for NO_x control, only one major technology is anticipated for particulate control: a trap to intercept particulates in the exhaust. Traps are undergoing intensive development for light-duty diesel engines (LDDEs), and EPA assumed that a trap oxidizer with an efficiency of 60 percent would be available for HDDEs to meet the 0.25-g/bhph standard. The NRC study indicated that HDDE traps could be ready by 1990 (13). However, the feasibility of such HDDE traps in the near future is seriously questioned by the manufacturers. Because many HDDEs are turbocharged and are designed (for durability reasons) to have a lower exhaust temperature than that of LDDEs, the exhaust does not reach the temperatures required by the traps for self-cleaning (3,8). Furthermore, the maximum exhaust flow of an HDDE is much greater than that of an LDDE; the traps for HDDEs therefore must be much larger than those for LDDEs to ensure that undue increases in back pressure do not occur (3,8). Use of auxiliary heating for regeneration of large traps is considered very difficult for HDDEs; it is complicated by the need to apply heat evenly over a large surface (3,8).

Heavy-Duty Gasoline Engines

The major control problems for HDGEs are related to HC and CO emissions. However, some changes in emission controls in these engines can also be anticipated to meet the NO_x standard. (Control of particulates is not a concern with HDGEs.) NO_x levels from current HDGEs are above the 4.0-g/bhph standard on the EPA transient test cycle. Engine modifications and EGR will probably be used for NO_x control in all HDGEs. However, these technologies have also been suggested for HC and CO control in HDGEs, and trade-offs in control of the three pollutants exist. Furthermore, some of these technologies will affect fuel economy. For example, in several tests by manufacturers, EGR led to HC levels at or above 3.0 g/bhph (the standard for HDGEs is currently 1.9 g/bhph on the Motor Vehicle Manufacturers Association test cycle) and fuel economy losses of 6 to 8 percent as low-mileage NO_x targets of 3.0 and 3.3 g/bhph were approached or achieved, or both (6,8). The NRC study concluded that with both EGR and engine calibration, NO_x levels of 3.0 g/bhph could be achieved in vehicles with new engines, but with a 3 to 6 percent loss in fuel economy (13).

Comments

The manufacturers of HDDEs and HDGEs perceive greater difficulty in achieving the proposed NO_x and particulate standards than does EPA. EPA has been more optimistic than the manufacturers about development of emission control technologies, particularly particulate traps; EPA did not consider in its regulatory analysis the potential for increased HC emissions associated with NO_x control, and did not estimate the fuel economy loss associated with NO_x control. The manufacturers, concerned with fuel economy and emissions trade-offs and developmental problems, have proposed that the NO_x and particulate standards for HDGEs be substantially higher than EPA has proposed, that is, 6 to 10.7 g/bhph for NO_x and 0.6 to 0.8 g/bhph for particulates (3,4,6, 9,10 and letter with comments from J. Feiten of G.M. to M.K. Singh).

BENEFITS, COSTS, AND COST-EFFECTIVENESS OF STRINGENT NO_x AND PARTICULATE CONTROL

Emissions Reduction

Estimated total NO_x and particulate emissions attributable to heavy-duty trucks in 1980 (baseline), 1988 (first year of stringent standard), and 1995 (majority of fleet covered) under alternative NO_x standards are given in Table 2. Implementation of the 4.0-g/bhph NO_x standard would result in a 45 percent reduction in NO_x emissions in 1995 from those that would occur under the current 10.7-g/bhph standard. If this 10.7-g/bhph standard remains in effect, NO_x emissions attributable to heavy-duty trucks will increase by more than 50 percent between 1980 and 1995. If the lower standard is implemented, NO_x emissions from trucks will be reduced by 16 percent. Implementation of the 0.25-g/bhph particulate standard would similarly lead to a substantial reduction in particulate emissions from what would otherwise occur by 1995. Even with the standard, particulate emissions from HDDEs will increase slightly by 1995.

Emission factors for NO_x in g/mi used to develop these totals are given in Table 3. They are based on EPA's MOBILE2.5 emission factors (15,16), which take into account assumptions about the age distribution of the fleet, mileage driven per year, ambient atmospheric conditions, speed of operation, and changes in emission control performance over time. Emission factors for particulates used to develop Table 2 are 2.0 g/mi (no control) and 0.7 g/mi (controlled to 0.25 g/bhph) (17). Truck VMT used in the derivation of Table 2 values are given Table 4. Manufacturer weightclass sizes progress from Class IIB (Trucks of 8,501 to 10,000 lb gross vehicle weight) to Class VIII (all trucks of 33,000 lb gross vehicle weight and above). The VMT figures are derived from freight projections developed by ANL (M. Millar, unpublished information, 1983). Further documentation of the derivation of Tables 2-4 is provided by Singh and Saricks (11).

Cost and Cost-Effectiveness of NO_x Control

Estimates of per-vehicle capital costs and lifetime costs per mile increase in fuel consumption associated with NO_x control are given in Tables 5 and 6. The estimates are basically from EPA and NRC reports; manufacturers' cost estimates for NO_x control systems are generally not available (13,22). Within the HDD and HDG truck categories, capital costs and fuel penalties are not expected to vary with vehicle size (weight). Variation does occur in the lifetime cost estimates for increases in fuel consumption because of differences in lifetime vehicle-miles traveled (VMT) and vehicle fuel economy.

ANL, in its study of the cost and benefits of stringent NO_x control, independently evaluated the lifetime costs (both capital and operating) for heavy-duty trucks produced under a 4.0-g/bhph NO_x standard beginning in 1988. EPA's capital cost estimate for NO_x control in HDD trucks was assumed, although modified to assign 50 percent instead of 100 percent of the cost of electronic engine controls to emission controls; in addition, General Motor's (GM's) capital and maintenance cost estimate for HDG trucks was assumed at face value. A range of lifetime fuel penalties was assumed for HDD and HDG trucks to reflect the greatest ranges shown in these tables. Lifetime costs per 1%/mi increase in fuel consumption were determined to be lower than those in the NRC study due to lower lifetime mileage assumptions in the ANL study and differences in as-

TABLE 2 Estimated Total NO_x and Particulate Emissions from Heavy-Duty Trucks Under Alternative Standards for 1980, 1988, and 1995

Vehicle Type	Particulates					NO_x				
	No Standard			0.25 g/bhph		10.7 g/bhph			4.0 g/bhph	
	1980	1988	1995	1988	1995	1980	1988	1995	1988	1995
HDD	0.142	0.186	0.233	0.171	0.148	1.606	2.115	2.644	1.658	1.499
HDG	–[a]	–	–	–	–	0.537	0.545	0.616	0.453	0.302
Total	0.142	0.186	0.233	0.171	0.148	2.143	2.660	3.260	2.111	1.801

Note: Date are in 10^6 short tons.

[a]Virtually no particulates are emitted from HDGEs.

TABLE 3 Fleet Average NO_x Emission Factors for HDD and HDG Trucks by Year Under Alternative Standards (11,15,16)

Vehicle Type	Emission Factors (g/mi) by Year		
	1980	1988	1995
Standard: 10.7 g/bhph			
All HDD	22.70	22.70	22.70
All HDG	9.78	9.82	11.31
Standard: 4.0 g/bhph			
All HDD	22.70	17.79	12.87
All HDG	9.78	8.15	5.54

TABLE 4 Heavy-Duty Truck VMT by Class Size, Fuel Type, and Year *(11,18-20)*

Manufacturer Weight Class	VMT (10^9) by Year		
	1980	1988	1995
Vehicle Type: HDD			
IIB	0	0.923	2.135
III-V	0.248	1.039	2.495
VI	3.067	10.016	16.546
VII	4.042	4.816	5.609
VIII	56.841	67.737	78.888
Total	64.198	84.531	105.673
Vehicle Type: HDG			
IIB	19.861	25.105	27.608
III	3.729	5.565	6.676
IV-V	3.202	1.719	0.352
VI	19.701	16.537	14.101
VII	1.793	0.777	0.353
VIII	1.557	0.675	0.307
Total	49.843	50.378	49.397

Note: Data are also from M. Millar, ANL, 1983 unpublished information.

TABLE 5 Estimated Cost per HDD Truck to Meet 4.0-g/bhph NO_x Standard

Manufacturer Weight Class	Capital/ Maintenance Cost[a] ($)	Lifetime Fuel Penalty (%)	Lifetime Cost of a 1%/mi Increase in Fuel Consumption ($)	Total Lifetime Cost ($)
IIB	NA	NA	NA	NA
III-V	NA	NA	306[b]	NA
VI	NA	NA	342[b]	NA
VII-VIII	NA	NA	1,151[b]	NA
All	733[c]; 1,000[d]	7-12[b]; 9-14[e]	754[c]	NA

Note: Assumes 1.3-g/bhph HC standard and 15.5-g/bhph CO standard.
[a]Where applicable and available.
[b]NRC *(13)*; year of cost data is unknown.
[c]Ford Motor Co. *(22)*; cost data are given in $1980.
[d]Energy and Environmental Analysis *(12)*; cost data are given in $1981.
[e]Ford Motor Co. *(21)*.

sumed fuel economies and price of fuel. The results of this analysis on a lifetime cost increase (¢/mi) basis are given in Table 7. Lifetime cost increases, which are largely due to fuel consumption increases, are higher on a per-mile basis for larger trucks in both HDD and HDG categories. Lifetime cost increases are larger for HDD trucks than for HDG trucks.

ANL estimated the overall cost-effectiveness of the 4.0-g/bhph NO_x standard by using these lifetime cost increases, estimates for VMT by trucks

TABLE 6 Estimated Cost per HDG Truck to Meet 4.0-g/bhph NO_x Standard

Manufacturer Weight Class	Capital/ Maintenance Cost[a] ($)	Lifetime Fuel Penalty (%)	Lifetime Cost of a 1%/mi Increase in Fuel Consumption ($)	Total Lifetime Cost ($)
IIB	NA	NA	NA	NA
III	NA	NA	258[b]	NA
IV-V	NA	NA	258[b]	NA
VI	NA	NA	293[b]	NA
VII	NA	NA	550[b]	NA
VIII	NA	NA	550[b]	NA
All	70[c]; substantially less than 279[d]	3-7[b]; 8[e]	150[d]	1,220[c]

Note: Assumes (a) for Class IIB-III, 1.3-g/bhph HC and 15.5-g/bhph CO standard, and (b) for Class IV-VIII, 2.5-g/bhph HC standard and 40.0-g/bhph CO standard.
[a]Where applicable and available.
[b]NRC *(13)*; year of cost data is unknown.
[c]General Motors *(8)*.
[d]EPA *(22)*; cost data are given in $1980.
[e]Ford Motor Co. *(21)*.

TABLE 7 Lifetime Cost Increases Because of NO_x Control to 4.0 g/bhph

Manufacturer Weight Class	Cost Increases (¢/mi) by Vehicle Type	
	HDD	HDG
IIB	1.2-1.9	0.4-1.1
III-V	1.7-2.8	0.6-1.5
VI	1.7-3.0	0.8-1.9
VII	1.7-3.1	0.9-2.4
VIII	1.8-3.4	1.0-2.5

meeting the 4.0-g/bhph NO_x standard in 1988 and 1995, and the ANL estimates of total NO_x removal that were due to this standard; these results are given in Table 8. The total cost of NO_x control, total NO_x reduction, and cost/ton reduced is greater for HDD trucks than for HDG trucks. However, if the higher lifetime cost estimates for HDG trucks and the lower lifetime cost estimates for HDD trucks were the more accurate estimates, respectively, cost/ton removed could be higher for HDG trucks in both years.

Cost and Cost-Effectiveness of Particulate Control

Considerable difference exists between EPA and some manufacturers over the costs of particulate traps. EPA estimated that the retail price of each HDD truck would increase by $527 to $650 ($ 1980) because of the particulate trap (17). Alternatively, Caterpillar Tractor Company estimated the cost of the trap to be at least $2,000, and GM from $2,000 to $3,500 ($ 1982) (3,8). This wide variation is not easy to explain, but may in part reflect different assumptions regarding research and development costs. Further, EPA expects maintenance costs to be reduced with use of a trap, while Caterpillar does not (3,22). Finally, EPA does not project fuel economy loss with traps, while the manufacturers project at least a 1 percent loss.

Because of this wide variation in cost estimates, ANL assumed in its study a range of costs reflecting EPA's estimates at the low end and Caterpillar's and GM's at the high end. Table 9 gives these assumptions and the resulting cost/mile. By using these results, together with estimates of VMT driven by

TABLE 8 Cost-Effectiveness of NO_x Control to 4.0 g/bhph

Vehicle Type	NO_x Benefit (10^6 tons) 1988	1995	Total Cost for NO_x Removal ($\$10^6$) 1988	1995	Cost/Ton (\$1982) 1988	1995
HDD	0.457	1.145	188-352	1,047-1,945	411-470	914-1,699
HDG	0.092	0.314	27-69	197-505	293-750	627-1,608
Total	0.549	1.459	215-421	1,245-2,450	392-767	853-1,679

TABLE 9 ANL Cost Estimates per HDD Truck to Achieve 0.25-g/bhph Particulate Standard

Manufacturer Weight Class	Capital Cost (\$)	Lifetime Fuel Cost (\$)	Maintenance Savings (\$)	Net Cost[a] (\$)	Lifetime Cost Increase (¢/mi)
IIB	539-645	0-104	0-308	231-749	0.21-0.68
III	539-645	0-175	0-308	231-820	0.21-0.74
IV	539-2,000	0-175	0-308	231-2,175	0.21-1.98
V	617-2,000	0-175	0-402	215-2,175	0.20-1.98
VI	617-3,500	0-355	0-402	215-3,855	0.12-2.08
VII	663-3,500	0-370	0-438	225-3,870	0.12-2.09
VIII	655-3,500	0-662	0-519	136-4,162	0.05-1.44

Note: Costs are expressed in \$1982.
[a]Capital cost + lifetime fuel cost - maintenance savings.

trucks meeting the 0.25-g/bhph standard and the ANL estimates of total particulate removed because of the standard, ANL also estimated the overall cost-effectiveness of the proposed particulate standard. The estimated cost/ton of particulate removed ranges from \$427-\$1,059 in 1988 to \$461-\$10,778 in 1995. The high estimates are 6 to 14 times as high as the corresponding estimates for NO_x control presented previously.

Summary: Cost of NO_x and Particulate Control

Estimates of the cost-effectiveness of total potential additional emission control (particulates and NO_x combined) for both HDD trucks and HDG trucks are given in Table 10. Emission-control costs for HDD trucks are significantly higher than those for HDG trucks, although additional costs will be associated with HC and CO control from HDG trucks. Over the life of a Class IIB or Class III HDG truck, EPA estimates that these costs will range from \$400 to \$900/ton (23). Although these figures are not directly additive to those in Table 10, it is clear that when all control costs are combined, the cost/ton of emission removal from the HDD fleet is greater than that from the HDG fleet.

TRUCKS AND AIR QUALITY IN CITIES: A CASE STUDY

Raw estimates of total emissions reduction, as presented previously, have little to do with the primary purpose of air quality standards, that is, the protection of public health. To focus more selectively on the effectiveness of emission controls on heavy-duty trucks in reducing the threat to public health represented by ambient pollutants, the impact of these controls on reducing ambient NO_x in two high-volume traffic corridors was evaluated. Dispersion of NO_x in these corridors was simulated and potential exposure to NO_x was evaluated.

Traffic Corridors

The choice of prototypical truck traffic corridors for a comparative air quality analysis was governed by availability of data and proximity of the research team to candidate sites. On both counts, locations in the Chicago standard metropolitan statistical area proved superior to other alternatives. Chicago has long been a hub of national freight movement, with extensive inter- and intramodal cargo transfer occurring around the clock. According to D.A. Zavattero, baseline (1975) data on heavy-duty truck movements in the Chicago area had been obtained from the Chicago Area Transportation Study (CATS) (personal communication, September 1983), together with forecasts of local heavy freight activity that included identification and targeting of roadway corridors where extensive movement of commercial goods is expected in the future (24). The researchers' location in relation to these corridors facilitated field surveillance of candidate locations and final selection of those that appeared to be both representative and of interest because of the presence of sensitive receptors. An expressway corridor and an

TABLE 10 Cost-Effectiveness of Particulate Control to 0.25 g/bhph and NO_x Control to 4.0 g/bhph

Vehicle Type	Particulate Control 1988	1995	NO_x Control 1988	1995	Total 1988	1995
HDD	427-10,592	461-10,778	411-770	914-1,699	838-11,362	1,375-12,477
HDG	NA	NA	293-750	627-1,608	293-750	627-1,608

Note: Costs are expressed in \$/ton removed; NA = not applicable.

arterial corridor that contains a major intersection were chosen for microscale air quality simulation.

The central feature of the expressway corridor is an elevated, mile long segment of urban freeway constructed to Interstate system standards. (The segment is actually a link of the Interstate network.) Three lanes of traffic in each direction are separated by a median at least 15 ft wide; alignment is roughly west-southwest to east-northeast. The corridor itself is largely industrial, but the freeway passes over surface streets along which commercial and industrial premises house employees throughout the workday; the closest establishment is 88 lateral meters from the edge of the freeway (25). Numerous heavy-truck trips originate and terminate in this corridor daily.

The arterial corridor is functionally linked to the expressway corridor with respect to the origin-destination points for much of the heavy-duty truck traffic; many of Chicago's intercity truck freight terminals (important break-in-bulk points) are north of this corridor. Considerable truck traffic is channeled along the corridor between these terminals and the heavy-industry districts of western and southeastern Chicago. A key intersection in this corridor is heavily used by commercial traffic turning east toward destinations in southern and southeastern Chicago and north toward the truck terminals and expressway system. This intersection historically has experienced high volumes of heavy-truck movement, and these are expected to continue.

Dispersion Analysis

The CALINE-3 model, developed by the California Department of Transportation and endorsed by EPA for microscale simulation, was used in the dispersion analysis. Because NO_x dispersion was to be simulated, the molecular weight of the pollutant species (hard-coded for CO) was changed from 28 to 46 (NO_x as NO_2) before source compilation. The result did not take into account the reactivity of NO_x species, but carried the assumption that chemical reduction of NO_2 has a negligible effect in the estimation of short-term (<1 hr) concentrations from local emission sources.

The baseline truck network assignment performed by CATS (for which link and turn volumes were graciously provided to the ANL researchers) had generated heavy-truck flow volumes for the study corridors; these were converted to percentages of average daily traffic based on total traffic data (25). The results were used to weight the heavy-duty portion of the 1987 and 1992 time-of-day VMT fractions used by the Illinois EPA in its 1982 NO_2 analysis (26). It was assumed that 1987 splits would reasonably approximate the 1988 simulated distribution and that 1992 splits would serve as a reasonable surrogate for 1995. The sum of the relevant VMT fractions for arterials or freeways in each year (for both HDG and HDD trucks) was multiplied by a factor that made it equivalent to the appropriate value above; all fractions were then renormalized to reflect the revised heavy truck share. Off-peak splits were used because of the higher truck share of off-peak volume. Table 11 presents a summary of the simulation inputs used by MOBILE2.5 and CALINE-3.

Results: Hourly Exposures for Worst-Case Conditions

For the case in which current heavy-duty emission standards are retained through 1995, short-term (hourly average) NO_x exposures undergo no significant reduction throughout the period in the arterial corridor. Exposures to total NO_x species in the roadway itself in 1988 range from about 220 $\mu g/m^3$ (250 ft from the intersection) to 425 $\mu g/m^3$ (in a vehicle actually stopped at the intersection), while exposure at the sensitive-receptor distance from the roadway can reach as high as 400 $\mu g/m^3$ near the interection. By 1995, the corresponding roadway concentration range is 225 to 440 $\mu g/m^3$, and sensitive-receptor exposure is up to 415 $\mu g/m^3$. (Note that NO_2 accounts for 30 to 70 percent of total NO_x.)

Under the same set of heavy-duty standards, the expressway corridor experiences a modest improvement

TABLE 11 Emission and Dispersion Model Inputs

Input	Freeway Corridor	Arterial Corridor
Road azimuth (degrees)	70	Link A: 180 Link B: 90
Link length (m)	1700	Link A: 600 Link B: 300
Wind azimuth (degrees)	185	120
Wind speed (m/s)	1.5	1.5
Stability class	D (urban)	D (urban)
Mixing height (m)	1500	1500
Mixing-cell width (m)	42	31
Background NO_x (ppm)	0.04 (75 $\mu g/m^3$)	0.03 (66 $\mu g/m^3$)
Surface roughness, settling velocity, deposition velocity	0,0,0	0,0,0
Source height (m)		
Above roadway	0.6	0.6
Above datum	9.8	0.6
Receptor heights (m) (above datum)	1.8 (on surface street) 11.0 (on expressway)	1.8
Ambient temperature (°F)	54	54
Altitude (ft)	1,000	1,000
Region	49 states	49 states
Cold-start percentage	38.5	18.5
Composite emission factor (g/mi) from MOBILE2.5		
1988 current	5.6	3.8
1988 stringent	5.1	3.3
1995 current	5.4	2.8
1995 stringent	3.4	1.9
Heavy-duty truck traffic as percentage of average daily traffic	10.6	Link A: 11.7 Link B: 21.3
Bidirectional daytime off-peak average hourly traffic volume	7,800	Link A: 2,500 Link B: 2,200

in worst-case NO_x from 1988 to 1995, but this is due primarily to reduction in NO_x emissions from automobiles. In 1988, conditions appear to be potentially serious: exposures to total NO_x species of more than 930 μg/m³ in the roadway itself (a vehicle occupant could be caught in this situation for 15 to 30 min, depending on traffic), with the sensitive-receptor location on the surface street experiencing up to 415 μg/m³ as the 1-hr average. By 1995, peak exposure has declined to 900 μg/m³ in the roadway and 405 μg/m³ at the receptor. It appears in both cases that the relatively high truck emissions are neutralizing the gains in air quality that otherwise would be achieved in these corridors by the current (or impending) tighter controls on light-duty cars and trucks.

Under the stringent (4.0-g/bhph) NO_x standard for heavy trucks commencing with the 1988 model year, significant reductions are seen in both the arterial and expressway corridor. By 1995, hourly NO_x exposures in excess of 280 μg/m³ in the arterial corridor are confined to the roadway itself, in the immediate vicinity of the intersection. Peak exposures on the expressway have fallen to about 600 μg/m³ and to 280 μg/m³ at the sensitive receptor. Exposure levels under this stringent standard represent a 21 to 35 percent reduction in these corridors by 1995 from exposure levels experienced under the 10.7-g/bhph standard. If high NO_x exposure risks exist today in these corridors, they should diminish significantly or (in the case of the arterial) vanish by 1995 under stringent NO_x control for heavy trucks.

Table 12 presents the modeled concentrations at representative receptor points in each corridor for each year and each emission control stringency case.

Case-Study Conclusions

Two general conclusions can reasonably be drawn from the corridor analysis:

1. The current standard (10.7 g/bhph) would, if left in place, produce an apparent retention of status quo conditions in each of the corridors. That is, the reduced NO_x emissions of the light-duty fleet will, over time, only balance the increased NO_x emissions from heavy-duty trucks because of increased numbers of trucks and (possibly) deterioration of emission control equipment. It should therefore be concluded that, if there is a problem today, it will persist into the future.

2. Stringent NO_x control standards (4.0 g/bhph) for heavy-duty trucks result in a significant net improvement in the arterial corridor. Potential peak NO_x exposures in the expressway corridor are reduced but remain very high.

In addition, although NO_x emissions from heavy-duty vehicles have been shown to be substantial, it has not been established how or whether this gaseous effluent is borne aloft to the upper troposphere. Because these emissions cannot be traced (with current modeling processes) to a substantial distance from their point of origin without considerable conjecture about their buoyancy, it is not yet clear what beneficial effect the stringent NO_x control standards for heavy-duty trucks would actually have in reducing acid precipitation precursor emissions, or if such standards would even constitute an effective ozone control strategy.

CONCLUSIONS

The case for stringent emission controls for heavy-duty trucks is not well grounded in the argument of improved air quality. There are few areas today exceeding the ambient NO_2 standard; retention of the current heavy-duty truck emission standard alone would apparently lead to no net degradation of NO_2. Furthermore, any other grounds, such as reduction of acid rain precursors, are only tenuous if heavy-duty vehicles are considered in isolation. The costs of stringent control are high; whatever justification--beyond the letter of the law--is finally put forward, the ultimate attributable costs of such controls are far from being a bargain.

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TABLE 12 Modeled Hourly Average NO_2 Concentration at Selected Receptors

Corridor	NO_2 Concentration (μg/m³) 1988 Current Standard	1988 4.0-g/bhph Standard for Model-Year 1988	1995 Current Standard	1995 4.0-g/bhph Standard for Model-Year 1988 and Later
Expressway				
Median	811	698	787	527
Downwind lanes	938	806	910	605
Upwind lanes	734	633	713	480
Northeast terminus of link (street level)	523	455	509	351
Sensitive receptor	415	363	404	284
Roadway edge (street level)	465	405	453	315
365 m from roadway (street level)	226	203	221	168
Arterial[a]				
Link A; southbound vehicle stopped for left turn	421	374	438	309
Link A; southbound vehicle 75 m north of intersection	302	274	311	228
Link A; northbound vehicle 75 m north of intersection	268	243	277	206
30 m west of intersection	196	179	200	153
Link B; 30 m east of intersection on north side of street: sensitive receptor	302	268	315	223
30 m east of A, 100 m north of B	132	121	136	108

[a]A is the north-south link; B is the east-west link.

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