Final Report

ON-ROAD MOTOR VEHICLE NO_x EMISSIONS REDUCTION MEASURES FOR THE SACRAMENTO METROPOLITAN AREA

Prepared for
Sacramento Area Council Of Governments
3000 “S” Street, Suite 300
Sacramento, CA 95816

Prepared by
ENVIRON International Corporation
101 Rowland Way, Suite 220
Novato, CA 94945
(415) 899-0700

and

Engine, Fuel, and Emissions Engineering, Inc.
9812 Old Winery Place, Suite 22
Sacramento, CA 95827
(916) 368-4770

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EXECUTIVE SUMMARY

BACKGROUND AND SUMMARY

Nature of This Report

Sacramento Emergency Clean Air and Transportation Pilot Program (the SECAT program) was created by California Assembly Bill (AB) 2511 to help assure that the Sacramento region remains in conformity with its State Implementation Plan (SIP) for air quality attainment. Grant funding under the SECAT program is available to offset the costs of projects that reduce oxides of nitrogen (NOx) emissions from on-road vehicles in the Sacramento federal ozone nonattainment area. A total of $70 million in funding has been allocated for grants under this program, and it is anticipated that these funds will be awarded through several rounds of applications and awards during 2000 and 2001.

This report presents the results of preliminary analyses intended to assess the prospective feasibility and cost-effectiveness of reducing NOx emissions from on-road motor vehicles. This analysis was originally carried out during the legislative consideration of AB 2511, in order to verify that the emission reduction goals could be reached given the proposed budget. The present, final version of the report is the fourth draft; earlier versions were dated April 11, June 2, and June 16, 2000. Comments received from reviewers of those earlier versions have been reflected in the present document.

This revised report is being released and distributed in the hope that it will be useful to prospective project developers and applicants for grant funding under the SECAT program: first as an indicator of the potential emission reductions and cost-effectiveness of different technological approaches, and second as an example of how these quantities can be calculated. As will be stated repeatedly here, this report is *not* intended to be either a comprehensive assessment of all viable NOx control measures nor a prescription of the best combination of such measures. Rather it is an examination of a subset of viable control technologies that *might* be applied. One would expect that the collective expertise and creativity of the automotive and emission control industries will lead to the development of a wide range of measures to reduce on-road NOx emissions, which may or may not include many of the measures evaluated here.

Bluntly stated, this report is fuel and technology "neutral". Proposals put forth for funding will surely be evaluated based on their effectiveness in achieving the needed emissions reductions in a cost effective manner, regardless whether they are based on fuel changes, exhaust treatment devices, use changes, or engine design changes, and regardless of whether they resemble technologies evaluated in this preliminary analysis.

This report is a snap-shot in time and thus is both interim and incomplete. Interim because it represents work in progress on several areas that offer potential for air pollutant NOx emissions reductions. Incomplete because all potential control measures have not been evaluated. As requests for funding are received and processed under the SECAT effort, more up-to-date technical and cost information will surely become available. Future reports will reflect that information.

In later portions of the effort being carried out by the ENVIRON team in support of the Sacramento Area Council of Governments (SACOG), the ENVIRON team will explore additional measures that may offer the potential for NOx emissions reductions, including transportation control measures (TCMs) such as improved mass transit, speed limitations, episodic controls during days of high ozone (so called "episode days"), car pool or bus lanes, and so on. Also in later portions of work to be carried out by the ENVIRON team, the following additional analyses are planned:

- Identification and quantification of the effects of all control measures committed to in the 1994 State Implementation Plan, based on an assessment of current implementation levels.
- Analyses to ensure that SACOG will be able to defend its 1999 and subsequent "conformity" assessments.
- Development of public information or outreach materials that assist in the implementation of cleaner air programs, including but not limited to those described in this report.

Thus, this report narrowly addresses certain changes in the on-road heavy duty truck and bus fleet. These changes include those that reduce N0x emissions through the use of:

- Diesel fuel of special formulations
- Installation of newer technology engines in older vehicles
- Replacement of older vehicles with newer vehicles
- Installation of emissions reduction devices on existing vehicles

Several alternative combinations of such categorical changes are described in detail in this report. The combination of such controls appears to offer substantial opportunity for sufficient NOx emissions reductions to meet the immediate and near term air quality and transportation issues facing the Sacramento area. It is important to point out that the measures described here, and the combinations of those measures that form control strategies that show that the level of NOx emissions reductions desired for the Sacramento region, are not meant to be prescriptive or exclusive. Rather, the purpose of this report is to provide insight and some confidence that the level of emissions reductions desired is an attainable goal. How that goal is specifically achieved will be the result of subsequent support of specific applicant technologies that are chosen by SACOG and other collaborating agencies as offering the most likely cost effective methods for NOx emissions reductions.

While these emissions reductions seemingly meet the immediate needs for achieving an on-road emissions level that is consistent with the requirements of the Federal Clean Air Act and regulations of the U.S. EPA and FHWA, we want to emphasize that the longer term air quality issues (attaining and maintaining air quality that meets the Federal and state of California standards) will require a more in-depth assessment of the entire air quality planning effort in the area. This is best served through a revision to the State Implementation Plan. That plan, required under the Federal Clean Air Act, has been adopted in the Sacramento region in the form of a 1994 revision. Further revision of that plan is the most appropriate process for the development of a sustainable balance between air quality goals and economic expansion of the Sacramento area.

Many decisions go into the selection of the most appropriate measures to be looked to for reducing the level of air pollution in urban areas. These include cost, emissions reduction potential, air quality effects of the emissions change, population exposure dynamics, political and/or other implementation issues, and technical feasibility. Of these, this report only addresses the cost, emissions reduction potential, and technical feasibility. As noted above, the SIP becomes the vehicle to examine many of these other considerations.

Lastly, while the focus of the work being carried out for SACOG and described here is NOx emissions reductions, all of the suggested measures also reduce, in varying degrees, emissions of particulate. This is especially important in light of current research indicating that heavy duty vehicles are an important source of these particulates, and that such particulates have been determined by the California Air Resources Board to be potential cancer causing agents.

The federal Clean Air Act requires that urban areas that have not attained the national ambient air quality standards (NAAQS) must adopt a state implementation plan (SIP) for attaining these standards in order to be eligible to receive federal highway funds. Furthermore, each metropolitan area must demonstrate that it is in conformity with the emissions budgets and other provisions established in the SIP, or it may lose its eligibility. The Sacramento Area Council of Governments (SACOG) is the agency responsible for planning transportation programs and for assuring that these plans conform with the SIP. SACOG has determined that, in order to assure that the Sacramento region continues to conform to the emissions budget stated in its SIP, it may be necessary to undertake additional air pollution control measures to reduce motor vehicle emissions in the region by an additional two tons of NOx per day by 2002, and three tons of NOx per day by 2005. Otherwise, the region could lose eligibility to receive federal funds for highway development.

A consulting team led by ENVIRON International and including Engine, Fuel, and Emissions Engineering, Inc. (EF&EE) as a subcontractor has been contracted by SACOG to assist it in identifying, evaluating, and implementing control measures adequate to achieve the needed reductions in vehicular NOx emissions. This version and earlier versions of this report are the first products of that effort. It provides preliminary descriptions, feasibility evaluations, and cost-effectiveness evaluations for eight types of measures designed to reduce NOx emissions from motor vehicles.

The NOx control measures evaluated in this study are summarized in Table 13. A "strawman" set of control measures that we think would be feasible and cost-effective to achieve the needed two tons of NOx emission reductions from on-road vehicles by 2002 are summarized in Table 14 and three tons by 2005 in Table 15. Again, we emphasize that this is an example. The actual, most cost effective mix of controls selected to attain the needed emissions reductions will be a result of future evaluations by SACOG and collaborating agencies.

The reader should be warned that the evaluations presented in this report are *preliminary*. Many of the technologies evaluated here have never been deployed on a large scale. The demand created by the proposed NOx reduction program is already drawing new technologies into the market and leading to improvements and refinements of existing technologies. Many of the costs used in the analyses for this report are reflective of prototype or low-volume production systems, and it is likely that these would be reduced substantially as production volumes increase over the life of the program.

Thus, while the analysis in this report is sufficient to demonstrate the *potential* for achieving the needed NOx reductions within the levels of funding allocated, and to identify a number of feasible methods for achieving this reduction, it is likely that the final costs of the program may be significantly different (and probably lower) than those estimated here. At the same time, the list of specific emission control measures ultimately employed in the NOx reduction program is likely to include some new technologies that are not evaluated here, and may well exclude some of the measures that are evaluated.

Control measures evaluated in this study include the following:

- CNG School Buses
- CNG Transit Buses
- Emulsified Diesel Fuel
- LNG Garbage Trucks
- LNG Tractors
- Repower with 2 g Electronic Engines
- Repower Electrical Engines with NTE 4 g Electronic Engines
- Repower Mechanical Engines with NTE 4 g Electronic Engines
- Retrofit Lean NOx Catalysts
- Retrofit SCR Catalysts
- Ultra-Low Sulfur Low Aromatic Diesel Fuel

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1. INTRODUCTION

Recognizing that motor vehicles are the largest source of air pollution in most metropolitan areas, the federal Clean Air Act requires that urban areas that have not attained the national ambient air quality standards (NAAQS) must adopt a state implementation plan (SIP) for achieving attainment in order to be eligible to receive federal highway funds. Furthermore, each metropolitan area must demonstrate that it is in conformity with the emissions budgets and other provisions established in the SIP, or it may lose its eligibility. The Sacramento Area Council of Governments (SACOG) is the agency responsible for planning transportation programs and for assuring that these plans conform with the SIP.

The southern Sacramento Valley has had a long history of addressing the serious air pollution problems resulting from its rapid population growth and poor meteorological and topographical setting. Since 1970, a series of air quality plans have been developed at the local, regional, State, and even Federal level to attempt to bring the area into attainment of the various Federal and state air quality standards for protecting public health. While considerable progress has been made, the area still faces a difficult challenge in reaching these standards by the federally mandated date of 2005.

A consequence of the length of time needed for Sacramento to attain the ozone NAAQS has been increasingly stringent and complex requirements in both the federal clean air and transportation funding programs. The ability of citizens to litigate over failures to meet all the requirements of law has also heightened the need for approvable air quality and transportation programs.

In order to assure that the Sacramento Metropolitan Area continues to conform to the emissions budget stated in the SIP, SACOG has determined that it may be necessary to undertake additional air pollution control measures to reduce on-road emissions in the region by two tons of oxides of nitrogen (NOx) per day by 2002, and three tons of NOx per day by 2005. Otherwise, the region could lose eligibility to receive federal funds for highway development. A budgetary allocation of $50 million has been appropriated by the California legislature to fund such additional NOx control measures, and another $20 million in federal CMAQ funds has also been allocated. Legislation (AB 2511) to create the Sacramento Emergency Clean Air and Transportation Pilot Program (the SECAT program) has passed the state Assembly, and - as of this writing - is being considered by the Transportation Committee of the State Senate.

A consulting team led by ENVIRON International and including Engine, Fuel, and Emissions Engineering, Inc. as a subcontractor has been contracted by SACOG to assist it in identifying, evaluating, and implementing control measures adequate to achieve the needed reductions in vehicular NOx emissions. This report is one of the first products of that effort.

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Following this introduction section, Section 2 briefly discusses the motor vehicle NOx emissions in the Sacramento Metropolitan Area. Sections 3 to 6 discuss the NOx emission control measures that we evaluated, as well as present the preliminary cost-effectiveness results for these measures. Finally, Section 7 presents some preliminary conclusions based on these analyses.

2. MOTOR VEHICLE NOx INVENTORY

The inventory of NOx emissions in the Sacramento nonattainment area is dominated by emissions from vehicles and other mobile sources. Out of estimated 2000 emissions of 152.5 tons of NOx per day in the Sacramento region, on-road vehicular sources were estimated to account for 99.7 tons per day, or 65%, while non-road mobile sources accounted for another 24% of total emissions.

For purposes of assessing eligibility for federal highway funds, an area is considered to be in conformity with its SIP if the total emissions from on-road vehicles do not exceed the budget established in the SIP. Reducing emissions from sources other than on-road vehicles would not affect this calculation, and thus could not be used to demonstrate conformity in the near term. For this reason, our study focused only on measures to reduce on-road vehicle emissions. Although the potential for cost-effective emission reductions from non-road sources is also very substantial, these potential reductions were not evaluated in this study.

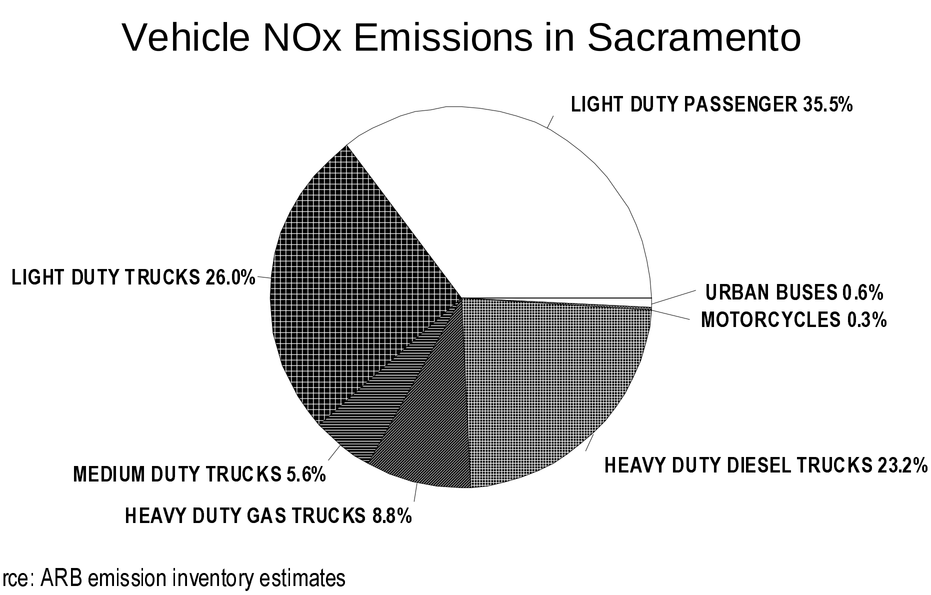

Figure 1. Year 2000 NOx emissions by vehicle class.

The estimated breakdown of vehicular NOx emissions among different vehicle classes is shown in Figure 1. As this figure shows, light-duty passenger cars and light-duty trucks account for the lions' share of NOx emissions: 35.5% and 26.0%, respectively in 2000. Unfortunately, these emissions are distributed across a very large number of vehicles, each one of which emits relatively little. Thus, to achieve any significant further NOx reduction from these vehicles would require dealing with a large number of individual vehicles. Further, late-model passenger cars and light-duty trucks already incorporate highly effective NOx controls, so that the potential for large further reductions is very limited. Thus, with the exception of certain high-mileage vehicle categories such as taxicabs, police cars, and airport shuttles, there is little potential for achieving large, cost-effective emission reductions from light-duty vehicles.

The other large source of NOx emissions among motor vehicles is the heavy-duty diesel category. Heavy-duty diesel trucks account for an estimated 23.2% of the on-road vehicle inventory in the Sacramento region, while transit buses account for another 0.6%. Unlike light-duty vehicles, heavy-duty diesel trucks have relatively large NOx emissions per mile, and usually operate many miles per year. Furthermore, new technologies now appearing in the marketplace can substantially reduce diesel NOx emissions compared to current levels. Thus, there is a high potential for cost-effective reductions in NOx emissions from this category of vehicles. For this reason, the analysis in the sections that follow focuses primarily on heavy-duty diesel vehicles.

Table 1. Vehicle categories targeted for emission reductions[1].

Vehicle Type	Annual Mileage	Conv. Factor Bhp-hr/mile	NOx Emissions		
			g/bhp-hr	g/mile	tons/yr
Truck Tractor – California	50,000	2.6-2.9	3.14-7.93	9.25-21.75	0.51-1.20
Truck Tractor – Federal	50,000	2.7-2.9	4.74-8.00	15.08-35.98	0.83-1.98
School Bus	10,400	2.6	4.5	11.7	0.13
Transit Bus	44,000	4.3	4.5	19.4	0.94
			Fuel usage	**NOx Emissions**	
			gal	**g/gal**	**tons/yr**
Garbage Truck	12,000	N/A	5,734	51.20	0.46

Within the heavy-duty vehicle category, our analysis focuses primarily on the categories of heavy-duty diesel vehicles listed in Table 1, namely truck tractors, garbage trucks, transit buses, and school buses. These will be briefly described in the sections that follow.

Tractors – The tractor is the front, powered, part of a tractor-trailer combination – commonly referred to as an “18-wheeler” or “line-haul truck”. These are among the most common and versatile of all truck types, and are also among the most intensively used. New tractor units are generally used for long-haul trucking, in which it is not unusual for them to accumulate more than 100,000 miles per year. As they age and become less reliable, tractor units tend to gravitate more and more toward short-haul applications within a single metropolitan area. The oldest, highest-emitting tractor units are generally found in short-haul operations such as hauling sand and gravel to construction sites and excavated materials from them, hauling bulk commodities such as rice and wood chips to the Port of Sacramento, and drayage of intermodal containers to and from the rail intermodal facilities in Stockton and Modesto and the ports of Richmond and Oakland.

Because tractor units generally start their lives in interstate trucking, a very high percentage of those in use in California were originally certified to federal rather than California emission standards. Until 1990, federal NOx standards were much less stringent than California’s, so that many tractor units built before that year have engines certified to 6, 8, or even 10 grams of NOx per bhp-hr, compared to 5 g/bhp-hr for most California engines. This, combined with their high fuel consumption per mile and annual mileage estimated at 50,000 per year in the Sacramento area make these trucks attractive targets for measures to reduce NOx emissions.

[1] Complete lists of the model year specific emission factors for these vehicle categories developed based on EMFAC7F can be found in the appendix of the report.

For this analysis, we used an emission rate based on the average heavy-duty vehicle, while a targeted strategy focusing on only the heaviest vehicles would be more effective.

Garbage trucks – Garbage trucks are another truck category that receives intensive use. Although they accumulate only limited annual mileage, their unique operating cycle results in very high fuel consumption and emissions per mile. The fact that garbage trucks tend to operate in large fleets, and that most are either publicly owned or operate under franchise from public agencies also makes them an attractive target from an administrative standpoint.

Transit buses – Transit buses are another category of intensively used heavy-duty vehicles that are publicly owned. For this reason, and because they tend to operate in close proximity to people, buses have historically been singled out for special attention in reducing emissions. The majority of transit buses operating in the Sacramento Region already use low-emitting compressed natural gas engines, so the opportunities for further emission reductions from this source are limited.

School buses – Unlike transit buses, most school buses are not intensively used, and annual NOx emissions per vehicle are much less than for the other categories considered. However, concerns about school children's exposure to diesel exhaust and the ready availability of field-proven CNG alternatives makes these school buses an attractive target for replacement with low-emitting vehicles.

3. DIESEL FUEL MODIFICATIONS

State funds would be used to provide the incremental capital cost and/or operating cost for vehicle fleets to use "low-emission" diesel fuels. These include ultra-low sulfur and low-aromatic petroleum-derived diesel fuel (e.g. ARCO EC-D) and emulsified diesel fuel. While synthetic diesel fuels (e.g. Syntroleum) derived from natural gas seem to be promising "low-emission" diesel fuels, limited technical data and information have precluded us from including fully-synthetic fuels in this analysis.

3.1 LOW-SULFUR LOW-AROMATIC DIESEL FUEL

Table 2 tabulates the potential NOx emission reduction as well as the cost-effectiveness results for the use of ultra-low sulfur, low-aromatic diesel fuel. These results, as well as assumptions used in the analysis, are discussed in the following sections.

Table 2. Cost-effectiveness of "low emissions" diesel fuel.

Model Year	1984-97	1998+
Baseline NOx (g/mile)	14.00	10.17
Fuel Economy (mpg)	5.21	5.54
Annual Mileage	50,000	50,000
Baseline Fuel Use (gal/year)	9,597	9,025
Baseline Fuel Cost ($/year)	$8,637	$8,123
Baseline NOx (ton/year)	0.77	0.56
EC-D Fuel Use (gal/year)	9,338	8,782
EC-D Fuel Cost ($/year)	$9,805	$9,221
Added Fuel Cost ($/year)	$1,167	$1,098
EC-D NOx (ton/year)	0.74	0.54
NOx Reduction (ton/year)	0.03	0.02
NOx Reduction (ton/day)	0.00007	0.00005
Cost-Effectiveness ($/ton)	$43,263	$55,999

Emissions

EMFAC7f NOx emission factors for heavy-duty trucks produced from 1984 to 1997 vary only slightly, ranging from 13.04 to 14.49 grams per mile. For this example, we used the emission factor for a MY1996 vehicle, which was 14.00 g/mile. For 1998 and later-model trucks the NOx emission factors range from 9.73 to 10.94 g/mile, and we used the MY 2000 value of 10.17 g/mile. We note that the actual emission reduction could be considerably more, as EMFAC7F does not account for the prevalence of higher-emitting federal-standard engines among pre-1990 vehicles, or the occurrence of NOx defeat[2] devices among later-model engines.

[2] Here and in several other sections of this report we mention the implications of the diesel emissions controls defeat devices. In general, replacing older engines (pre-2001) with later engines (2001-2007) will result in a reduction of actual emissions that is greater than shown by emissions models. This is significant since the vast majority of vehicles on the road over the timeframe of 2002-2005, the period of interest in this study, would have emissions defeat devices.

ARCO has stated that a 3.5% NOx reduction can be achieved with its EC-D fuel[1], and this information was used in the cost-effectiveness calculation. For illustrative purposes, we have assumed that the fuel would be used in a short-haul tractor operating in and around the Sacramento region, with an assumed annual travel of 50,000 miles per year. Since the costs and emission reductions are both proportional to the amount of fuel consumed, the actual cost-effectiveness would not depend substantially on type of vehicle, as long as vehicle operation was confined to the Sacramento region.

Cost

No changes are required to the vehicle in order to use ultra-low sulfur and low-aromatic diesel fuels. For EC-D, ARCO has indicated that the incremental production cost is about $0.15 compared to existing CARB diesel fuel, but that fuel economy can also be expected to improve by 2.7%. These assumptions were used for the cost-effectiveness analysis.

Cost-effectiveness calculations are properly based on social costs, excluding the effects on transfer payments such as fuel tax. For this calculation, we assumed a social cost (i.e. pump price less state and federal taxes) of $0.90 cents per gallon of California diesel, and $1.05 per gallon for EC-D or an equivalent fuel.

Emission Reductions

The reduction in NOx emissions would depend on the baseline NOx levels of the engine using the fuel. For an engine certified to pre-1998 California emission standards, the NOx reduction would be about 0.03 tons per year, or 0.00007 tons/day for EC-D fuel. For 1998 and later engines, the reduction would be about 0.02 tons per year. Higher NOx reductions could be achieved by using the fuel in pre-1990 trucks equipped with federal engines certified to higher NOx levels.

Cost-effectiveness

The cost-effectiveness of this measure would depend on the NOx level of the engine. For California pre-1998 engines, the cost-effectiveness would be about $43,000 per ton of NOx reduced, and about $56,000 per ton for 1998 and later-model engines.

Technical Implementation Feasibility and Ranking

The feasibility of requiring HD vehicles to use the ultra-low sulfur, low-aromatic diesel fuel would depend on the fuel availability, and the demonstration of the fuel on engines in terms of fuel consumption, performance and potential engine durability problems. Also, there is still a need to demonstrate that this fuel would be available for larger scale commercial applications.

Political/Social/Public Acceptance

Using clean diesel fuels would depend on the acceptance of vehicle owners/operators of the fuels that potentially would increase the fuel costs and would affect the engine performance and durability.

3.2 Diesel Fuel Emulsions

In this proposed control measure, state funds would subsidize the costs of using emulsion diesel fuels. Several companies are now developing fuels combining diesel fuel in an emulsion with water and sometimes with alcohols. The percentage of non-diesel components in the fuel varies among the different emulsion systems under development, as does the degree of reduction in NOx. Generally, the more non-diesel components, the greater the NOx benefit, but the greater the potential effects on engine power output and durability. Table 3 shows the cost-effectiveness calculation for one emulsion fuel system.

Table 3. Cost-effectiveness of diesel emulsion fuel.

	1984-97 Engines		1998+ Engines	
	Baseline	**w/ Emulsion Fuel**	**Baseline**	**w/ Emulsion Fuel**
Certification NOx	5.0	5.0	4.0	4.0
Annual Mileage (miles)	20,000	20,000	20,000	20,000
Diesel miles/gallon	5.21	4.43	5.54	4.71
Fuel Cost/mile	$0.30	$0.36	$0.28	$0.33
Fuel Cost/year	$6,039	$7,105	$5,679	$6,681
Incremental Fuel Cost/year		$1,066		$1,002
NOx g/mile	14.00	11.20	10.17	8.14
NOX tons/year	0.31	0.25	0.22	0.18
NOx Reduction tons/year		0.06		0.04
NOx Reduction tons/day		0.0002		0.0001
Cost-Effectiveness ($/ton)		17,278		22,364

Emissions

As noted earlier, EMFAC7F NOx emission factors for pre-1998 heavy-duty trucks are about 14.0 g/mile. For 1998 and later trucks, the NOx emission factor is about 10.17 g/mile. Based on a technical presentation by Lubrizol[2], we assumed that the use of emulsion fuel would reduce NOx emissions by 20%, while increasing volumetric fuel consumption by 15%.

Cost

Lubrizol indicated that the use of its emulsion fuel would entail no incremental capital cost, while the fuel would sell at the same price as diesel on a volumetric basis. Thus, the only cost would be due to the 15% increase in volumetric fuel consumption. Therefore, the assumed profit of the fuel/water emulsion supplier is approximately $0.39 per gallon of diesel fuel, which may be a subject of negotiation.

Emission Reductions

The emission reduction would be proportional to the amount of fuel used. For illustrative purposes, we have calculated the effect on emissions from a heavy-duty tractor traveling 50,000 miles per year. Higher NOx reductions could be achieved if the fuel were to be used by vehicles equipped with federal engines certified to higher NOx levels.

Cost-effectiveness

The cost-effectiveness of this measure would depend on the baseline level of NOx emissions of the engine. For 1998 and later California engines, the cost-effectiveness would be about $22,000 per ton of NOx eliminated, and for 1997 and earlier engines, about $17,000 per ton. For older federal engines certified to NOx levels in the 6 to 10 g/bhp-hr range, the cost-effectiveness would be proportionally better.

Technical Implementation Feasibility and Ranking

The feasibility of requiring vehicles to use the emulsion fuel would depend on the fuel availability, and demonstrated effects of the emulsion fuel on fuel consumption, performance and engine durability. Without engine adjustment, which is not likely feasible, the use of fuel/water emulsions will result in a reduction of the maximum power of the engine.

Political/Social/Public Acceptance

Again, using clean diesel fuels would depend on the acceptance of vehicle owners/operators of the fuels that potentially would increase the fuel costs and would affect the engine performance and durability.

4. ALTERNATIVE FUELS

4.1 NEW LNG GARBAGE TRUCKS

We analyzed two scenarios. In the first one, State funds would pay the entire cost of buying new LNG garbage trucks to replace existing diesel trucks. This tends to overstate the cost per ton, since it does not account for the residual value of the diesel truck being replaced, nor for the fact that a certain number of diesel trucks must be replaced each year in any case. In the second scenario, State funds would be used only to pay the *incremental* cost of buying new dedicated LNG garbage trucks instead of new trucks using diesel engines. The County Sanitation Department or private garbage collection service would be responsible for an amount equal to the cost of a new diesel truck, but would experience significant savings in fuel cost. Cost-effectiveness analyses for these two scenarios are shown in Table 4.

Table 4. Cost-effectiveness of LNG in garbage trucks.

	Diesel	LNG	
	Baseline	whole truck	incremental cost
Certification NOx Standard	4.0	2.0	2.0
Capital Cost	0	150,000	40,000
Useful Life (years)	8.0	8.0	8.0
Annualized Incremental Capital Cost ($/yr)	0	23,208	6,189
Daily fuel consumption (gal)	22.0	41.1	41.1
Annual Fuel Consumption (gal)	5,736	10,726	10,726
Fuel Cost/year	$9,023	$8,299	$8,299
Net Cost/Year		$22,484	$5,465
NOx g/gallon	51.23	13.70	13.70
NOx tons/year	0.32	0.16	0.16
NOx Reduction tons/year		0.162	0.162
NOx Reduction tons/day		0.00044	0.00044
Cost-Effectiveness ($/ton)		138,952	33,771

Emissions

We assume that a new diesel garbage truck would be certified to the 1998 4.0 g/bhp-hr standards, and would have actual EMFAC7F NOx emissions of about 51.2 g/gal of fuel used. Because of their unique operating cycle, garbage trucks consumer much more fuel and produce much more emissions per mile than do most other types of heavy-duty vehicles. For this reason, fuel consumption is a better indicator of emissions than is mileage.

The new LNG garbage trucks are assumed to be certified to a 2.0 g/bhp-hr standard, with an average NOx emission factor of 25.62 gram/gal of LNG. Data provided by the Sacramento government operators indicated that the average daily fuel usage for their garbage trucks is about 22 gallons or about 6,000 gallons per year. Using these values, the NOx emissions in ton per year were calculated.

Cost

The cost of a diesel garbage truck was estimated at $110,000, while the incremental cost for an LNG truck was estimated at $40,000 based on information provided by Mack Trucks. The LNG option cost will likely decline over time – for example, the incremental cost of a CNG school bus, with a similar engine and more expensive fuel system, is less than $20,000. The incremental cost for a dual-fuel LNG/diesel engine, LNG fuel system, and catalytic converter would be about $25,000. The $150,000 cost was used for this analysis. We also assume energy consumption 10% greater for the LNG truck than a similar diesel.

Emission Reductions

NOx emissions would be reduced by about 50% compared to diesel levels, while PM emissions would be reduced 80% or more. Potential emission reductions amount to 0.16 tons of NOx per year per vehicle or 0.00044 tons of NOx per day per vehicle.

Cost-effectiveness

The costs per ton for the first scenario are rather high at $140,000 per ton of NOx eliminated, as this calculation fails to account for the benefit of the new truck to the user. If only the incremental capital cost for the LNG system is considered (i.e. $40,000), the costs per ton are much lower. The incremental capital cost for the LNG engine and fuel system would be largely offset by the fuel cost savings to the user, giving a net cost of about $34,000 per ton of NOx eliminated. The cost effectiveness would be substantially reduced, by about half, if the emission rate per mile were in fact higher than assumed here using the lower conversion factor.

Technical Implementation Feasibility and Ranking

LNG trucks using both dedicated and dual-fuel engines have operated successfully for several years. Engine suppliers indicate that the assumed 2.0 g/bhp-hr NOx level is achievable with present technology. Also, engine operators are expected to benefit from the fuel cost savings without additional investment.

Political/Social/Public Acceptance

Widespread use of LNG may pose some safety concerns for the public, but these are considered to be manageable. Participation by truck operators would be voluntary, so should meet little resistance.

4.2 NEW ULEV LNG TRACTORS FOR SHORT-HAUL SERVICE

State funds would be used to purchase a fleet of "city" truck-tractors designed for liquefied natural gas (LNG) fuel. Engines would be certified to NOx and PM levels at least 50% below current standards. LNG fuel would be provided by small liquefaction projects already under development. The trucks would be leased to state and federal agencies, trucking fleets, and owner-operators for use in short-haul pickup and deliveries for cargo such as mail, intermodal containers, wood chips and bulk agricultural products to and from the Port of Sacramento, sand and gravel for construction, etc. Lease terms would be structured to be attractive to truckers who presently use older trucks with higher NOx and PM emissions, on the condition that these trucks are to be disposed of outside California.

Table 5. Cost-effectivness of LNG tractors in short-haul service.

	Diesel	Dedicated LNG		Dual Fuel	
	Baseline	whole truck	incremental cost	whole truck	incremental cost
Certification NOx	4.00	2.00	2.00	2.00	2.00
Annual Mileage (miles)	50,000	50,000	50,000	50,000	50,000
Incremental Capital Cost	0	110,000	40,000	105,000	25,000
Useful Life	12.00	12.00	12.00	12.00	12.00
Annualized Capital Cost ($/yr)	0	12,411	4,513	11,847	2,821
Diesel gal/mile	0.18	0.00	0.00	0.02	0.02
LNG gal/mile	0.00	0.34	0.34	0.28	0.28
Fuel Cost/mile	$0.28	$0.26	$0.26	$0.24	$0.24
Fuel Cost/year	$14,198	$13,058	$13,058	$12,104	$12,104
Net Cost/Year		$11,271	$3,373	$9,752	$726
NOx g/mile	9.25	4.62	4.62	4.62	4.62
NOX ton/year	0.51	0.25	0.25	0.25	0.25
NOx Reduction ton/year		0.25	0.25	0.25	0.25
NOx Reduction ton/day		0.0007	0.0007	0.0007	0.0007
Cost-Effectiveness ($/ton)		44,267	13,249	38,303	2,853

Emissions

A NOx emission factor of 9.25 g/mile was used as the baseline emission factor for new diesel vehicles in 2002. It should be noted that the actual emission reduction could be considerably more, as EMFAC7F does not account for the occurrence of NOx defeat devices among later-model engines. It could also be much higher targeting only the heavier vehicles. The new LNG tractors to be purchased are assumed to be certified to a 2.0 g/BHP-hr standard, equivalent to about 4.62 grams per mile. The program would target heavily-used short-haul trucks operating in and around the cities, with an assumed annual travel of 50,000 miles per year.

Cost

The cost of a full-size diesel tractor is quoted at about $75,000. The incremental cost for a dedicated LNG/diesel engine, LNG fuel system, and catalytic converter are estimated very conservatively at $40,000. This estimate reflects short-term, low-volume pricing for the LNG engine, and the incremental costs are expected to decline substantially in the future. Energy consumption for the LNG engine is assumed to be 10% higher than the diesel. Dual-fuel engines[3] are also available, at an incremental cost (installed) of around $25,000.

[3] Dual-fuel engines have the advantage of being less dependent upon fuel availability limitations. However, they f require some method to assure that the higher emitting diesel fuel is not used when the lower emitting LNG should be. Since LNG is cheaper than diesel, truckers would be incented to use it wherever possible. Additional incentives for LNG use can now be programmed into the dual-fuel engines' control systems. For the purposes of this study, we have assumed that the emissions are characteristic of LNG fuel only.

Emission Reductions

NOx emissions would be reduced by 65% and PM emissions by about 90% compared to pre-1991 diesel levels. Potential emission reductions amount to 0.25 tons per year of NOx and 120 pounds of PM per year per vehicle replaced. The effect on mass of VOC emissions is uncertain, but VOC reactivity and toxicity would be reduced.

Cost-effectiveness

The net costs of this measure to the State would depend on the terms of the lease. Each tractor would cost about $110,000; amortized across 12 years at 5% interest this would come to $12,400 per year. If use of the truck were *given* to the operator free of charge, this would come to about $44,000 per ton of NOx. If the operator were willing to pay a major portion of the current diesel truck lease rates of $1,400 per month, the State would potentially make money on the deal depending on the pay back period (i.e. there would be negative cost). To entice owners of pre-1994 tractors to sell them and lease LNG units, it might be necessary to offer these at a cost comparable to the carrying cost of older tractors – estimated at $8,000 per year. Cost-effectiveness in this case would be about $8,000 of cost to the state per ton of NOx eliminated. Net savings to the truck operator would exceed the cost to the state, so that the net social costs of this measure would still be negative.

Technical Implementation Feasibility and Ranking

LNG trucks using both dedicated and dual-fuel engines have operated successfully for several years. Engine suppliers indicate that the assumed 2.0 g/bhp-hr NOx level is achievable with present technology for both dedicated and dual-fuel engines.

Political/Social/Public Acceptance

Widespread use of LNG may pose some safety concerns for the public, but these are considered to be manageable. Participation by truck operators would be voluntary, so should meet little resistance.

4.3 New CNG School Buses

State funds would be used to pay the incremental cost of buying new dedicated CNG school buses instead of new buses using diesel engines. The County School Districts would be responsible for an amount equal to the cost of a new school bus, but would experience significant savings in fuel cost.

Table 6 tabulates the cost-effectiveness results of this measure.

Emissions

Based on EMFAC7F, a medium HDDV (like a school bus) with a diesel engine meeting 1998 4.0 g/bhp-hr standards would have 2002 NOx emissions of 8.0 g/mile.

The new CNG school buses are assumed to be certified to a 2.0 g/bhp-hr standard, with an emission factor of 3.96 g/mile.

Using the results from a study done by the Oak Ridge National Laboratory[3], an annual travel of 10,400 miles per year for school buses is used in this analysis.

Table 6. Cost-effectiveness of purchasing CNG school buses in place of diesel.

	Diesel	CNG
Certification Standard	4.00	2.00
Annual Mileage (miles)	10,400	10,400
Incremental Capital Cost	0	25,000
Useful Life	12.00	12.00
Annualized Incremental Capital Cost ($/yr)	0	2,821
Conversion Factor - BHP-hr / mi	2.25	2.25
Diesel gal/mile	0.17	0.00
NG gal/mile	0.00	0.31
Fuel Cost/mile	$0.26	$0.20
Fuel Cost/year	$2,727	$2,057
Net Cost/Year		$2,151
NOx g/mile	8.00	3.96
NOX tons/year	0.09	0.05
NOx Reduction tons/year		0.05
NOx Reduction tons/day		0.00013
Cost-Effectiveness ($/ton)		46,391

Cost

The incremental cost of a dedicated CNG school bus compared to a similar diesel was estimated to be about $25,000. We also assume energy consumption 10% greater for the CNG bus than a similar diesel. This is consistent with in-use experience, although some recent data show equal energy consumption between diesel and the latest-technology CNG school buses.

Emission Reductions

NOx emissions would be reduced by about 50% compared to diesel levels, while PM emissions would be reduced 80% or more. Potential emission reductions amount to 0.05 tons of NOx per year per vehicle or 0.00013 tons of NOx per day per vehicle.

Cost-effectiveness

The cost-effectiveness for this measure is rather high at about $46,000 due to the lower NOx reduction potential resulting from the relatively low vehicle mileage traveled.

Technical Implementation Feasibility and Ranking

CNG school buses have operated successfully in California for a number of years.

Political/Social/Public Acceptance

While many School Districts have some experience with CNG buses due to the California Energy Commission's Clean School Bus Program, widespread use of CNG may pose some safety concerns for the public, but these are considered to be manageable.

4.4 NEW CNG TRANSIT BUSES

State funds would be used to pay the incremental cost of buying new dedicated CNG transit buses instead of new buses using diesel engines. The County Transit Authorities would be responsible for an amount equal to the cost of a new transit bus, but would experience significant savings in fuel cost. Table 7 tabulates the cost-effectiveness results for this measure.

Table 7. Cost-effectiveness of purchasing CNG transit buses in place of diesel.

	Diesel	CNG
Certification Standard	4.0	2.0
Annual Mileage (miles)	44,000	44,000
Incremental Capital Cost	0	50,000
Useful Life (years)	12.00	12.00
Annualized Incremental Capital Cost ($/yr)	0	5,641
Conversion Factor - BHP-hr / mi	4.30	4.30
Diesel gal/mile	0.26	0.00
NG gal/mile	0.00	0.49
Fuel Cost/mile	$0.41	$0.38
Fuel Cost/year	$17,979	$16,633
Net Cost/Year		$4,295
NOx g/mile	15.12	7.56
NOx ton/year	0.73	0.37
NOx Reduction ton/year		0.366
NOx Reduction ton/day		0.0010
Cost-Effectiveness ($/ton)		$11,725

Emissions

Based on EMFAC7f, a transit bus with a diesel engine meeting 1998 4.0 g/bhp-hr standards would have 2002 NOx emissions of 15.12 g/mile.

The new CNG transit buses are assumed to be certified to a 2.0 g/bhp-hr standard, with NOx emissions of 7.56 g/mile.

Using the results from a study done by the Oak Ridge National Laboratory[3], annual travel of 44,000 miles per year for transit buses is used in this analysis.

Cost

The incremental cost of a dedicated CNG transit bus compared to a similar diesel was estimated to be about $50,000. We also assume energy consumption 10% greater for the CNG bus than a similar diesel.

Emission Reductions

NOx emissions would be reduced by about 80% compared to diesel levels, while PM emissions would be reduced 60% or more. Potential emission reductions amount to 0.366 tons of NOx per year per vehicle or 0.001 tons of NOx per day per vehicle.

Cost-effectiveness

The cost-effectiveness for this measure is very attractive at $12,000.

Technical Implementation Feasibility and Ranking

CNG transit buses have operated successfully for several years, including the Regional Transit in the Sacramento County.

Political/Social/Public Acceptance

While many transit authorities have some experience with CNG, widespread use of CNG may pose some safety concerns for the public, but these are considered to be manageable as proven in the Sacramento Regional Transit.

5. REPOWERING EXISTING VEHICLES

5.1 REPOWERING OLDER TRUCKS WITH MY 2000 ENGINES

State funds would be used to replace the existing high-NOx engines on older tractor-trailer rigs with new electronic engines certified to a 4.0 g/bhp-hr standard. Replacements would be performed at the time that the existing engine would require an overhaul in any event. To be eligible for purchase, the new engines would also have to meet not-to-exceed limits of 4.0 g/BHP-hr anywhere in their normal operating range.

New engines designed to meet the 4.0 g/bhp-hr standard all use electronic controls. The diesel engines found in existing heavy-duty tractors include both mechanically-controlled and electronically-controlled models. Electronic controls were introduced by Detroit Diesel on its Series 60 engines in the mid-‘80s, and by Caterpillar on its 3176 and 3406 PEEC engines in the late 1980s. Because of differences in engine instrumentation, gauges, and other electronic components, it is more costly to replace a mechanically-controlled engine with an engine having electronic control than to replace one electronically-controlled engine with another. However, some diesel repair shops have experience in making these replacements, and can do so at a moderate additional cost[4]. New electronic systems have also been developed by aftermarket suppliers specifically to interface new electronic engines to existing instrument clusters designed for mechanical engine inputs.

Table 8: Cost-effectiveness of replacing an older electronic engine with one meeting current standards.

	Diesel NTE 4.0g	California	Federal Engines	
		84-97	79-89	1990
Certification NOx Level	4.0	5.0	10.7	6.0
NOx g/mile	9.25	14.00	20.87	20.13
Annual Mileage (miles)	50,000	50,000	50,000	50,000
Incremental Capital Cost	25,000	5,000	5,000	5,000
Useful Life	5	5	5	5
Annualized Incremental Capital Cost ($/yr)	5,774	1,155	1,155	1,155
NOx tons/year	0.51	0.77	1.15	1.11
NOx Reduction tons/year		0.26	0.64	0.60
NOx Reduction tons/day		0.0007	0.0018	0.0016
Cost-Effectiveness ($/ton)		17,665	7,219	7,710

Both existing electronic and mechanical engines would be eligible for replacement under the proposed program. Retrofitting the former would cost less, but the PM benefits would also be less, as PM emissions tend to be lower from electronic engines. Table 8 shows the cost-effectiveness calculation for replacing an older electronic engine with one meeting current standards. Table 9 tabulates the cost-effectiveness results of replacing a mechanical engine with one meeting current standards. In both cases, the primary focus would be on replacing pre-1990 federal engines that had been certified to higher NOx emission levels. Typical certification NOx levels for the heavy-heavy duty engines used in tractors ranged from 6 to 11 gram per bhp-hr.

Table 9. Cost-effectiveness of replacing an older mechanical engine with an electronic engine meeting current standards.

	Diesel NTE 4.0 g	California 84-97	Federal Engines	
			79-89	1990
Certification NOx Level	4.0	5.0	10.7	6.0
NOx g/mile	9.25	14.00	20.87	20.13
Annual Mileage (miles)	50,000	50,000	50,000	50,000
Incremental Capital Cost	30,000	5,000	5,000	5,000
Useful Life	5	5	5	5
Annualized Incremental Capital Cost ($/yr)	6,929	1,155	1,155	1,155
NOx tons/year	0.51	0.77	1.15	1.11
NOx Reduction tons/year		0.26	0.64	0.60
NOx Reduction tons/day		0.0007	0.0018	0.0016
Cost-Effectiveness ($/ton)		22,082	9,024	9,638

Emissions

Again, we used the emission factor of 14.00 g/mile for 1984-1997 vehicles. For 1998 and later-model trucks, we used the emission factor for MY 2000 vehicles, 10.17 g/mile. The new electronic engines are assumed to be certified to an NTE 4.0 g/HBP-hr standard, with an emission factor equivalent to 9.25 grams per mile. Again, the program would target the highly used short-haul trucks in and around the cities, with an assumed annual travel of 50,000 miles per year.

Cost

The cost of installing a new electronic engine in place of an old one in the 300 to 350 hp range was estimated to be about $30,000, while the avoided cost of overhauling the existing engine was estimated at $5,000. The cost to install an electronic engine in place of an existing mechanical engine was estimated to be about $35,000, or about $5,000 more than replacing an electronic engine.

Emission Reductions

The reduction in NOx emissions would depend on the NOx levels of the existing engine that is replaced. For an engine meeting California emission standards (and not equipped with defeat devices), the reduction would be minimal – about 0.26 tons per year. However, many older tractor rigs are equipped with federal engines designed to much higher NOx levels. Since most electronic engines of this vintage are equipped with defeat devices, their real-world emissions are much higher than certification levels, and the potential benefits of repowering are also correspondingly large.

Cost-effectiveness

The cost-effectiveness of this measure would depend on the NOx emissions of the engine being replaced. For repowering older electronic engines, the cost-effectiveness would range from $7,000 to $18,000. For repowering mechanical engines, the range is from about $9,000 to $22,000 per ton. By selecting only engines with moderately high NOx emissions, it should be possible to ensure that cost-effectiveness would fall into the lower range. Also, the cost effectiveness can be improved by targeting only the most heavily used vehicles, rather than the average heavy-duty trucks.

Technical Implementation Feasibility and Ranking

The feasibility of repowering older trucks with new engines is well-established, and such modifications are not uncommon. Special technologies have also been developed to adapt the outputs from new electronic engines to match the instrument panels of older trucks designed for mechanical engine signals.

Political/Social/Public Acceptance

Repowering with a new engine instead of overhauling their existing engine would offer truck owners the possibility to save considerably on maintenance, and possibly fuel costs. If the incremental costs of this repowering were covered by the State, it is likely that this would be an attractive option for truck owners and operators.

5.2 REPOWERING WITH MY 2002/2003 ENGINES

Under the terms of the consent decree that settled the "defeat device" lawsuit by ARB and EPA against the principal diesel engine manufacturers, these manufacturers are required to bring to market by October, 2002 diesel engines that will meet the 2004 emission standards. These emission standards call for NOx+NMHC emissions of 2.5 grams per bhp-hr. Since NMHC from diesels are low, and can be reduced further by catalytic aftertreatment, we estimate that NOx emissions from these MY 2002/2003 engines will be about 2.2 g/bhp-hr. Retrofitting these low-emission diesel engines to existing trucks would result in substantially greater NOx reductions per vehicle than would retrofit of present 5.0 g/bhp-hr engines. Depending on the incremental costs and fuel-efficiency of the MY 2002/2003 engine, the cost-effectiveness of such retrofits would likely be substantially better than for present diesel engines.

Developing detailed cost-effectiveness calculations for this measure are quite challenging as data on the costs, fuel efficiency, and dates of availability of these advanced, low-emitting engines are not yet available. Based on the information we obtained from the industry, the MY 2002/2003 engines are not likely to be available in the market in time to contribute to achieving the needed two tons of NOx reduction per day in 2002. However, this measure would contribute to the additional one tons of NOx reduction per day in 2005. Therefore, we estimated the cost-effectiveness results based on very rough estimates of the engine cost and emissions benefit. These estimates are shown in Table 10. As this table shows, the potential cost-effectiveness for replacing present 4-5 g/bhp-hr NOx engines would be moderately attractive - ranging from $13,500 to $22,700 per ton.

Table 10. Cost-effectiveness of replacing an older electronic engine with an MY2002/2003 engine (a 2 g/bhp-hr of NOx engine).

	MY2002/3	California Engines	
		84-97	98-02
Certification NOx Level	2.5	5.0	4.0
NOx g/mile	4.62	14.00	10.17
Annual Mileage (miles)	50,000	50,000	50,000
Incremental Capital Cost	35,000	5,000	5,000
Useful Life	5	5	5
Annualized Incremental Capital Cost ($/yr)	8,084	1,155	1,155
NOx tons/year	0.25	0.77	0.56
NOx Reduction tons/year		0.52	0.31
NOx Reduction tons/day		0.0014	0.0008
Cost-Effectiveness ($/ton)		13,426	22,677

6. NOx AFTERTREATMENT SYSTEMS

Aftertreatment technologies to reduce diesel NOx and PM emissions have been the subjects of intense research and development efforts for more than two decades, but have only recently reached the point where widespread deployment in vehicles appears feasible[5]. Because diesel engines typically operate with very lean air-fuel ratios, the three-way catalytic converter systems used to control NOx emissions from spark-ignition engines are ineffective. Lean NOx catalysts work to reduce NOx despite the overall oxidizing nature of diesel exhaust by reacting the NOx with unburned hydrocarbons (HC), which serve as the reductant. NOx adsorbers (NOx traps) capture NOx chemically under lean conditions, and must be regenerated periodically under rich conditions to remove and reduce the trapped NOx. Selective catalytic reduction (SCR) systems react NOx with ammonia to produce nitrogen and water.
A number of companies have now developed NOx aftertreatment systems for heavy-duty diesel vehicles. Promising technologies include SCR and lean-NOx catalyst systems.

6.1 RETROFITTING OLDER TRUCKS WITH SCR CATALYST SYSTEMS

State funds would be used to retrofit older trucks with SCR systems using aqueous urea as the reductant. Funding would also be needed for incentives to truck operators sufficient to offset the incremental costs of the reductant and additional maintenance required by the system. Table 11 shows the estimated cost-effectiveness of this measure.

Emissions

Similar to previous measures, the emission factors of 10.2 to 14.0 g/mile generated from EMFAC7F were used as the baseline NOx emissions for California trucks. Again, the actual emission reduction could be considerably more, as EMFAC7F does not account for the occurrence of NOx defeat devices among later-model engines. For this analysis, we assumed that the SCR catalyst system would be 50% effective in reducing NOx emissions. This is a very conservative estimate for an open-loop SCR system - lower than the performance documented in a published report by Siemens and Mack Trucks[6]. Again, the program would target intensively-used short-haul trucks in and around the cities, with an assumed annual travel of 50,000 miles per year.

Cost

The cost to buy and install an SCR system on an existing diesel truck was estimated at $15,000. In the long run, prices are likely to be lower; EF&EE has estimated the cost of a SCR system in large volume for new trucks at about $3,700 each[7]. Also, cost information for SCR systems provided by industry ranged from $5,000 to $15,000. In addition to the capital cost, each system was assumed to require maintenance amounting to $200 per year. The SCR system was also assumed to require urea at $1.10 per gallon, at a rate equal to 4% of the fuel consumption rate.

Table 11. Cost-effectiveness of urea SCR systems.

	California Engines		Federal Engines	
	84-97	**98-02**	**79-89**	**1990**
Certification NOx Level	5.0	4.0	10.7	6.0
Baseline NOx grams/mile	14.0	10.2	20.9	20.1
NOx w SCR System (g/mile)	7.0	5.1	10.4	10.1
NOx reduction (tons/yr)	0.39	0.28	0.57	0.55
NOx reduction (tons/day)	0.0011	0.0008	0.0016	0.0015
SCR Cost	$15,000	$15,000	$15,000	$15,000
Useful Life (yr)	5	5	5	5
Annualized Capital Cost	$3,465	$3,465	$3,465	$3,465
Annual Mileage	50,000	50,000	50,000	50,000
Fuel Consumption (MPG)	5.2	5.5	5.2	5.3
Baseline Fuel Use (gal/yr)	9,597	9,025	9,709	9,434
Urea Cost $/year	426	401	431	419
Extra Maint Cost $/year	200	200	200	200
Total added cost/year	$4,091	$4,065	$4,096	$4,083
Cost effectiveness $/ton	$10,615	$14,515	$7,129	$7,369

Emission Reductions

The reduction in NOx emissions would depend on the NOx levels of the engine installed in the retrofitted vehicle. For an engine meeting California emission standards (and not equipped with defeat devices), the reductions range from 0.3 to 0.4 tons per year. However, many older tractor rigs are equipped with federal engines designed to much higher NOx levels. For federal engines with typical NOx levels ranging from 6 to 10 g/bhp-hr, the emission reduction would be about 0.6 tons per year. Since most electronic engines of this vintage are equipped with defeat devices, their real-world emissions are much higher than certification levels, and the potential benefits of adding NOx controls are correspondingly large.

Cost-effectiveness

The cost-effectiveness of this measure would depend on the NOx emissions of the engine installed in the vehicle, and these values range from about $7,000 to $15,000.

Technical Implementation Feasibility and Ranking

SCR systems for heavy-duty trucks are under active research and development, and a number of systems have entered the preliminary demonstration stage. At this point it appears likely that suitably durable, reliable, and safe systems will be commercially available within a year or two – especially since California has created a potential market for such systems by funding NOx retrofit programs. In addition, the recent EPA announcement of its Voluntary Retrofit Program for HD vehicles would also accelerate the commercial deployment of these technologies. The goal of the EPA Voluntary Retrofit Program is to retrofit 10,000 vehicles by the end of 2000.

Political/Social/Public Acceptance

The addition of the SCR system would provide no benefit to the truck owner, while adding some costs in maintenance and urea. Therefore, truck owners are unlikely to volunteer unless compensated in some way. Such compensation could include cash payments (linked to continuing checks that the NOx control system was working), preferential consideration for contracting opportunities, or similar incentives. As long as the incentives are not seen as coercive, this approach should raise little opposition.

6.2 RETROFITTING WITH LEAN NOX CATALYST SYSTEMS

State funds could be used to retrofit older trucks with lean NOx catalyst systems. Like SCR systems, these systems are a subject of active commercial development, and it is likely that commercial systems will be available in low-volume production in the near future. Table 12 tabulates the estimated cost-effectiveness for this measure.

Table 12. Cost-effectiveness of retrofitting lean NOx catalyst systems.

	California Engines		Federal Engines	
	84-97	98-02	79-89	1990
Certification NOx Level	5.0	4.0	10.7	6.0
Baseline NOx grams/mile	14.0	10.2	20.9	20.1
NOx w Lean NOx System (g/mile)	10.5	7.6	15.7	15.1
NOx reduction (tons/yr)	0.19	0.14	0.29	0.28
NOx reduction (tons/day)	0.0005	0.0004	0.0008	0.0008
Lean NOx system cost	$8,000	$8,000	$8,000	$8,000
Useful Life (yr)	5	5	5	5
Annualized Capital Cost	$1,848	$1,848	$1,848	$1,848
Annual Mileage	50,000	50,000	50,000	50,000
Fuel Consumption (MPG)	5.21	5.54	5.15	5.30
Baseline Fuel Use (gal/yr)	9,597	9,025	9,709	9,434
Fuel Consumption Penalty (3%)	288	271	291	283
Extra Fuel Cost $/year	453	426	458	445
Total added cost/year	$2,301	$2,274	$2,306	$2,293
Cost effectiveness $/ton	$11,941	$16,236	$8,027	$8,275

Emissions

Similar to previous measures, the emission factor of 10.2 to 14.0 g/mile generated from EMFAC7F was used as the baseline for California trucks. Again, the actual emission reduction could be considerably more, as EMFAC7F does not account for the occurrence of NOx defeat devices among later-model engines. For this analysis, we assumed the lean NOx catalyst systems to be 25% effective in reducing NOx emissions, with a 3% fuel consumption penalty for the fuel injected to act as the reductant. Again, the program would target the highly use short-haul trucks in and around the cities, with an assumed annual travel of 50,000 miles per year.

The cost to buy a lean NOx catalyst system was quoted by one developer at $7,500, to which we added $500 for the cost of installing it on an existing vehicle. In the long run, prices are likely to be lower. EF&EE has estimated the cost of lean NOx catalyst systems in large volume for new trucks at about $2,500 each. Again, the fuel required for the catalyst regeneration was estimated to add 3% to total fuel consumption.

Emission Reductions

The reduction in NOx emissions would depend on the NOx levels of the engine installed in the retrofitted vehicle. For an engine meeting California emission standards, the reduction would range from 0.14 to 0.19 tons per year. However, many older tractor rigs are equipped with federal engines designed to much higher NOx levels. For Federal engines with NOx levels ranging from 6 to 10 g/bhp-hr, the emission reduction would be about 0.3 tons per year. Since most electronic engines of this vintage are equipped with defeat devices, their real-world emissions are much higher than certification levels, and the potential benefits of adding NOx controls are correspondingly large.

Cost-effectiveness

The cost-effectiveness of this measure would depend on the NOx emissions of the engine installed in the vehicle, ranging from about $8,000 to $16,000.

Technical Implementation Feasibility and Ranking

A number of lean NOx catalyst systems have entered the preliminary demonstration stage. At this point it appears that some commercial systems are available now – especially if California creates a market for such systems by funding NOx retrofits of this nature. In addition, the EPA's recent announcement of its Voluntary Retrofit Program for HD vehicles will tend to accelerate the commercial deployment of these technologies.

Political/Social/Public Acceptance

The addition of the lean NOx catalyst system would provide no benefit to the truck owner, while adding some costs in diesel fuel. Therefore, truck owners are unlikely to volunteer unless compensated in some way. Such compensation could include cash payments (linked to continuing checks that the NOx control system was working), preferential consideration for contracting opportunities, or similar incentives. As long as the incentives are not seen as coercive, this approach should raise little opposition.

7. CONCLUSIONS

The preliminary analyses presented in the preceding sections show that a wide variety of cost-effective measures are potentially available to reduce NOx emissions from existing vehicles. As an example, some of the measures evaluated are listed in Table 13. Among the most cost-effective measures identified are: purchasing ULEV natural gas tractors and buses (when considered on an incremental cost basis); retrofitting NOx catalyst systems such as SCR or lean-NOx catalysts to existing high-NOx vehicles; and repowering existing vehicles with low-NOx engines when these become available. Emulsion fuels may also exhibit competitive cost-effectiveness, but better data on the costs and in-use performance of different emulsion fuel blends are needed to assess this measure.

Table 13. NOx control measures in order of cost-effectiveness.

	Cost Eff ($/ton NOx)	Cost/Veh. ($)	NOx Red (tons/day/veh)	Est. PM Red. (%)
CNG Transit Buses (Incremental cost)	11,725	50,000	0.0010	60%
LNG Tractors (Incremental cost)	13,249	40,000	0.0007	90%
Retrofit SCR Catalysts	9,676	15,000	0.0013	20%
Retrofit Lean NOx Catalysts	10,868	8,000	0.0006	20%
Repower w/ 2 g Electronic Engines	18,052	30,000	0.0011	0%
LNG for Garbage Trucks (Incremental cost)	33,771	40,000	0.0004	80%
Emulsified Diesel Fuel (Cost/year)	19,821	1,066	0.0001	45%
Repower Elect. w/ 4 g Electronic Engines	12,492	20,000	0.0012	0%
Repower Mech. w/ 4 g Electronic Engines	15,614	25,000	0.0012	80%
LNG Tractors (whole truck)	44,267	110,000	0.0007	90%
CNG School Buses (Incremental cost)	46,391	25,000	0.0001	80%
Ultra-low sulfur low aromatic diesel (Cost/year)	49,631	1,167	0.0001	15%
LNG Garbage Trucks (whole truck)	138,952	150,000	0.0004	80%

In order to achieve the required emission reduction of 2 tons per day in 2002 and 3 tons per day in 2005, it will most likely be necessary to combine several emission control measures from the list in Table 13. The ultimate combination of measures selected will no doubt be based partly on considerations of cost-effectiveness, and partly on other concerns such as the desire to reduce school children's exposure to diesel particulate matter, as well as political considerations. One of the many possible combinations of measures to achieve the needed emission reductions are shown for 2002 in Table 14 and 2005 in Table 15.

Table 14. Example of NOx control measures to achieve two tons/day reduction by 2002.

Control Measure	Number of Vehicle	Cost Per Vehicle	Total Cost	NOx Red. (Tons/Day)	Cost Eff ($/ton NOx)
LNG for Garbage Trucks (whole truck)	25	150,000	3,750,000	0.01	138,952
LNG Tractors (whole truck)	30	110,000	3,300,000	0.02	44,267
Retrofit SCR Catalysts	50	15,000	750,000	0.06	9,676
Retrofit Lean NOx Catalysts	2000	8,000	16,000,000	1.25	10,868
Repower Mech. w/ 4 g Electronic Engines	250	25,000	6,250,000	0.31	15,614
Repower Elect. w/ 4 g Electronic Engines	250	20,000	5,000,000	0.31	12,492
Repower w/ 2 g Electronic Engines	100	30,000	3,000,000	0.11	18,052
CNG Transit Buses (Incremental cost)	50	50,000	2,500,000	0.05	11,725
CNG School Buses (Incremental cost)	50	25,000	1,250,000	0.01	46,391
Emulsified Diesel Fuel	1500	5,328	7,992,746	0.22	19,821
Total	**4305**		**49,792,746**	**2.35**	

The reader should be warned that the evaluations presented in this report are *preliminary*. Many of the technologies evaluated here have never been deployed on a large scale. The demand created by the proposed NOx reduction program is already drawing new technologies into the market and leading to improvements and refinements of existing technologies. Many of the costs used in the analyses for this report are reflective of prototype or low-volume production systems, and it is likely that these would be reduced substantially as production volumes increase over the life of the program.

Table 15. Example of combining emission control measures to achieve 3 tons/day NOx reduction by 2005.

Control Measure	Number of Vehicle	Cost Per Vehicle	Cost (million $)	NOx Red. (tons/day)	Cost Eff ($/ton)
LNG for Garbage Trucks (whole truck)	50	150,000	7.50	0.02	138,952
LNG Tractors (whole truck)	30	110,000	3.30	0.02	44,267
Retrofit SCR Catalysts	100	15,000	1.50	0.13	9,676
Retrofit Lean NOx Catalysts	2700	8,000	21.60	1.69	10,868
Repower Mech. w/ 4 g Electronic Engines	250	25,000	6.25	0.31	15,614
Repower Elect. w/ 4 g Electronic Engines	250	20,000	5.00	0.31	12,492
CNG Transit Buses (Incremental cost)	100	50,000	5.00	0.10	11,725
CNG School Buses (Incremental cost)	100	25,000	2.50	0.01	46,391
Emulsified Diesel Fuel	1500	5,328	7.99	0.22	19,821
Repower w/ 2 g Electronic Engines	300	30,000	9.00	0.34	18,052
Total	**5380**		**69.64**	**3.14**	

Thus, while the analysis in this report is sufficient to demonstrate the *potential* for achieving the needed NOx reductions within the levels of funding allocated, and to identify a number of feasible methods for achieving this reduction, it is likely that the final costs of the program may be significantly different (and probably lower) than those estimated here. At the same time, the list of specific emission control measures ultimately employed in the NOx reduction program is likely to include some new technologies that are not evaluated here, and may well exclude some of the measures that are evaluated.

APPENDIX:
EMISSION FACTORS FOR HEAVY-DUTY DIESEL VEHICLES DEVELOPED BASED ON EMFAC7F

Emission Factors for Different HD Vehicle Types developed based on EMFAC7F

California Heavy Heavy-Duty Trucks (Class 8)

MY	Cert. Std (g/bhp-hr)	Engine NOx (g/bhp-hr)	Det. Rate Engine	Conv. Factor (bhp-hr/mi)	Zero Mile, Veh. (g/mi)	Det. Rate Vehicle	Accum. Miles Jan, 2002	Fuel Econ. (mpg)	Base E.F. (g/mi)	Fuel C.F.	Tampering C.F.	Smoke I/M C.F.	2002 E.F. (g/mi)	2002 E.F. (g/gal)
1977	7.5	7.93	0.00	2.87	22.76	0.00	852954	4.93	22.76	0.93	1.029	0.999	21.75	107.22
1978	7.5	7.93	0.00	2.86	22.68	0.00	838883	4.96	22.68	0.93	1.030	0.999	21.69	107.61
1979	7.5	7.93	0.00	2.84	22.52	0.00	824812	4.99	22.52	0.93	1.029	0.999	21.53	107.44
1980	6	7.93	0.00	2.82	22.36	0.00	810741	5.02	22.36	0.93	1.032	0.997	21.40	107.42
1981	6	7.93	0.00	2.81	22.28	0.00	796670	5.05	22.28	0.93	1.030	0.998	21.31	107.60
1982	6	7.93	0.00	2.78	22.05	0.00	782599	5.09	22.05	0.93	1.032	0.997	21.08	107.29
1983	6	7.93	0.00	2.77	21.97	0.00	768528	5.12	21.97	0.93	1.033	0.996	21.01	107.58
1984	4.5	3.93	0.02	2.75	10.81	0.06	753086	5.15	14.95	0.93	1.031	0.998	14.31	73.67
1985	4.5	3.93	0.02	2.74	10.77	0.05	736140	5.18	14.80	0.93	1.033	0.997	14.17	73.40
1986	4.5	3.93	0.02	2.72	10.69	0.05	717543	5.21	14.59	0.93	1.035	0.997	14.00	72.95
1987	6	3.93	0.02	2.70	10.61	0.05	697135	5.24	14.38	0.93	1.034	0.996	13.77	72.13
1988	6	3.93	0.02	2.72	10.69	0.05	674739	5.27	14.36	0.93	1.008	0.999	13.45	70.87
1989	6	3.93	0.02	2.71	10.65	0.05	650161	5.3	14.17	0.93	1.008	0.999	13.28	70.36
1990	6	3.93	0.02	2.69	10.57	0.05	623189	5.33	13.92	0.93	1.008	0.999	13.04	69.50
1991	5	3.93	0.02	2.71	10.65	0.05	593590	5.36	13.87	0.90	1.080	0.999	13.47	72.20
1992	5	3.93	0.02	2.69	10.57	0.05	561107	5.39	13.59	0.90	1.090	0.999	13.32	71.81
1993	5	3.93	0.02	2.68	10.53	0.05	525460	5.42	13.35	0.90	1.090	0.999	13.09	70.92
1994	5	3.93	0.02	2.68	10.53	0.05	486341	5.45	13.14	1.00	1.119	0.999	14.69	80.07
1995	5	3.93	0.02	2.66	10.45	0.05	443411	5.48	12.81	1.00	1.119	0.999	14.33	78.52
1996	4	3.93	0.02	2.65	10.41	0.05	396300	5.51	12.51	1.00	1.120	0.999	14.00	77.12
1997	4	3.93	0.02	2.63	10.34	0.05	344600	5.54	12.15	1.00	1.120	0.999	13.59	75.27
1998	4	3.14	0.02	2.63	8.27	0.05	287863	5.54	9.78	1.00	1.120	0.999	10.94	60.61
1999	4	3.14	0.02	2.63	8.27	0.05	225600	5.54	9.46	1.00	1.120	0.999	10.57	58.58
2000	4	3.14	0.02	2.63	8.27	0.05	157272	5.54	9.10	1.00	1.120	0.999	10.17	56.36
2001	4	3.14	0.02	2.63	8.27	0.05	82288	5.54	8.70	1.00	1.120	0.999	9.73	53.91
2002	4	3.14	0.02	2.63	8.27	0.05	0	5.54	8.27	1.00	1.120	0.999	9.25	51.23
2003	2.5	1.57	0.02	2.63	4.13	0.05	0	5.54	4.13	1.00	1.120	0.999	4.62	25.62
2002 NGV	2	1.57	0.02	2.63	4.13	0.05	0	2.96	4.13	1.00	1.120	0.999	4.62	13.70

Transit Buses

Model Year	Cert. Std (g/bhp-hr)	Engine NOx (g/bhp-hr)	Det. Rate Engine	Conv. Factor (bhp-hr/mi)	Zero Mile, Veh. (g/mi)	Det. Rate Vehicle	Accum. Miles Jan, 2002	Fuel Econ. (mpg)	Base E.F. (g/mi)	Fuel C.F.	Tampering C.F.	Smoke I/M C.F.	2002 E.F. (g/mi)	2002 E.F. (g/gal)
1977	7.5	7.93	0	4.3	34.10	0.00	915380	3.29	34.10	0.93	1.029	0.999	32.59	107.22
1978	7.5	7.93	0	4.3	34.10	0.00	892290	3.30	34.10	0.93	1.030	0.999	32.62	107.61
1979	7.5	7.93	0	4.3	34.10	0.00	869200	3.30	34.10	0.93	1.029	0.999	32.60	107.44
1980	6	7.93	0	4.3	34.10	0.00	844886	3.29	34.10	0.93	1.032	0.997	32.63	107.42
1981	6	7.93	0	4.3	34.10	0.00	819347	3.30	34.10	0.93	1.030	0.998	32.60	107.60
1982	6	7.93	0	4.3	34.10	0.00	792583	3.29	34.10	0.93	1.032	0.997	32.60	107.29
1983	6	7.93	0	4.3	34.10	0.00	764594	3.30	34.10	0.93	1.033	0.996	32.62	107.58
1984	4.5	3.93	0.02	4.3	16.90	0.09	735380	3.29	23.22	0.93	1.031	0.998	22.22	73.19
1985	4.5	3.93	0.02	4.3	16.90	0.09	704941	3.30	22.96	0.93	1.033	0.997	21.98	72.55
1986	4.5	3.93	0.02	4.3	16.90	0.09	673278	3.30	22.69	0.93	1.035	0.997	21.77	71.74
1987	6	3.93	0.02	4.3	16.90	0.09	640390	3.29	22.41	0.93	1.034	0.996	21.46	70.60
1988	6	3.93	0.02	4.3	16.90	0.09	606277	3.33	22.11	0.93	1.008	0.999	20.71	69.03
1989	6	3.93	0.02	4.3	16.90	0.09	570939	3.34	21.81	0.93	1.008	0.999	20.43	68.23
1990	6	3.93	0.02	4.3	16.90	0.09	534376	3.33	21.49	0.93	1.008	0.999	20.13	67.11
1991	5	3.93	0.02	4.3	16.90	0.09	496589	3.38	21.17	0.9	1.080	0.999	20.56	69.47
1992	5	3.93	0.02	4.3	16.90	0.09	457487	3.37	20.83	0.9	1.090	0.999	20.42	68.86
1993	5	3.93	0.02	4.3	16.90	0.09	417250	3.38	20.49	0.9	1.090	0.999	20.08	67.84
1994	5	3.93	0.02	4.3	16.90	0.09	375788	3.40	20.13	1	1.119	0.999	22.51	76.46
1995	5	3.93	0.02	4.3	16.90	0.09	333101	3.39	19.76	1	1.119	0.999	22.10	74.92
1996	4	3.93	0.02	4.3	16.90	0.09	289190	3.40	19.39	1	1.120	0.999	21.68	73.62
1997	4	3.93	0.02	4.3	16.90	0.09	244054	3.39	19.00	1	1.120	0.999	21.25	71.99
1998	4	3.14	0.02	4.3	13.52	0.09	197693	3.39	15.22	1	1.120	0.999	17.02	57.67
1999	4	3.14	0.02	4.3	13.52	0.09	150107	3.39	14.81	1	1.120	0.999	16.56	56.12
2000	4	3.14	0.02	4.3	13.52	0.09	101296	3.39	14.39	1	1.120	0.999	16.09	54.53
2001	4	3.14	0.02	4.3	13.52	0.09	51260	3.39	13.96	1	1.120	0.999	15.61	52.90
2002	4	3.14	0.02	4.3	13.52	0.09	0	3.39	13.52	1	1.120	0.999	15.12	51.23
2003	2.5	1.57	0.02	4.3	6.76	0.09	0	3.39	6.76	1	1.120	0.999	7.56	25.62
2002 NGV	2	1.57	0.02	4.3	6.76	0.09	0	1.81	6.76	1.00	1.120	0.999	7.56	13.70

Emission Factors for Different HD Vehicle Types developed based on EMFAC7F
School Buses

Model Year	Cert. Std (g/bhp-hr)	Engine NOx (g/bhp-hr)	Det. Rate Engine	Conv. Factor (bhp-hr/mi)	Zero Mile, Veh. (g/mi)	Det. Rate Vehicle	Accum. Miles Jan, 2002	Fuel Econ. (mpg)	Base E.F. (g/mi)	Fuel C.F.	Tampering C.F.	Smoke I/M C.F.	2002 E.F. (g/mi)	2002 E.F. (g/gal)
1977	7.5	7.93	0	2.29	18.16	0.00	211110	6.53	18.16	0.93	1.029	0.999	17.35	113.32
1978	7.5	7.93	0	2.29	18.16	0.00	207074	6.54	18.16	0.93	1.030	0.999	17.37	113.61
1979	7.5	7.93	0	2.28	18.08	0.00	203038	6.55	18.08	0.93	1.029	0.999	17.29	113.22
1980	6	7.93	0	2.28	18.08	0.00	199002	6.56	18.08	0.93	1.032	0.997	17.30	113.49
1981	6	7.93	0	2.27	18.00	0.00	194966	6.57	18.00	0.93	1.030	0.998	17.21	113.08
1982	6	7.93	0	2.27	18.00	0.00	190930	6.58	18.00	0.93	1.032	0.997	17.21	113.25
1983	6	7.93	0	2.27	18.00	0.00	186894	6.59	18.00	0.93	1.033	0.996	17.22	113.48
1984	4.5	3.93	0.02	2.26	8.88	0.05	182523	6.6	9.71	0.93	1.031	0.998	9.29	61.30
1985	4.5	3.93	0.02	2.26	8.88	0.05	177789	6.61	9.69	0.93	1.033	0.997	9.27	61.28
1986	4.5	3.93	0.02	2.26	8.88	0.05	172663	6.62	9.66	0.93	1.035	0.997	9.27	61.37
1987	6	3.93	0.02	2.25	8.84	0.05	167111	6.63	9.59	0.93	1.034	0.996	9.19	60.91
1988	6	3.93	0.02	2.26	8.88	0.05	161099	6.64	9.61	0.93	1.008	0.999	9.00	59.76
1989	6	3.93	0.02	2.25	8.84	0.05	154588	6.65	9.54	0.93	1.008	0.999	8.93	59.41
1990	6	3.93	0.02	2.25	8.84	0.05	147536	6.66	9.51	0.93	1.008	0.999	8.90	59.29
1991	5	3.93	0.02	2.27	8.92	0.05	139899	6.67	9.56	0.9	1.080	0.999	9.28	61.92
1992	5	3.93	0.02	2.27	8.92	0.05	131629	6.68	9.52	0.9	1.090	0.999	9.33	62.33
1993	5	3.93	0.02	2.26	8.88	0.05	122673	6.7	9.44	0.9	1.090	0.999	9.25	61.98
1994	5	3.93	0.02	2.27	8.92	0.05	112973	6.72	9.43	1	1.119	0.999	10.55	70.89
1995	5	3.93	0.02	2.27	8.92	0.05	102433	6.74	9.39	1	1.119	0.999	10.50	70.75
1996	4	3.93	0.02	2.26	8.88	0.05	91057	6.76	9.29	1	1.120	0.999	10.39	70.26
1997	4	3.93	0.02	2.25	8.84	0.05	78737	6.78	9.20	1	1.120	0.999	10.29	69.74
1998	4	3.14	0.02	2.25	7.07	0.05	65395	6.78	7.37	1	1.120	0.999	8.24	55.87
1999	4	3.14	0.02	2.25	7.07	0.05	50946	6.78	7.30	1	1.120	0.999	8.17	55.38
2000	4	3.14	0.02	2.25	7.07	0.05	35298	6.78	7.23	1	1.120	0.999	8.09	54.84
2001	4	3.14	0.02	2.25	7.07	0.05	18352	6.78	7.16	1	1.120	0.999	8.00	54.27
2002	4	3.14	0.02	2.25	7.07	0.05	0	6.78	7.07	1	1.120	0.999	7.91	53.64
2003	2.5	1.57	0.02	2.25	3.54	0.05	0	6.78	3.54	1	1.120	0.999	3.96	26.82
2002 NGV	2	1.57	0.02	2.25	3.54	0.05	0	3.63	3.54	1	1.120	0.999	3.96	14.34

Federal Heavy Heavy-Duty Trucks (Class 8) used in California

Model Year	Cert. Std (g/bhp-hr)	Engine NOx (g/bhp-hr)	Det. Rate Engine	Conv. Factor (bhp-hr/mi)	Zero Mile, Veh. (g/mi)	Det. Rate Vehicle	Accum. Miles Jan, 2002	Fuel Econ. (mpg)	Base E.F. (g/mi)	Fuel C.F.	Tampering C.F.	Smoke I/M C.F.	2002 E.F. (g/mi)	2002 E.F. (g/gal)
1977	16	8	0.06	2.87	22.96	0.17	852954	4.93	37.65	0.93	1.029	0.999	35.98	177.37
1978	16	8	0.06	2.86	22.88	0.17	838883	4.96	37.28	0.93	1.030	0.999	35.66	176.86
1979	10	7.93	0.00	2.84	22.52	0.00	824812	4.99	22.52	0.93	1.029	0.999	21.53	107.44
1980	10	7.93	0.00	2.82	22.36	0.00	810741	5.02	22.36	0.93	1.032	0.997	21.40	107.42
1981	10	7.93	0.00	2.81	22.28	0.00	796670	5.05	22.28	0.93	1.030	0.998	21.31	107.60
1982	10	7.93	0.00	2.78	22.05	0.00	782599	5.09	22.05	0.93	1.032	0.997	21.08	107.29
1983	10	7.93	0.00	2.77	21.97	0.00	768528	5.12	21.97	0.93	1.033	0.996	21.01	107.58
1984	10.7	7.93	0.00	2.75	21.81	0.00	753086	5.15	21.81	0.93	1.031	0.998	20.87	107.47
1985	10.7	7.93	0.00	2.74	21.73	0.00	736140	5.18	21.73	0.93	1.033	0.997	20.80	107.74
1986	10.7	7.93	0.00	2.72	21.57	0.00	717543	5.21	21.57	0.93	1.035	0.997	20.70	107.82
1987	10.7	7.93	0.00	2.7	21.41	0.00	697135	5.24	21.41	0.93	1.034	0.996	20.50	107.44
1988	6	7.93	0.00	2.72	21.57	0.00	674739	5.27	21.57	0.93	1.008	0.999	20.20	106.45
1989	6	7.93	0.00	2.71	21.49	0.00	650161	5.3	21.49	0.93	1.008	0.999	20.13	106.68
1990	6	4.74	0.02	2.69	12.75	0.05	623189	5.33	16.10	0.93	1.008	0.999	15.08	80.37
1991														
1992														
1993														
1994														
1995														
1996	SAME AS CALIFORNIA EMISSION FACTORS													
1997														
1998														
1999														
2000														
2001														
2002														
2003														

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