UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

ANN ARBOR, MICHIGAN 48105

OFFICE OF
AIR AND RADIATION

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NOTE

SUBJECT: Comments on Report Entitled "Emission Control Technology Distribution Report"

FROM: Larry Landman
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TO: The Record

The report entitled "Emission Control Technology Distribution Report" was prepared under contract by Energy and Environmental Analysis, Inc. (EEA). EPA proposes to use in MOBILE6 the estimates of the technology distributions for LDVs and LDTs contained in Tables 3-1 through 3-4 and for the HDVs in Tables 4-2, 4-4, and 4-5.

As with all contractor prepared reports, this report does not necessarily represent final EPA positions. In particular, it should be noted that EEA makes two potentially significant statements in the report that EPA staff believe are incorrect, specifically:

(1) On page 2-11, while discussing changes expected in the coming years to catalytic converters, the contractor states:

> "Catalyst volume and/or noble metal loading is expected to be increased to provide a 40 percent increase (on average) in active catalyst surface area to meet the needs of the revised high load FTP cycle. (This conclusion is documented in the third reference detailed on page 1-2.)"

EEA repeated this statement in Table 2-1.

The document referenced by EEA is one of their earlier analyses. EPA had previously studied that analysis and concluded that only a recalibration (not an increase in catalyst loading) would be needed to meet the needs of the revised high load FTP cycle.

(2) On page 3-1, while discussing the differences between the emission standards of LDVs and LDTs, the contractor states:

> "LDT emission standards have typically trailed the LDV emission standards in stringency by 3 to 4 years, but the standards have now converged to a point where the effective stringency is identical across vehicle weight classes for LDV and LDT I (light trucks up to 6000 lb GVW)."

EEA statement is correct only for the LDTs with a GVWR up to 3,750 pounds. For the LDTs having GVWRs between 3,750 and 6,000 pounds (i.e., for most of the LDTs), their emission standards are twice those of the LDVs.

Although both of these statements are potentially significant, neither affects the estimates in those seven tables that EPA proposes to use in MOBILE6. I, therefore, recommend the use of this report in MOBILE6 for the purpose of estimating the future technology distributions of LDVs and LDTs.

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EMISSION CONTROL TECHNOLOGY DISTRIBUTION

FINAL REPORT

EPA Contract No. 68-D30035
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1. INTRODUCTION

In its highway vehicle emission factor model, EPA has historically constructed in-use emissions for emission control technology groups that have similar in-use emission characteristics. EPA plans to periodically update and revise the model, and this requires an update of the appropriate technology groupings, as well as an estimate of the market share of each group for the historical period and the forecast period. In this work assignment, the objective was to

- identify the technology groups that (will) have similar in-use emission characteristics for both the historical (1990-1996) period and the future from 1996 to 2020,
- estimate the distributions of these groupings for each year over the historical period from available sales data
- forecast the technology distributions for future model years

The original intent was to obtain information from a review of articles published in the automotive trade press, engineering journals and air pollutant related journals. However, a literature search quickly revealed that these is little or no information on this specific topic that treats the issues at the level of detail required by EPA. While some reports by EPA and the Air Resources Board discuss the issues related to the in-use performance of technologies and standards, there was no information publicly available on which to derive detailed technology forecasts. As a result, EEA obtained such information by meeting with experts at the automanufacturers and at the heavy-duty truck engine manufacturers.

The interviews were conducted with four of the six largest sales volume light-duty vehicle manufacturers and three of the four largest diesel engine manufactures. While the expert opinion on future market shares were not quantitative, information was obtained to translate their statements into quantitative forecasts by having the experts identify penetration in ranges of (1) less than 5 percent, (2) 10 to 20 percent, (3) 30 to 50 percent, and (4) the majority of the market, 60 to 90 percent. These expert opinions were combined with historical trends to subjectively derive market shares for various technology groups of interest. The market share forecasts have some assumptions regarding future standards and related regulations, and also assume that fuel prices will rise moderately (1 percent per year real) through 2020. This information was part of the general backdrop against which experts formulated their opinion on technology market penetration.

Section 2 of this report provides a discussion of current and future technology groups of interest to EPA in the light and heavy-duty vehicle sectors. It provides a basis on which future in-use technology performance can be grouped, and discusses current and future technologies in this context. Sections 3 and 4 present EEA's estimates on the technology distributions for light-duty vehicles/light-duty trucks and heavy-duty vehicles, respectively. Appendix A has detailed information on 1990 and 1995/96 vehicle technologies compiled from EPA certification records and AAMA (or MVMA) vehicle specifications that were utilized to construct technology distributions for some less well publicized technologies. Data for intermediate years (i.e. 1991, 1992, 1993, 1994) were not analyzed in as much detail but estimated from the two end points for some technologies.

While no existing reports provided specific guidance in estimating technology groups or forecasts of technology distributions, three reports provided guidance on future technologies to meet standards. They are:

(1) Regulatory Impact Analysis: $NMHC+NO_X$ Standards for 2004 and Later Model Years On-Highway Heavy Duty Engines, EPA 1/26/96

(2) Low-Emission Vehicle and Zero-Emission Vehicle Program Review, ARB, November 1996

(3) Assessment of Technology Costs to Comply with Proposed FTP Revisions, EEA report to EPA, September 1995

These reports were useful in constructing technology distributions for 2000 to 2005 period. Specifically, these reports were utilized to estimate technology introduction is response to standards that could or will be imposed before the year 2005. Longer range forecasts for 2010 and 2020 are based primarily on data obtained at meetings with the manufacturers. In addition, the technology forecast implied in the three reports were also part of the discussion with the manufacturers, and this data was presented to the expert group for their comment. The forecasts presented in this report represents the majority opinion of the experts groups across manufacturers, although it should be noted that there was some variation in opinion between experts even at a specific manufacturer, and between manufacturers. EEA had agreed that specific manufacturers or experts' opinions would not be revealed to protect confidentiality, and the data in the report presents only the majority opinion as interpreted by EEA.

2. EMISSION CONTROL TECHNOLOGIES OF INTEREST

2.1 BACKGROUND

The MOBILE5a model calculates emission factors by emission control technology type for light duty vehicles and post-1990 light duty trucks. To calculate emission factors, the EPA has chosen to distinguish only among different fuel metering systems (carburetor, throttle body fuel injection and multipoint fuel injection), fuel control type - open loop and closed loop, and catalyst type - oxidation catalyst and three way catalyst. For the purposes of estimating tampering's emission effects, EPA also utilizes the market penetration of exhaust gas recirculation (EGR) systems, and of air pumps or pulse air systems. However, the MOBILE5a model does not distinguish between all combinations of these variables, and indeed, many combinations need not have any significant difference in their in-use emission behavior.

The current MOBILE5a model does not have any representation of heavy-duty engine technology; in fact, the in-use emission factors for heavy-duty diesel engines are based largely on certification levels, and not on analysis of in-use data. However, the lack of technology specific emission factors may not be a major drawback historically, since most heavy-duty diesels did not rely on add-on emission controls or exhaust aftertreatment for meeting standards.

Based on previous analysis for several regulatory agencies worldwide, in-use emission have been found by EEA to be dependent on four basic factors:

- The extent of emission control occurring within the cylinder.
- The efficiency of any exhaust aftertreatment device

- The use of "add-on" emission control components which, if disabled, can provide real or perceived benefits to the user

- The use of technology that can radically affect "off-cycle" emissions

In general, most testing programs around the world have found that "engine-out" emissions do not deteriorate significantly over time for well maintained engines, and even for poorly maintained engines that are repaired properly. In contrast, aftertreatment efficiency declines over time and with use, and declines irreversibly for certain types of malfunctions. Add-on components that are readily accessible and provide benefits in engine performance by disablement have included EGR valves, air pumps and catalyst, as well as pulse-air systems (to a lesser extent). Examples of technologies that can change off-cycle emissions include multipoint fuel injection which lets the gasoline engine operate with reduced enrichment at cold ambients or during acceleration, and the close coupled catalyst, which reduces catalyst light-off time at cold start.

Our recommendation for future technological distinctions of interest to the EPA are based on the four criteria listed above, and we have included our estimates of the effects of these technologies on in-use emissions factors of interest to the EPA by estimating the difference in engine out emissions or catalyst efficiency. The following is <u>not</u> intended to be a comprehensive discussion of technology characteristics.

2.2 CURRENT LIGHT-DUTY CAR AND TRUCK GASOLINE ENGINE TECHNOLOGY

Since 1981, a majority of vehicles utilize homogenous charge spark ignition engines, with "closed-loop" fuel system control that automatically adjusts air fuel ratio to stoichiometric, once the engine is warmed-up, under most conditions except at high loads. Exhaust Gas Recirculation has been used on a majority of cars to reduce in-cylinder NO_X formation with a typical EGR rate of 12 to 15 percent under mid-load conditions. (EGR is not used at idle or high load) Catalysts are currently (1997) all of the "three-way" type that require engine-out exhaust gas composition to be stoichiometric. Non-stoichiometric (open-loop) systems using an oxidation type catalyst declined in market share in the 1980s and were completely phased out in 1991 for cars and 1992 for light-trucks. However, even within this group of closed-loop three-way catalyst vehicles, there have been significant detail variations of interest, as described below.

Fuel Systems - The broad distinctions in technology are (1) carburetor (2) throttle-body or single-point fuel injection (SPFI) and (3) multipoint fuel injection (MPFI) and (4) sequential multipoint fuel injection (SMPFI). SMPFI systems trigger each injector in conjunction with the intake valve opening event, while MPFI systems trigger all injectors in one or two groups. The precision of fuel metering increases from carburetor to SMPFI and EPA already recognizes the first three variations for the purposes of modeling. While SMPFI does represent an improved control step relative to MPFI, the differences are not large and it is not clear if any difference in-use emissions between vehicles with MPFI and SMPFI will prove statistically significant. SMPFI may offer only some modest improvement in driveability relative to MPFI for vehicles calibrated to the same standard; experts at the manufacturers question if any emission difference will exist in-use.

EGR Systems - While some LDVs/LDTs have no EGR, most LDVs and LDTs use this technology. EGR systems can be further subdivided into:

- Mechanical backpressure systems
- Electronically controlled, vacuum actuated systems
- Electronically controlled, electrically actuated systems.

From a performance viewpoint, electronic control permits better tailoring of EGR rates to engine speed/load, although the near constant rate provided by mechanical backpressure systems is not too far from optimal. Electrically actuated systems can deliver EGR even at low vacuum levels, which is not necessary to meet current standards but may become necessary in the near future with the high load cycle added to the FTP. However, from an in-use emissions viewpoint, engine-out emissions differences between the three systems will be small and all three types of systems can be tampered with. Hence, EEA does not believe that recognizing the type of EGR system will be useful for in-use emissions analysis, although the presence or absence of EGR is a variable of interest for analysis.

Secondary Air Systems: Secondary air has been used in "closed loop" fuel system equipped cars with dual bed catalyst to supply secondary air to the second (oxidation) bed of the catalyst. Engines equipped with such systems have usually had significantly higher engine-out HC/CO, and are typically larger displacement engines. A smaller fraction of vehicles have utilized secondary air with a single bed three way catalyst, with the air being used only during warmup. The market penetration of secondary air equipped vehicles has declined since the mid-1980s; at this point, no LDVs utilize the dual bed system (although Ford LDTs continue to use this) while only about 5 percent of LDVs and LDTs currently use secondary air for warmup. Because of the relatively high market penetration of the latter system historically, we suggest that EPA distinguish these systems as well in its in-use modeling, especially for model year 1984 to 1992 vehicles.

The type of air system is also an issue, as secondary air systems can be classified into:

- Pulse air systems
- Engine driven air pumps
- Electric motor driven air pumps

Pulse air systems are passive devices that rely on exhaust negative pressure pulsations to provide secondary air, and may be less prone to tampering than air pumps; limited evidence exists that pulse air systems malperform more in use than air pumps, however. Electric motor driven air pumps have been used only in some luxury vehicles with a control strategy for warmup requiring secondary air. At this point, EEA suggests examining the rates of malperformance among pulse-air and air pump systems to determine if distinguishing between these systems is warranted. Due to the limited market penetration of electric motor driven air pumps, we do not suggest that EPA pursue separate analysis of such systems.

Catalyst Systems - catalysts used in conjunction with closed loop fuel systems are either of the single bed three-way catalyst type or of the dual bed three-way + oxidation catalyst type. (As noted, the latter utilizes secondary air to the oxidation bed). Typically, the dual bed system has higher HC/CO efficiency but lower NO_x conversion efficiency than the single bed type and is more forgiving of air fuel ratio oscillations. As a result, the dual bed system has been used in conjunction with larger displacement engines and/or engines with less sophisticated fuel metering systems. Analysis done by EEA for ARB suggested that dual bed systems have different in-use emission characteristics than single bed systems, partly due to the characteristics described above, and partly due to differences in emissions during malperformances as a result of air pump/emissions interactions.

Another development with catalysts is the use of smaller "start" catalyst for quick "light-off" to control cold start emissions. Although these catalysts were used in limited markets even in the 1980s, their use has expanded recently since the imposition of Tier I standards. Such catalysts could provide superior cold start emissions performance at low ambients, although we are unaware of any data to substantiate this claim. One problem, however, is that historical data identifying engine families using start catalysts is not easily available, and a compilation of such data is possible only from hard copy certification data filed by the manufacturers. The data could be included if EPA develops such a compilation.

In conclusion, EEA recommends that EPA distinguish between the following emission control technologies in its analysis of in-use data from 1996 and earlier model years for both LDVs and LDTs:

(1) EPA should continue to distinguish between carburetor, single point FI and multipoint FI. At present, it does not appear that sequential fuel injection needs to be identified separately from "group-fire" multipoint fuel injection.

(2) EPA should recognize the presence or absence of EGR. However, the need to identify the type of EGR control and actuation seems unnecessary.

(3) EPA should recognize the differences between single and dual-bed catalysts. Since most dual bed catalysts incorporate secondary air this distinction itself accounts for much of the secondary air use.

(4) Single bed catalyst using secondary air for warmup should be recognized as a separate group. It is not clear if pulse-air and air pump based system should be treated separately, but some analysis of the in-use malperformance rates for each type may be useful.

2.3 EVAPORATIVE EMISSIONS

Evaporative emissions regulations had remained unchanged from 1980 until recently, and was based on a prescribed test with a 2 gm/test evaporative HC standard. EPA imposed an "enhanced" evaporative emission test procedure that simulates multi-day diurnal heat builds and different vehicle preconditioning requirements; the standards on this test are 2.5 g/test for LDVs and LDTs, and 3.0g/test for LDTs with tanks larger than 30 gallons. The new requirements are phased-in, over the 1996-1999 time frame. The EPA has also promulgated a rule requiring on-board refueling vapor recovery (ORVR) systems. These regulations are to be phased in between 1998 and 2000 for LDVs, between 2001 and 2003 for LDGTI and between 2004 and 2006 for LDGTII vehicles.

It is not clear if future evaporative emissions regulations will expand the types of evaporative emission (i.e. diurnal, hot soak, running, resting and refueling loss) to other types but it seems unlikely. However, it is quite possible that post-2000 standards for evaporative emissions may be made more stringent numerically.

The technology to meet the standards based on the new test procedure and the ORVR regulation is well understood, and essentially involves refinement and upsizing of current evaporative emission control technology. These include leak proof joints in the fuel system, multi-layer plastic hoses to resist fuel permeation, multi-layer plastic tanks, improved injector 0-rings, etc. The ORVR rule will require the venting of tank vapors during refueling to a much larger canister capable of holding the tank vent vapors, as well as a anti-spitback valve and fill-neck seal. These technologies have already been extensively documented in the Regulatory Impact Assessments supporting the two regulations.

Although the topic of evaporative emissions received only minor attention during the interviews with manufacturers, there was a consensus that no fundamental changes in technology would be required if standards were made more stringent. In terms of MOBILE5a, the most significant factor appears to be the interaction of the ORVR rule with the evaporative emissions requirements. In order to meet ORVR regulations, canister sizes may increase so that evaporative emissions, even on multiday diurnals, may be reduced significantly with evaporative emissions well below standards according to some experts. Other experts doubted that this would happen, as tank vapors may load up the canister significantly during refueling. In fact, EPA's position is that canister sizes do not need to increase under ORVR regulations beyond those required to meet the enhanced evaporative emissions tests requirements.

Future increase to the stringency of evaporative emissions standards will likely require improved fuel line and joint seal technology, larger canisters and improved full neck seals, but is not expected to affect technology performance in any fundamental way. Hence, EEA does not recommend any technology based approach for evaporative emissions. EPA could examine the interaction between the ORVR and evaporative emissions rules, but there is no significant change associated with future technologies.

2.4 FUTURE LDV/LDT TECHNOLOGIES

With the phase in of "Tier I" technologies complete by 1996 model year, new technologies are expected to be developed primarily to reduce costs or increase in-use reliability, or in response to additional changes to standards in the future. These standards include the Tier I and/or NLEV standards being contemplated for imposition in the early-2000 time frame. It is also possible that standards can become even more stringent in the 2010+ time frame and could conceivably include standards requiring zero-emission for vehicles operating in air quality non-attainment regions. As noted in the introduction, data on future technologies was obtained largely from discussions with experts from four of the six highest sales automanufacturers.

All auto-manufacturers uniformly believed that the homogeneous charge spark ignition engine would be the dominant power plant to 2010, although the direct injection stratified charge engine and battery powered electric or hybrid vehicles would have some market penetration (details on market penetration are provided in Section 3). However, manufacturers expect continuing improvements in emission control technology for conventional spark ignition engines. The changes are described by area below.

Fuel Injection - Manufacturers do not expect any major charges in fuel delivery systems, and believe that non-sequential MPFI systems will be converted over to sequential by the early-2000 time frame.

Air-Fuel Mixture Preparation - Currently, fuel is atomized by the injectors, and some luxury cars have featured air-assisted atomization. Manufacturers do not believe that air-assisted atomization is helpful except in isolated cases. Heated spray targets (used in some flexible fuel vehicles) were also found to be of limited value, and manufacturers believe that a very small minority of future vehicles will feature either air assisted atomization or fuel spray heaters. Split intake manifolds, (with separate air runners for each valve) are likely to the more common with the increasing use of 4-valve engines, with higher velocities of air in each runner assisting atomization. However, no significant in-use emissions issues are associated with this technology, according to the manufacturers.

Electronic Controls/Diagnostics - Significant advances in electronic controls are likely to continue to occur. Adaptive control is a very general name for a number of strategies that utilize software to sense long range changes in engine behavior, fuel quality and ambient conditions and compensate for changes. Since it is difficult to define exactly what this term implies and even more difficult to identify its implementation in specific vehicles, we do not suggest that EPA attempt to specifically estimate the benefit of such controls. Indeed, adaptive controls of some type have been phased-in already in most vehicles over the last eight years. On the other hand, on-board diagnostics (OBDII) has very specific minimum requirements, and all vehicles have OBDII as part of the regulatory requirements for 1996. OBDII requirements have been partially met in some vehicle models since 1990, but the official phase in period began in 1994. OBDII can affect in-use emissions in two ways - first, it can give rise to earlier and more complete repair of malfunctions and second, it can influence emissions in failure modes. Of specific importance is the Dual Oxygen Sensors required by OBD to diagnose catalyst malperformance; since most high and super emitters are caused by rich failures, the presence of a second oxygen sensor can allow the detection of rich failures even if the first sensor has failed or the control system linked to the first sensor has a malfunction. Hence, EPA should specifically model the effects of OBDII on both malfunction repair rates and high/super emitter emissions.

EGR - Manufacturers expect that the majority of vehicles will continue to have EGR, although a small minority may be certified without EGR. When the revised FTP cycle is in force, EGR use at high loads is expected, and EGR systems will be either electrically actuated or utilize a vacuum reservoir. However, these changes do not alter EGR operation in any fundamental way and no separate treatment of EGR actuation systems is warranted for in-use emissions analysis.

Catalysts - Automanufacturers expect significant changes in catalyst formulation, size and design over the next twenty years. In the area of noble metal use, manufacturers expect widespread use of Palladium (Pd) catalysts by 2001 because of their improved thermal durability and higher temperature exposure capability. Palladium catalysts, however, are less resistant to poisoning by oil and fuel based additives than conventional Platinum-Rhodium catalysts. The expectation is that Palladium catalysts will be used in the close-coupled location while conventional or Palladium/Platinum/Rhodium catalysts will be used in the underfloor location. As Palladium technology improves, a single close-coupled catalyst could replace both catalysts. However, this may not imply any specific need to recognize the technology for in-use emissions analysis since the higher durability of Pd catalysts may be offset by exposure to higher temperature exhaust. At this point, there is insufficient data to resolve this issue and EEA recommends that EPA reconsider this issue when there is sufficient data in the future.

Catalyst volume and/or noble metal loading is expected to be increased to provide a 40 percent increase (on average) in active catalyst surface area to meet the needs of the revised high load FTP cycle. (This conclusion is documented in the third reference detailed on page 1-2.) While conventional FTP emissions may not be significantly impacted, this increase in catalyst volume will significantly impact emissions on non-FTP cycles, especially at high loads. EPA can recognize this change along with all other changes as a group, related to compliance with revised FTP regulations.

The imposition of NLEV/Tier II standards in conjunction with the revised FTP will lead to increased need to control cold start emissions so that small start catalysts may re-emerge at this point. Manufacturers were pessimistic about the prospects for any cold start emissions adsorption trap, but some manufacturers believed that electrically heated catalyst (EHC) could be used in a limited number of engine families, mostly large displacement V-8's where cold start emissions were difficult to control. Most experts believed that the EHC was an interim solution, and would be replaced by a variable insulation catalyst, where a vacuum insulation device would be activated at vehicle shutdown, permitting the catalyst to retain heat for several days. Both the EHC and insulated catalysts are of significance in the analysis of in-use emissions as they would significantly alter the emissions/soak time/ambient temperature relationships modeled in MOBILE5a. Essentially the EHC would almost eliminate cold start emissions, while the variable insulated catalyst would be similar to EHCs for soak periods of up to 24~36 hours.

Alternative Engines/Drivetrains - All manufacturers agreed that there were only two alternative engines with any potential for market entry in the 15 to 20 year time frame, the direct injection stratified charge gasoline engine (DISC) and direct injection diesel engine (DI diesel). Both engines operate at air fuel ratios substantially leaner than stoichiometric. Japanese manufacturers are more optimistic about the prospects of the DISC engine under Tier II standards and believed that DISC engine with the lean-NO_X catalyst would be commercialized by the 2005 time frame in the U.S. Such an engine would require fuel sulfur levels to be reduced to California Phase II Reformulated Gasoline levels or lower. In general, most features of the DISC engine with respect to in-use emissions are not substantially different from the current homogenous charge stoichiometric engine, with two exceptions. First, engine-out NO_X will be very low, and the lean NO_X catalyst is expected to have a NO_X cycle conversion efficiency of only ~50 percent compared to 85-90 percent for three-way catalysts. Second, the engine will require less cold start and acceleration enrichment than current MPFI gasoline engines so that its response to cold ambients and non FTP cycles is likely to the more similar to a diesel engine than to a gasoline engine. It is not yet clear if the NLEV standard can be met with a DISC engine, although it appears possible on lightweight vehicles.

Manufacturers were more pessimistic regarding the ability of a DI diesel to comply with NLEV regulations and believed that to meet even a 0.4 g/mi NO_X standard for LDVs, the D.I. diesel would need:

- Injection rate shaping with pre-injection
- External EGR at much higher rates than for a gasoline engine
- A lean-NO_X catalyst with an efficiency of 30 to 40 percent
- Catalytic control of particulate emissions

Manufacturers believed that all of the above technologies will be needed at the 0.4/mi NO_X standard, although the last two could be handled by the same catalyst. While EPA could explore the ramifications of these variations for diesel engines, its very limited market share forecasts suggest that EPA need not be concerned about future DI diesel in-use emissions for the LDV/LDT market.

Electric and electric hybrid vehicles have also been suggested as a possible set of vehicle technologies for the future. While electric vehicles are clearly zero emission vehicles (LEV) electric hybrid vehicles of any design can have the potential to act as LEVs in a limited area of 25 to 30 miles. In addition, hybrid vehicles of the series type will have emissions that are not a function of drive cycle or speed, but could be near constant in gm/mile, over a range of city and highway speeds, except at high speeds. Details of the emissions performance of hybrids could be worth studying under certain scenarios for future emissions regulations.

Our recommendations on LDV/LDT technologies for EPA's in-use emissions analysis are summarized in Table 2-1. The recommendations were based on both the anticipated market share and the emissions impact of a given technology; high importance implies both market share and emissions impacts are high, medium is a combination of high for one variable and low for the other, while low implies both variables are low. Market share related data are provided in the following sections of this report.

TABLE 2-1
LDV/LDT TECHNOLOGIES FOR POTENTIAL CONSIDERATION IN EPA EMISSION FACTOR MODEL

Technology	Importance	Reasons
Dual-Bed Catalyst (3WY+OX)	Medium (Historical Only)	Higher HC/CO efficiency but lower NO_X efficiency relative to single bed catalyst.
Sequential FI	Low	Slightly reduced cold start and acceleration enrichment, improved A/F control.
Dual Oxygen Sensor	Medium	Second sensor can correct or compensate for malfunctions.
Improved Fuel Vaporization	Low	Very minor effects on emissions, not likely to see widespread use.
Adaptive Controls	Low	Already in widespread use in different forms.
OBD II	High	Potentially lower in-use malperformance rates.
Palladium Catalyst	Low or Unknown	Lower deterioration due to higher thermal durability may be offset by higher temp exposure.
Increased Catalyst Volume to Meet New FTP Cycle	High	Reduced "off-cycle" emissions.
Close Coupled Catalyst	Medium	Reduced emission on short/medium duration soak time.
Variable Conductivity Insulated Catalyst	High	Substantial emissions reduction on medium/long duration soak.
Lean-NO_X Catalyst	High	See DISC.
Electrically Heated Catalyst	Medium	As per insulated catalyst, but market penetration may be quite low.
Direct Injection Stratified Charge (DISC)	High	Different engine out emissions, requires lean-NO_X catalyst with different efficiency.
Hybrid-Electric Drive	High	Emissions profile can be speed independent; limited ZEV capability.
ZEV	Medium	Zero emissions, but limited market.
Diesel	Low	Will likely require waiver to 0.4 NO_X level in the 2000+ time frame.

2.5 CURRENT HEAVY-DUTY ENGINE TECHNOLOGY

The heavy-duty fleet can be subdivided into three classes, called light-heavy, medium heavy and heavy-heavy respectively. Gasoline engines have over 60 percent of the market in the light-heavy class, but account for less than 30 percent of the medium-heavy class; no gasoline engine are sold in the heavy-heavy class.

Gasoline engines sold in the heavy-duty market utilize multipoint fuel injection since 1993 and, with the exception of two Ford MHDGE engines, utilize oxidation catalysts, secondary air and EGR. Manufacturers do not expect any significant change to this system even after the imposition of a 4.0 g/bhp-hr NO_x standard in 1998 as the current (1996) engines appear to be certified at 2.5 to 4.1 g/bhp-hr NO_x emissions. The imposition of a 2.5 g/bhp-hr HC+NO_x standard in the 2000+ time frame would likely cause a shift to closed loop control with palladium based three-way + oxidation (dual-bed) catalysts and secondary air. Dual bed catalysts would be required since the engines will need to operate richer than stoichiometric at high loads to prevent overheating.

Manufacturers believe that such systems could meet a 1.5 g/bhp-hr standard for NO_x, and possible even a 1.0 g/bhp-hr standard with refinement over time.

Diesel engines have (at least to 1994) met all historical standards by basic improvements in the combustion process rather than through add-on controls or aftertreatment. The major improvements to HHDDE and MHDDE include:

- Elimination of all naturally aspirated diesels since 1988
- Incorporation of intercooling in all engines since 1990
- Conversion of all jacket water intercoolers to the air-to-air type

- Reduction of oil consumption by improving the design of the valve seals and piston oil rings
- Increased injection pressure to produce a more finely atomized spray.
- Electronic control of fuel injection timing and rate
- "Quiescent" combustion chambers with low air swirl and squish

By 1996, most HHDDE/MHDDEs incorporate these technologies. A few diesels equipped with non-electronic fuel systems continue to be sold in the U.S. under the averaging, banking and trading provisions but are expected to phased out by 2000. A couple of MHDDE models were initially certified with oxidation catalysts in 1994, but have been since recertified without these catalysts.

Issues of possible concern for in-use emissions include:

- The very high injection pressures in the post-1994 time frame (over 25k psi on HHDDEs) could potentially lead to injector spray hole erosion, causing increased PM emissions.
- The use of electronic injection systems could lead to reduced tampering and improved diagnostics and repair, relative to mechanical systems.
- The use of air-to-air intercoolers could lead to slow deterioration in cooling performance as dust accumulates on the intercoolers, relative to the performance of jacket water systems.

Light Heavy-Duty Diesel engines (LHDDE) are somewhat different from other heavy-duty diesel engines. Until 1990 the majority of engines sold were of the pre-chamber type, which has inherently lower NO_X emissions. However, the potential to reduce PM emissions to very low levels is limited, and very high injection pressures to reduce particulate emissions is not useful in the context of pre-chamber engines. Since 1991, only GM continues to offer a pre-chamber diesel, while all others are of the direct injection type. Since 1994, the majority of LHDDEs utilize an oxidation catalyst for particulate control; industry experts confirm that its efficiency is quite low, averaging about 25 to 30 percent. Unlike the other engine classes, LHDDEs have retained mechanical injection systems in over two-thirds of the engines sold in 1996, and the injection systems operate at lower pressures of 14-16 kpsi in this class. Hence, the only significant issue of concern to EPA is the durability of the catalyst, and this concern is partially offset by the low catalyst efficiency.

2.6 FUTURE HDDE TECHNOLOGIES

HDDE emission control technology will continue to evolve over the next fifteen to twenty years with the near term drivers being the 1998 4.0 g/bhp-hr NO_x standard and the "statement-of-principles" on the 2.5 g/bhp-hr HC+NO_x standard. Heavy-duty diesel manufacturers are also investigating the possibility of meeting even lower standards, up to a 1.0 g/bhp-hr NO_x standard. At present, HDDE manufacturers believe that the 2.5 HC+NO_x standard could potentially be met without any aftertreatment but standards lower than that would almost certainly require aftertreatment. The following is a list of potential improvements to HDDE technology. It should be noted that low emission HDDE technology is progressing rapidly, and forecasts even for 2010 are very speculative.

Turbochargers - Current turbochargers are not very efficient in much of the diesel engine's operating range of airflow and future improvements in turbocharging are aimed at providing high boost and high efficiency over a large part of the operating range. A widely investigated technology is the variable vane turbocharger, but most manufacturers believed that its cost and complexity limits its market to certain specific applications such as a very high HP rating for given engine family. Manufacturers believed that simpler (and confidential) designs hold promise, such as the variable plenum or twin plenum turbo, or matched twin turbo chargers in series. Longer time-horizon designs include the electrically assisted turbocharger where turbo speeds could be controlled by electrical power addition or absorption by a high speed electric motor. Manufacturers anticipate that electrical technologies will likely be realized only in the post-2005 time-frame. In-use concerns with advanced turbochargers include mechanical and/or electrical malfunctions, and the variable vane turbocharger, in particular, could experience in-use malfunctions in its vane controls. Such malfunctions may not disable the turbocharger but simply cause it operate less efficiently. Current turbochargers rarely experience partial failures that reduce boost, although they can have oil leaks or can experience catastrophic failure.

Intercoolers may be developed to be "on-demand" so that air flow and cooling rates can be varied depending on engine load/speed and temperature. However, this technology is unlikely to affect in-use emissions in any significant way, as the net effect of "on-demand" intercooling is expected to be small.

Fuel Injection Systems - Engine manufacturers were of the opinion that fuel injection systems would be all electronic, and HHDDEs and MHDDEs would all incorporate high pressure unit injector or "common rail" technology. The design distinctions are not of specific concern to EPA as they do not affect emissions in a significant way. Manufacturers also believe that injection pressures could continue to increase from 1996 levels of 25 to 30 kpsi to about 40 kpsi by 2004 in HHDDEs and from 18 to 20 kpsi in 1996 to 25 to 28 kpsi in MHDDEs. These pressures could result in increased injector spray hole erosion under in-use conditions. In addition, aftermarket injectors could have more significant problems with these high pressures. Hence, increased injector problems would be an issue for in-use emissions.

The electronically controlled unit injector or common rail injectors are also likely to be used for fuel delivery rate "shaping". Recent testing indicates that a small amount of fuel preinjected before the main injection event reduces NO_x emissions.

Preinjection is just one form of rate shaping that could involve multiple injections. This increase in injection complexity will be achieved through advanced electronic control with on-board diagnostics so that experts did not believe that it would give rise to special in-use problems, and EEA concurs with this judgement.

The use of on-board diagnostics could lead to reduced in-use malfunctions and improved diagnostics and repair; however, the diagnostics are not being designed especially for emission problems so it is not clear at what level items like injector spray hole erosion or rate shaping errors are detected and indicated to the user. As a result, it's influence may not be quite as large as in the case of OBDII for light duty vehicles.

EGR - All manufacturers stated that EGR was the single most important technology available to meet the potential 2.5 g/bhp-hr HC+NO_x standard. All manufacturers also believe that an external EGR system capable of providing a 50 percent EGR rate at light loads (decreasing to near zero at full load) would be necessary. In addition, the use of EGR would entail the need to cool the exhaust gas being recirculated and EGR intercoolers are seen as an additional requirement. The addition of EGR would also require a sophisticated control system to control EGR flow over the transient test cycle.

EGR is a major issue for EPA since it could be a target for intentional disablement; without EGR, engine power would improve as would driveability, and even possibly fuel economy. EGR intercooler fouling could also be a problem in-use, but would definitely have a much smaller effect on emissions than EGR disablement.

Exhaust Aftertreatment - All manufacturers are reluctant to use any form of trap or catalyst with HDDE due to the cost and complexity of packaging. However, they also believe that at NO_x standards of about 1.5 g/bhp-hr or lower, there is no alternative to aftertreatment.

The lean NO_x catalyst is potentially the leading contender for aftertreatment if its efficiency can be raised from current very low levels to about 30 to 35 percent, which some manufacturers see as a reasonable goal. The lean-NO_x catalyst requires some HC in the exhaust to catalyze NO_x, and the HC could be provided by injecting a small quantity of diesel fuel into the exhaust (e.g. the injectors could be programmed to inject fuel in the exhaust stroke). The lean NO_x catalyst may also be able to reduce particulate, although its efficiency for this pollutant may be quite low, at 20 to 25 percent. At a NO_x conversion efficiency of 35 percent, an engine-out emission level of 2.1 g/bhp-hr NO_x will allow meeting a standard of 1.5 g/bhp-hr.

Very low NO_x levels below even 1 g/bhp-hr can be attained by injection of urea or ammonia, although such systems for use in trucks are in their early stages of research. Current systems have high conversion efficiency for NO_x only at limited temperature ranges and flow rates, while urea/ammonia emissions are still problematic. Hence, manufacturers regard this technology as very speculative and many in the industry doubt that such a system for commercial use will ever be practical. Nevertheless, the capability to attain 80 to 90 percent NO_x conversion efficiency even over limited temperature and exhaust flow ranges suggests that cycle NO_x conversion efficiency over 50 percent is a possibility, which would be the minimum level acceptable for a 1 g/bhp-hr standard. Other system drawbacks are the need to periodically refill the system with urea/ammonia, and the emissions (however small) of urea/ammonia as an unreacted compound could be an issue of concern for EPA. The system is unlikely to be commercialized until about 2010, if ever.

Most medium and all heavy-heavy duty engines appear to be able to meet the 0.10 g/bhp-hr particulate standard without any aftertreatment, while a few MHDDES and all LHDDEs have used an oxidation catalyst. Due to NO_X/PM tradeoff, manufacturers believe that a larger fraction of MHDDEs will require oxidation catalysts at the 1988 standard 4.0 g/bhp-hr NO_X and expect a significant fraction of MHDDEs to require oxidation catalysts at 2.5 g/bhp-hr $HC+NO_X$. In addition, some manufacturers believe a metal based fuel additive (such as copper or cerium) may be required at the 2.5 g/bhp-hr standard to bring many MHDDEs and all LHDDEs into compliance with a 0.10 particulate standard. Navistar, in particular, believes that standards of 0.05 g/bhp-hr particulate can be met on almost all engines with oxidation catalysts and a cerium additive. It is not clear if EPA has concerns with the emissions of the additive, although Navistar believes that cerium emissions are too low to be of concern. At this point, most manufacturers believe that the oxidation catalyst/fuel additive approach is preferred over any particulate trap based aftertreatment system.

Table 2-2 summarizes technologies of importance to EPA in its analysis of HDDE in-use emissions. The methodology to rank the importance of the technologies is identical to the one used for LDV/LDT technologies.

TABLE 2-2
TECHNOLOGIES OF POTENTIAL IMPORTANCE IN EPA HDDE EMISSION FACTOR ANALYSIS

Technology	Importance	Reasons
Variable Vane Turbocharger	Medium	Higher in-use malfunction rate possible.
Electronic Injection System Control Diagnostics	Medium	Lower in-use malfunction rate due to diagnostics but diagnostics not specific to emission problems.
Very High Pressure FI (>25,000 psi)	High	Potentially higher injector erosion; potential malfunctions with aftermarket injectors.
EGR (external)	High	Potential disablement for improved performance.
EGR Intercooler	Low	Intercooler plugging with use, small emission effect.
Multiple Injection (rate shaping)	Low	Electronic control makes tampering unlikely, no tampering benefit.
Oxidation Catalyst	High	Higher engine out PM emissions, possible disablement in-use.[1]
PM Trap	High	As above, but unlikely to be commercialized
Urea/Ammonia Injection	High	In-use characteristics unknown at present.

[1]May require fuel additives in the post 2000 time frame.

3. LIGHT DUTY VEHICLES/TRUCKS TECHNOLOGY DISTRIBUTION

3.1 OVERVIEW

Light Duty Vehicles (LDV) and Light Duty Trucks (LDT) cover the range of vehicles under 8,500 lb GVW, and the two classes of vehicles have generally featured very similar emission control technology. Gasoline engines are used in over 99.5 percent of both LDV/LDT fleets, with the remainder being diesel powered.

LDT emission standards have typically trailed the LDV emission standards in stringency by 3 to 4 years, but the standards have now converged to a point where the effective stringency is identical across vehicle weight classes for LDV and LDT I (light trucks up to 6000 lb GVW). LDT II (light trucks between 6000 and 8500 lb GVW) have less stringent standards, especially for NO_X but a review of the certification data for 1996 does not show any significant control technology differences between the two classes. The significant exception to this rule is in the case of Ford's LDGT II trucks which use dual-bed catalysts in most applications. Emissions of NO_X on heavier trucks in the LDT II class are higher than those in the LDT I class but still in the 0.4 g/mi range, which is only slightly above the LDGT I standard of 0.4 g/mi at 50,000 miles, but much higher than typical certification levels of about 0.2 g/mi.

3.2 TECHNOLOGY AND STANDARDS TO 1996

As noted, the major change from oxidation catalyst technology to "closed-loop" electronic fuel system control with a 3 way catalytic converter had occurred across the LDV fleet by 1984, and across the LDT fleet by 1987. Emission standards remained constant until 1990, after which several additional standards have come into place for 1996. The standards include:

- Tier I emission standards phased-in between 1994 and 1996
- Enhanced evaporative emissions test procedures applicable to 20 percent of 1996 vehicles, increasing to 100 percent for 1999 and later vehicles
- On-board diagnostics (OBDII) applicable to 100 percent of the 1996 fleet
- Cold CO standards, phased in with the Tier I emission standard.

Technologies to meet these standards have relied upon evolutionary improvements to engine technology and to emission control technology. A detailed description of the technologies is provided below.

Air Fuel Mixture Preparation - Multipoint fuel injection has largely replaced carburetors and throttle body injection (TBI) in all LDV and LDT models by 1996. In 1990, only about 1.5 percent of LDV sales and 5 percent of LDT sales were carbureted engines, and these have since disappeared completely. By 1995, only a handful of models offer TBI and these are likely to be phased out by 1997. In the early 1990s, it was envisaged that meeting the "cold CO" standard would require fuel atomization assistance during cold start, such as the use of heated spray targets or air assisted atomization. A survey of the most popular models for 1996 revealed that most vehicles have not used this type of atomization assistance. However, a majority of multipoint fuel injection systems use sequential injector firing so that the fuel is more precisely tailored to the cylinder intake event.

Combustion Systems - The use of high turbulence chambers to promote complete fuel burning is now very common, and the use of 4-valve cylinder heads with very compact (hemispherical) chambers in growing. In 1990, 26.2 percent of LDVs had 4-valve engines, but by 1995, this had increased to 51.6 percent. The use of 4-valve engines in LDTs has not kept pace with the use in LDV, and has grown from only 1.76 percent in 1990 to 5.9 percent in 1995, all in import trucks. 4-valve engines, while offering better specific power and lower fuel consumption, do not have significantly different emission characteristics relative to modern 2-valve engine with "fast burn" combustion chambers. Hence, we recommend that EPA not concern itself with the use of this technology.

Exhaust Gas Recirculation - Although EGR was already in wide use in 1990, it's use has grown slightly between 1990 and 1995, rising from 77.6 percent to 90.5 percent in LDVs and 72.7 to 77.6 percent in LDTs. However, a majority of systems in 1990 were of the simpler backpressure type (which results in a near constant EGR rate over a wide load range). By 1995, many EGR systems were of the electronic flow control type to achieve better tailoring of EGR flow rates to both local and speed. Details on EGR control for select models have been obtained from the major manufacturers and listed in tables in the appendix to this report. In the absence of specific model by model data, EEA expects that about 75 percent of LDVs and 65 percent of LDTs have electronic EGR control in 1996.

Secondary Air Systems - The use of air pumps or pulse air systems to assist in cold start emission reduction, and to serve as an auxiliary air source for dual-bed catalysts, has declined over the 1990-1995 time frame. EEA estimates that air pump use has declined from 18.1 percent in 1990 to 4.80 percent in 1995 and pulse air from 9.4 percent in 1990 to 1.1 percent in 1995 in LDVs. The decline has been as significant in LDTs, especially in LDT II where only Ford continues to use dual bed catalysts. 56.3 of all LDTs had secondary air (mostly air pumps) in 1990, but this declined to 15.9 percent in 1995. A few electronic motor driven air pumps (rather than engine driven) have emerged in luxury car models as of 1994 to permit better tailoring of secondary air to engine temperature, load and speed.

Electronic Control - The use of sequential fuel injection and electronically controlled EGR has been discussed above, but there are other development as well. Adaptive control was utilized in a majority of LDVs and about half of all LDTs by 1990, and has since been standardized. By 1995, about 85 percent of LDTs and nearly all LDVs vehicles feature adaptive control. Control algorithms and electronic filtering have been improved to tighten the air-fuel ratio control band around stoichiometry, in order to maximize catalyst efficiency. Heated oxygen sensors, not used in 1990, are now used across the board, to permit quicker transition to closed loop operation after cold start, and to reduce oxygen sensor response time. These improvements alone are responsible for much of the emission reductions to meet Tier I standards.

Catalysts - although three-way catalysts were used in all LDVs and 98.2 percent of LDTs even in 1990, two major shifts have occurred. First, dual-bed catalyst systems have been phased out in LDVs and LDGTI vehicles, but continue to be used by Ford in LDGTII vehicles. Second, the use of close-coupled catalysts has become popular as a way to reduce cold start emissions. Many vehicles now feature a close-coupled catalyst in addition to the underfloor catalyst, thereby providing fast "light-off" as well as increased total catalyst volume. In addition, catalyst formulations have changed to improve their thermal shock resistance; some manufacturers have incorporated palladium catalysts that are capable of withstanding the higher temperatures associated with closed coupled catalysts. Details on close coupled catalysts were available only for select high sales volume models.

On-Board Diagnostics - Many vehicles offered basic mechanic accessible diagnostics for electronic components in 1990. With the advent of the OBD rule, all LDV and LDT models feature OBDII level diagnostics in 1996 vehicles.

Other Technologies - Several specialized technologies that affect emissions are used in select models. Many vehicles use double walled exhaust pipe to retain exhaust heat to the catalyst, but detailed information on its use rate was still being compiled at the time of this reports writing. Variable valve timing is used in several select Japanese models; although this is not strictly an emission control technology, it does have a significant effect on emissions at light loads. As of 1996, we are not aware of any vehicles using an electrically heated catalyst.

While basic control technology distinctions were available from certification data, more detailed data required contacts with the manufacturers. Table 3-1 and 3-2 lists the technology distributions of current interest to EPA. There tables were derived by EEA by matching certification data on engine families and their technology to sales data from CAFE Submissions to DOT. (For 1994 and 1995, the sales data are mid-model year submissions since the final data are not yet available). More detailed technology identification can be found in the tables in the appendix. The tables are provided for GM, Ford, and Chrysler and Nissan, Toyota and Honda. EEA was unable to obtain detailed information on some LDT models, so that the tables are incomplete for these vehicles.

TABLE 3-1

LDV TECHNOLOGY DISTRIBUTION

TECHNOLOGY	1990	1991	1992	1993	1994	1995
MPFI/3CL	21.52	19.63	31.57	19.32	16.76	9.18
MPFI/3CL/EGR	34.65	39.77	43.22	62.58	72.69	83.76
MPFI/3CL/AIR/EGR	12.21	12.36	11.68	7.16	6.67	5.86
MPFI/3CL+OXD/AIR/EGR	10.95	7.22	3.68	0.00	0.00	0.00
SPFI/3CL	2.69	5.22	4.70	2.43	1.72	0.00
SPFI/3CL/EGR	13.53	12.45	2.36	6.47	1.31	1.20
SPFI/3CL/AIR/EGR	1.89	3.00	2.50	2.04	0.85	0.00
SPFI/3CL+OXD/AIR/EGR	0.71	0.11	0.00	0.00	0.00	0.00
CARB/3CL+OXD/AIR/EGR	1.44	0.03	0.00	0.00	0.00	0.00
OTHER	0.41	0.21	0.29	0.00	0.00	0.00

SPFI is Single-point or Throttle-body FI

TABLE 3-2

LDT TECHNOLOGY DISTRIBUTION

TECHNOLOGY	1990	1991	1992	1993	1994	1995
MPFI/3CL	27.39	20.74	33.06	22.70	8.33	10.96
MPFI/3CL/EGR	8.94	8.68	13.00	26.48	46.05	47.80
MPFI/3CL/AIR/EGR	5.91	9.38	8.09	8.82	7.75	5.15
MPFI/3CL+OXD/AIR/EGR	12.96	9.57	11.86	10.82	10.66	10.72
SPFI/3CL	0.00	7.99	1.22	1.00	0.00	0.00
SPFI/3CL/EGR	7.36	27.94	26.76	25.88	27.21	25.36
SPFI/3CL/AIR/EGR	27.07	9.90	3.84	3.20	0.00	0.00
SPFI/3CL+OXD/AIR/EGR	5.01	3.62	0.06	0.00	0.00	0.00
CARB/3CL+OXD/AIR/EGR	2.22	1.13	0.76	1.10	0.00	0.00
CARB/OPLP	1.80	0.69	0.87	0.00	0.00	0.00
OTHER	1.34	0.36	0.48	0.00	0.00	0.00

SPFI is Single–point or Throttle–body FI,GM Central Port FI listed as SPFI

3.3 FORECASTS FOR TECHNOLOGY DISTRIBUTION

Light-duty vehicles and light-duty truck emission control technology is already quite advanced, with some vehicle models already certifying to the stringent California LEV standards in 1996. With the phase-in of the Tier I standards as well as OBD requirements completed in 1996, the two major future changes in emission requirements are (1) the revised FTP with the standards and (2) future Tier II standards that will likely be imposed between 2000 and 2005. It seems that further reductions in certification standards are less likely to 2010, and new strategies may be developed beyond 2010. One possible strategy that has gained currency in Europe and in California is a zero emission vehicle requirement that may apply only to non-attainment areas. Such a strategy would force the introduction of electric or electric/hybrid vehicles with the latter operating as a pure electric vehicle in non-attainment areas.

The forecast scenarios assume that California will continue with its zero-emission vehicle (ZEVs) mandate, but we do not assume that the Northeastern United States follow California's lead as far as ZEVs. Hence, electric vehicles penetration in non-California regions is primarily a "spill-over" effect from California, and may be concentrated in Southern States where excessively cold ambients are not encountered.

The LDV technology forecast is shown in Table 3-3. A 49-State EV market share of 1.5 percent is forecast by experts based on 6 to 8 model offerings in LDVs, while manufacturers expect the first hybrid vehicles to be introduced by European and Japanese manufacturers in 2000. On conventional engines, sequential fuel injection will increase market share slightly, as will close-coupled and insulated catalysts.

TABLE 3-3

LDV TECHNOLOGY FORECAST

TECHNOLOGY	1996	2000	2005	2010	2020a	2020b
ENGINE TYPE						
–CONVENTIONAL	100	97	87	80	55	70
–DISC	0	0	5	10	30	5
–HYBRID ELECTRIC	0	0.5	3	5	10	20
–ELECTRIC	0	1.5	3	3	3	3
–DIESEL	0	1	2	2	2	2
CONVENTIONAL ENG.						
–SMPFI/3CL	10	8	5	5	4	0
–SMPFI/3CL/EGR	74	77	77	75	51	70
–MPFI/3CL/EGR	9	4	0	0	0	0
–SMPFI/3CL/EGR/AIR	7	8	5	0	0	0
CATALYST TYPE						
–CLOSE COUPLED+MAIN	50	55	47	25	15	25
–ELEC. HEATED	0	0	10	5	0	0
–VARIABLE INSULATED	0	2	30	50	40	45
–LEAN NOx	0	0	7	12	32	7
–CONVENTIONAL	50	40.5	3	5	10	20

SMPFI is Sequential FI

The effect of imposition of the Tier II standards will be to substantially increase the market share of insulated or electrically heated catalysts. Given the low fuel price forecast, manufacturers do not expect to see much consumer motivation to pay for fuel efficient technologies such as the DISC and diesel. Indeed, domestic manufacturers believe that these technologies will have very low penetration levels, but import manufacturers are more optimistic. Manufacturers expect to see:

- first introduction of the DISC engine, probably by Japanese manufacturers in the 2002-2005 time frame
- Small market shares for advanced diesel engines and electric vehicles that could be stable at 2 to 3 percent
- Increasing interest in the hybrid/electric vehicle for its fuel efficiency, resulting in growth in market share

EEA's 2010 estimates represent a continuation of these trends. DISC engines are expected to be used in smaller and lighter cars due to the limited NO_x conversion efficiency of the lean NO_x catalyst.

Beyond 2010, Scenario A assumes no further significant changes to emission standards, while scenario B assumes regulations requiring ZEV performance in non-attainment areas and/or ULEVs. Under scenario A, the DISC engine has increasing market share, while under scenario B, conventional engines with advanced catalysts and electric hybrids become more popular.

Table 3-4 shows that forecast for LDTs, which is similar to the one for LDVs. We estimate that technology difference between LDGT I and LDGT II classes will narrow further so that it may not be necessary to distinguish the two classes for modeling.

TABLE 3-4

LDT TECHNOLOGY FORECAST

TECHNOLOGY	1996	2000	2005	2010	2020a	2020b
ENGINE TYPE						
–CONVENTIONAL	99	97	91	85	74	85
–DISC	0	0	2	5	10	2
–HYBRID ELECTRIC	0	0	3	5	10	10
–ELECTRIC	0	1	1	1	1	1
–DIESEL	1	2	3	4	5	2
CONVENTIONAL ENG.						
–SMPFI/3CL	12	10	10	5	4	5
–SMPFI/3CL/EGR	28	30	75	80	70	80
–SPFI or MPFI/3CL/EGR	48	45	0	0	0	0
–SMPFI/3CL+OXD/EGR/AIF	12	15	6	0	0	0
CATALYST TYPE						
–CLOSE COUPLED+MAIN	30	40	45	35	14	5
–ELEC. HEATED	0	0	15	10	0	0
–VARIABLE INSULATED	0	0	15	40	60	75
–LEAN NOx	0	0	5	9	15	3
–CONVENTIONAL	69	57	19	5	10	10

SMPFI is Sequential FI, SPFI is Single point FI

Significant differences between the LDV and LDT forecasts are:

- electric vehicles will have even more limited market share in LDTs due to its poor load carrying capacity
- DISC engines are expected to have lower market share due to the higher weights of trucks
- the hybrid may be more popular in LDTs, especially in 4-wheel drive versions, because the hybrid may be better suited to 4WD design
- Conventional engines will retain a larger share of the market in part because of LDT technology has historically lagged LDV technology by 5 to 7 years. (The lag is not due to regulatory forces alone, since even the introduction of 4-valve engines and 4-speed automatic transmissions have lagged in LDTs).

The forecasts are based on automanufacturer inputs, but their qualitative inputs have been translated to numerical values by EEA.

4. HEAVY-DUTY ENGINE EMISSION CONTROL TECHNOLOGY

4.1 OVERVIEW

Diesel engines are certified in all three subclasses, light heavy, medium heavy and heavy heavy-duty (LHDE, MHDE and HHDE). while most gasoline engines are certified for use in the light-heavy subclass only. In addition, the number of engine models that account for 90 percent of sales in each subclass is relatively limited, with 3 to 5 models accounting for most of the sales. Among diesel engines, each engine model is sold in a variety of horsepower ratings, but emission control technologies are generally similar across most ratings.

In the gasoline engine field, only GM, Ford, and Chrysler continue to offer engines in any significant volume, and over 90 percent of sales are in the light-heavy category. GM and Ford offered 4 LHDG engine lines, three V-8 models and one six-cylinder model each. Chrysler offered only one V-8 model (the 5.9L V-8) until 1996, when it began offering a V-10 engine. Ford has dropped the six-cylinder engine as of 1994, but is introducing a V-10 in 1997. GM and Ford also offer medium duty versions of two V-8s each, for use in trucks over 14,000 lb GVW.

Diesel engines in the light heavy-duty segment (LHDDE) are used in Ford, GM and Chrysler vehicles but are typically manufactured by others. Ford uses the 7.3L Navistar V-8 and Chrysler uses the 5.9L Cummins I-6 engines, while GM uses an in-house diesel, the 6.5L V-8. These three engines account for over 90 percent of sales in this category, but Isuzu and Mitsubishi offer a few engines used in vehicles in the 12,000 to 14,000 lb GVW range. Cummins and Navistar offer versions of the 5.9L and 7.3L for use in 14,000 to 26,000 lb GVW trucks and buses.

Very few engines lines also dominate the medium heavy-duty diesel engines (MHDDE) market. In 1990, the Caterpillar 3208, the Ford 7.8L I-6, the GM 8.2L V-8 and Navistar DT-360 and DT-466 accounted for a majority of the sales. By 1996, however, the GM 8.2L was dropped from production while Caterpillar has replaced the 3208 with the 3116 model, and Navistar has dropped the DT-360. The new engines now account for about 75 percent of MHDDE sales, but there are several imports from Nissan, Isuzu, Mercedes and Volvo in this market.

The heavy heavy-duty diesel engines (HHDDE) have traditionally featured two engine sizes per manufacturer, one for the 250-320 HP and the other for 320 + HP range. Cummins, Caterpillar and Detroit Diesel have traditionally dominated this subclass with the L10/N14, 3306/3406 and 6-71/6-92 engines respectively. In recent years, Cummins has replaced the L10 with the M11 engine, while Caterpillar has replaced the 3306 with the 3176 engine. Detroit Diesel was the only manufacturer of 2-stroke engines but decided to replace the 6-71 and 6-92 two-stroke engines with the Series 50 and Series 60 four-stroke engines respectively. Although the two stroke engines are still being offered in 1996, they are expected to be phased out in the next two years. Two-stroke engines are still sold in the bus market and in select truck models designed for use with the DDC 6-71/6-92 models. Mack has been the only other significant (but smaller than Cummins, Caterpillar or Detroit Diesel) seller in this market with the E7 and E9 engines, but virtually no import manufacturers are represented in this subclass of engines.

Heavy-duty engine emission standards have changed in 1990, 1991 and 1994 (although the 1990 change was actually a delay from a planned 1988 change). The main changes have been to NO_X and particulate (PM) standards which primarily affect diesel engines. Gasoline engines are more affected by HC/CO standards which remained unchanged over the period. Most gasoline engines met the

1994+ emission standards in 1990 itself. In contrast, the reduction of NO_X/PM standards (in grams per bhp-hr) from 6/0.6 to 5/0.25 in 1991 and 5/0.1 in 1994 has resulted in substantial changes to diesel engine emission control technology. The incorporation of averaging, banking and trading (ABT) in regulations has allowed manufacturers to continue selling some low sales volume engine lines that do not meet 1994+ emission regulations. HC/CO standards in grams per bhp-hr are 1.1/14.4 for engines used in trucks below 14,000 lb GVW and 1.9/37.1 for engines used in trucks above 14,000 lb GVW. In addition, EPA allows the certification of heavy-duty vehicles between 8,500 and 10,000 lb GVW on the basis of compliance with light truck standards and test procedures.

There is a consensus that emission control technology based on exhaust aftertreatment for diesels is well behind the state-of-the-art for gasoline engines. As a result, some researchers believe that the future holds substantial emission reductions through improvements in aftertreatment technology, while others are more pessimistic. Hence, forecasts even to 2010 are more speculative than for LDV/LDT technology.

4.2 CURRENT GASOLINE HEAVY-DUTY ENGINES

As noted, gasoline heavy-duty engines are affected mostly by the HC/CO standards, which have remained consistent over the period 1990-1996. Hence, certification emission levels and emission control technology for these engines have not been affected as significantly as for the diesel engines over this period, although emissions reduction have been significant in prior years.

Table 4-1 shows a comparison of the 1990 emissions and 1994 certification levels (the last year for which certification data was published as of September 15, 1996) for most of the engine

TABLE 4-1

HEAVY-DUTY GASOLINE ENGINE CERTIFICATION LEVELS (Emissions in g/bhp-hr)

Manufacturer	Engine	Year	HC	CO	NO_X	Technology
Chrysler	360	1990	0.72	12.4	4.08	FI/EGR/AIR/OXCAT
	(V-8)	1994	0.60	11.7	3.0	FI/EGR/AIR/OXCAT
	488	1994	0.20	11.2	2.4	FI/EGR/AIR/OXCAT
Ford	5.8E	1990	0.64	4.2	4.2	FI/EGR/AIR/OXCAT
		1994	0.80	7.8	4.4	FI/EGR/AIR/3CL
	7.0[1]	1990	1.05	26.03	2.6	CARB/EGR/AIR
		1994	0.80	16.90	4.0	FI/EGR/AIR/CL
	7.5	1990	0.47	7.88	3.5	FI/EGR/AIR/CL
		1994	0.20	9.30	4.2	FI/EGR/AIR/OXCAT
	7.5[1]	1990	0.47	7.88	3.5	FI/EGR/AIR/OXCAT
		1994	0.50	22.50	4.4	FI/EGR/AIR/CL
GM	262	1990	0.49	8.47	4.1	FI/EGR/OXCAT
		1994	0.50	6.10	4.3	FI/EGR/OXCAT
	350	1990	0.39	6.33	2.9	FI/EGR/OXCAT
		1994	0.60	7.50	2.7	FI/EGR/OXCAT
	366/427[1]	1990	1.25	26.40	3.8	CARB/EGR/AIR
		1994	1.10	16.20	2.6	FI/EGR/OXCAT
	454	1990	0.71	10.12	4.85	FI/EGR/OXCAT
		1994	0.50	11.50	3.5	FI/EGR/OXCAT

[1] MHDE weight class. All FI is multipoint.

families with significant sales. As can be seen, all of the engine families listed in Table 4-1 met the 1994 5.0 g/bhp-hr NO_x standard in 1990 (although these were a few families not listed in Table 4-1 that were at 5.1 ~ 5.5 g/bhp-hr levels). As a result, the technology used to meet standards has remained largely unchanged for Chrysler and GM HDGEs. Ford is an exception to this rule as it has adopted three way catalysts and closed loop fuel system controls on all engines used in trucks under 14,000 lb GVW. Conversations with Ford Certification staff revealed that the commonality between electronic control units has also led to many (but not all) OBDII diagnostic systems being adopted on these HDGEs. Chrysler and GM engines continue to utilize oxidation catalyst technology. Both Chrysler and Ford engines use air pump based secondary air systems, while GM engines do not use any secondary air. EGR is used in all HDGEs and is primarily the simple backpressure type (EEA was unable to confirm if any HDGEs used electronic EGR control).

HDGEs for trucks over 14,000 lb GVW are sold only by Ford and GM, each of which offer two engine models. In 1990, only the Ford 7.5 liter offered fuel injection and an oxidation catalyst, while the Ford 7.0 liter and the GM 366 and 427 engines used carburetors and were non-catalyst. While all engines now use fuel injection, both Ford engine models are non-catalyst while GM has adopted oxidation catalyst across the board. EGR is used on all these engines and is of the backpressure type, while on-board diagnostics have not yet appeared on these engines to the best of EEA's knowledge.

Market share estimates for emission control technology are based on approximate estimates of Chrysler, Ford and GM market shares in the 8500 to 14,000 lb GVW market and in the over 14,000 lb GVW market for HDGEs. Chrysler had only 10 percent of the market in the 8500 to 14,000 lb GVW range in 1990 but with the introduction of the new pickup truck in 1994, its market share has increased to

16 percent in 1995/96. GM and Ford had 50 and 40 percent of this market in 1990, but each of these manufacturers have lost about 3 points market share to Chrysler by 1996. The over 14,000 lb MHDGE market is dominated by Ford with about 60 percent market share, with GM being the only other competitor. Technology market shares were estimated using the above information, which was derived from AAMA (MVMA) sales data on trucks, and are shown in Table 4-2.

TABLE 4-2

ESTIMATED MARKET SHARES FOR EMISSION CONTROL TECHNOLOGIES FOR HDGEs

		1990	1996
HDGE < 14,000 lb			
Fuel Injection		100	100
Secondary Air (Pump)		50	55
Catalyst	OX CAT	100	73
	3 WAY	0	37
EGR		100	100
Closed Loop System		0	27
On-Board Diagnostics		0	27
HDGE > 14,000 lb			
Fuel Injection		30	100
Secondary Air (Pump)		100	100
Oxidation Catalyst		30	40
EGR		100	100
On Board Diagnostics		0	0

4.3 DIESEL ENGINES

Significant changes to diesel engines have occurred since 1990, when engines were certified to the 6.0 NO_x/0.6 particulate standards. Unlike gasoline engines, most of the HDDE emission reductions have resulted from evolutionary improvements to fuel injection and combustion chamber shape technology rather than as a result of addition of new components or exhaust aftertreatment devices. Only the light heavy-duty diesels have seen significant new technology add-ons as opposed to evolutionary improvements.

The diesel engines used in the light heavy class in 1990 were unique in that the GM and Navistar V-8 engines offered were of the pre-chamber type, and were naturally aspirated. The Cummins 5.9L litre engine entered the LHDE market in 1989 and was the first direct injection engine offered in a light-heavy truck, as well as the first turbocharged diesel. In 1992/3, the GM and Navistar V-8 were offered in turbocharged form and upsized, while the Navistar V-8 was converted to direct injection in 1994. The conversion to direct injection from pre-chamber type combustion systems actually increased NO_x, but significantly decreased particulate emissions.

In 1996, the Navistar 7.3L is a turbocharged direct-injection diesel, and it now utilizes an electronic fuel injection control system in conjunction with high pressure unit injectors. The light-heavy version of the engine uses an oxidation catalyst, while the version for vehicles over 14,000 GVW uses aftercooling with an air-to-air heat exchanger, but no oxidation catalyst. One particular technology of interest is EGR - the Cummins 5.9L utilizes EGR in versions for vehicles over 14,000 lb GVW. Electronic fuel injection control is not yet utilized in the Cummins 5.9L; however, it is expected to be utilized in 1998 model year. The Cummins DI diesel and GM IDI diesel for the LHDE market also utilize oxidation catalysts for most models.[1]

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[1] ABT rules allow some low sales volume models to be certified without a catalyst.

The larger medium and heavy-duty engine segments do not yet use any exhaust aftertreatment or EGR (Navistar offered some versions of the DT-466 with oxidation catalysts in model year 1994 but the catalyst was removed in 9 months from the start of the model year). However, all engines have since seen substantial improvements in technology as discussed below.

Air Intake - Most MHDDEs and all HHDDEs were turbocharged in 1990, and all naturally aspirated engines have been phased out by 1994. Improvements to turbocharging have included:

- Higher boost pressure
- Improved turbocharger response through the use of lighter rotating parts and smaller turbine casing
- Higher efficiency through better turbocharger-engine matching
- Wastegating, employed in some MHDDEs, and LHDDEs.

Intercooling - Most MHDDEs and all HHDDEs featured intercooling of the air exiting the turbocharger. While many intercoolers used water as the cooling medium in 1990, almost all intercoolers used now are of the air-to-air type. As a result, inlet air temperatures have come down from a typical 165^{o} to 175 ^{o}F for a jacket water cooled system to 115^{o} ~ 120^{o}F for an air-to-air system, with attendant decreases in NO_x emissions.

Fuel Injection System - In 1990, three major injection system types shared the market: the unit injector system used on DDC engines and the (then) newly introduced Caterpillar 3116/3176 engines, the Cummins "Pt" system used on Cummins HHDE engine and the "pump-and-line" system used on all other engines. (The Cummins system is a hybrid of the two concepts). By 1996, the unit injector system has largely replaced the "pump-and-line" systems, with Cummins still utilizing the Pt system. In addition, most engines, with the notable exception of DDC engines, utilized mechanical injection timing control in 1990, but by 1996 a majority of engines feature electronic timing control. Some of the LHDDEs such as the Cummins 5.9L still use the mechanical pump-and-line system, but these are expected to be phased out by 1998.

Injection pressures have continued to rise over time. In 1990, typical injection pressures for HHDDEs were in the 15 kpsi to 17 kpsi range. The advent of unit injectors has made higher pressure possible and a majority of HHDDE systems now operate 22~25 kpsi range. Injector spray tips have been optimized to produce finely atomized fuel sprays at these very high pressures.

Combustion Chamber - Changes to the combustion chamber shape and air motion in the chamber have occurred in most engines between 1990 and 1996. While each engine manufacturer has its proprietary designs, the general trend has been to reduce air swirl and squish, and to eliminate "dead" air volumes. The newer chamber designs are referred to as "quiescent" designs and require the high pressure finely atomized spray to deliver low NO_X and particulate emissions.

Oil Consumption - Considerable effort has gone into reducing oil consumption on engines as oil is a source of particulate emissions. These have included reductions in liner bore distortion, micro-finished liners, improved valve stem and turbocharger oil seals, and tapered oil rings to minimize oil films on the cylinder wall.

Other Technologies - Since emission standards are in g/bhp-hr, one way of reducing emissions in these units is by increasing the work output (or the bhp-hrs). Engine friction reduction has been widely exploited to increase work output. Special attention has been paid to engine driven accessories such as the oil pump, water pump and air compressor, and newer designs incorporate higher efficiency components to reduce parasitic losses. The overall effect of these technologies is small, in the range of 2 to 3 percent.

Diagnostics - electronic systems first introduced in the late 1980: have always incorporated some level of diagnostics, but this is for troubleshooting the injection system and is not specifically geared to emission related malperformances. With the expansion of electronic system usage, more engines offer diagnostics, which have also improved over time. However, its ability to recognize specific emission related malperformances needs further investigation.

Aftertreatment - Except for the LHDDE engines, aftertreatement is used exclusively on bus engines which are required to certify to the 0.05 g/bhp-hr particulate standard. As noted, some MHDDE engine were certified with oxidation catalysts in 1994, but non-catalyst versions have since superseded these versions. Particulate traps have not been used in any HDDEs to the best of EEAs knowledge.

A summary of the current and historical (to 1990) diesel engine technologies used is provided in Table 4-3. Unlike the tables provided for LDV/LDT, the information is more aggregated due to the lack of detailed engine family specific technology and sales data.

TABLE 4-3
SUMMARY OF TECHNOLOGY CHANGES
ON MEDIUM AND HEAVY-HEAVY DIESEL ENGINES

	1990 Models	1996 Models
Turbocharger	All HHDE and most MHDE turbocharged.	All turbocharged, with smaller turbine housing and higher boost pressure. Some turbos have wastegate.
Intercooling	All HHDE and most MHDE intercooled. Combination of Jacket water and air-to-air. Inlet temp about 165~175^{o}F.	All intercooled, most with air-to-air systems. Inlet temp. reduced to 115^{o}F ~ 120^{o}F
Fuel Control	Mostly mechanical systems (except DDC)	Most with electronic control (few mechanical systems remain)
Injection system	Pump and line, Cummins Pt system and unit injector	Mostly unit injector or Cummins Pt system
Injection pressure	16,000 to 17,000 psi	24,000 ~ 28,000 psi (HHDE) 16,000 ~ 18,000 psi (MHDE)
Combustion system	High swirl and squish	Low swirl, low squish or "Quiescent" shapes
Engine mechanical design	Base	- Top ring moved up - Oil ring taper changed - Reduced liner bore distortion - Improved valve stem oil and turbo seals
EGR	None	Offered on two MHDEs (with no cooling)
Aftertreatment	None	Oxidation catalyst on LHDEs and a few MHDEs, all bus engines
Diagnostics	On electronic systems, not specifically emission related	On almost all engines, but not specifically emission related
Other	Base	Reduced engine friction more efficient accessory drives

4.4. TECHNOLOGY DISTRIBUTION FORECAST

The technology forecast has been developed using the following assumptions about future standards over and above the 1998 NO_X standard of 4g/bhp-hr:

- between 2000 and 2004, a standard of 2.5 g/bhp-hr for $HC+NO_X$ will be promulgated
- in the 2010+ time frame, NO_X standards will change to 1.5 g/bhp-hr (Scenario A) or 1.0 g/bhp-hr (Scenario B) and HC standards will be about 0.5 g/bhp-hr
- PM standards will remain at 0.10 g/bhp-hr through 2005, and continue at that level beyond 2010 in Scenario A, or be reduced to 0.05 g/bhp-hr in scenario B.

4.4.1 Gasoline Engines

There are few surprises in the HDGE Control technology forecast. In the LHDGE segment, some increase in air pump usage is expected as a result of the 1988 standards, but significant changes are expected to occur by 2005. It is anticipated the LHDGEs will switch to closed-loop control and three way or three way (Pd) + oxidation catalysts, reflecting their transition from LDGTII technology used today. On-board diagnostics will become increasingly common as Ford, GM and Chrysler consolidate their ECU product line for commonality with LDTs.

In the 2010 + time frame under Scenario A, we anticipate that normal calibration development and catalyst improvements will allow a reduction of emissions from 2.5 to 2.0 g/bhp-hr HC + NO_X. Scenario B at a level of 1.0 g/bhp-hr NO_X could imply high efficiency closed coupled Pd single-bed catalysts, with restricted fuel enrichment at high loads, and increased cooling for the engine. Another possibility is that all MHDGEs would make a transition to CNG fuel; it should be noted that MHDGE sales by 2010 are expected to be very low, at 10 percent of the market or less. The forecasts are summarized in Table 4-4.

TABLE 4-4
FORECAST OF TECHNOLOGY DISTRIBUTION
FOR HDGE

	1996	2000	2005	2010 (a)	2010 (b)*
LHDGE					
MPFI/3CL+OXD/AIR/EGR	0	0	75	75	25
MPFI/OXD/AIR/EGR	28	35	0	0	0
MPFI/3CL/AIR	27	30	25	25	75
MPFI/OXD/EDGR	45	35	0	0	0
On-Board Diagnostics	27	65	100	100	100
MHDGE					
MPFI/AIR/EGR	50	20	0	0	0
MPFI/OXD/AIR/EGR	50	80	0	0	0
MPFI/3CL+OXD/AIR/EGR	0	0	100	100	100
On-Board Diagnostics	~0	40	100	100	100

* MHDGE may be CNG powered in this scenario

4.4.2 Diesel Engines

Heavy-duty diesel engines, while having many common technologies across subclasses, are also expected to differ in their control technology usage by subclass. Due to the ABT regulations, technology changes in response to new standards will be spread out over 3 to 4 years.

HHDDEs are not expected to change significantly by 2000 in response to 1998 standards, but market penetration of some technologies could increase due to fuel economy or driveability benefits. EEA anticipates that more sophisticated fuel injection technologies will enter the market in 1998, while phase-out of
HHDDEs are not expected to change significantly by 2000 in response to 1998 standards, but market penetration of some technologies could increase due to fuel economy or driveability benefits. EEA anticipates that more sophisticated fuel injection technologies will enter the market in 1998, while phase-out of

older models will lead to average fuel injection pressures increasing closer to today's high end of 28 to 30 kpsi. However, with the advent of the 2.5 g/bhp-hr HC + NO_X standard, all engines are expected to use cooled EGR, and a very large percentage of engines are likely to use more advanced forms of turbocharging. If a standard of 1.5 g/bhp-hr NO_X is imposed in the 2010+ time frame, it is expected that lean NO_X catalysts will be used across the board. Standards of 1.0 g/bhp-hr NO_X or lower will require the use of urea/ammonia reactors, assuming that current problems with this technology can be solved over the next decade.

MHDDEs feature emission control technology quite similar to HHDDEs with the following exceptions:

- Injection pressures are likely to be significantly lower than for HHDDEs.
- EGR cooling may not be used in a significant fraction of engines with lower than average specific power output.
- Oxidation catalysts are likely an over a third of all MHDDEs (also those with lower than average specific output) by 2005.

We have estimated MHDDE technology to be very similar to HHDDE technology for the 2010 + (A) and (B) scenarios, but the manufacturers were more uncertain of the ability of smaller engines to meet both the 1.5 or 1.0 g/bhp-hr NO_X standard and 0.10 or 0.05 PM standard simultaneously.

LHDDE technology to 2005 follows similar trends, although it is unlikely that EGR intercooling will be utilized, while the oxidation catalyst is expected on most engines in this category. At the 2.5 g/bhp-hr HC + NO_X standard it is possible that pre-chamber diesels with EGR could be significantly cheaper than high pressure injection DI diesel. Manufacturers were hesitant to speculate on LHDDE technology for 2010+ Scenario A and B, although they indicate that the lean NO_X catalyst and urea/ammonia injection are likely choices in this class as well subject to adequate resolution of current problems with these technologies. Navistar in particular, believed that cerium based additives to diesel fuel would be needed to meet 0.10/0.05 g/bhp-hr particulate standards at very low NO_X levels. We also expect the GM IDI diesel to convert to DI by 2005, if fuel additive based technology for particulate control is successful.

These forecasts are summarized in Table 4-5.

TABLE 4-5
FORECAST OF TECHNOLOGY DISTRIBUTION
FOR HDDE

	1996	2000	2005	2010 (a)	2010 (b)*
HHDDE					
Variable Geometry Turbo	0	0	25	15	25
Electric Turbo	0	0	0	15	30
Twin Plenum Turbo	0	20	50	60	45
FI (Pr > 35 kpsi)	0	0	65	90	90
(Pr > 25 kpsi)	30	65	35	10	10
EGR	0	0	100	100	100
EGR Intercooler	0	0	90	100	100
Lean NO_x Catalyst*	0	0	0	100	20
Urea/Ammonia Reactor	0	0	0	0	80
MHDDE					
Variable Geometry Turbo	0	0	10	10	20
Electronic Turbo	0	0	0	10	20
Twin Plenum Turbo	0	10	30	50	60
FI (Pr > 25 kpsi)	0	0	30	70	100
(Pr > 20 kpsi)	0	35	70	30	0
EGR	1	20	100	100	100
EGR Intercooler	0	5	70	90	100
Lean NO_x Catalyst	0	0	0	100	0
Oxidation Catalyst	10	20	35	0	0
Urea/Ammonia Reactor	0	0	0	0	100

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* Implies availability of low sulfur diesel fuels

TABLE 4-5
FORECAST OF TECHNOLOGY DISTRIBUTION
FOR HDDE

(Continued)

	1996	2000	2005	2010 (a)	2010 (b)*
LHDDE					
Variable Geometry Turbo	0	0	0	0	0
Electric Turbo	0	0	0	0	50
Twin Plenum Turbo	0	0	30	50	50
Intercooler	70	100	100	100	100
FI (Pr > 25 kpsi)	0	0	0	0	0
(Pr > 18 kpsi)	0	70	100	100	100
EGR	0	0	100	100	100
EGR Intercooler	0	0	20	100	100
Oxidation Catalyst	65	70	100	0	0
Lean NO_X Catalyst*	0	0	0	100	0
Electrical FI	20	70	100	100	100
IDI	30	30	0	0	0
Urea/Ammonia Reactor	0	0	0	0	100

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* Implies availability of low sulfur diesel fuels

APPENDIX A

DETAILS ON EMISSION CONTROL TECHNOLOGY FOR SELECT 1990 AND 1995/96 MODEL YEAR VEHICLES

(Available in "Hard Copy" Only)

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ABSTRACT:

The EPA mobile source inventory model MOBILE5, estimates emissions by emissions control technology type and vehicle type. The technology groupings and their market penetration are periodically reviewed and updated to reflect new regulatory initiatives and new technological development. This work assignment requires a review and forecast of appropriate technology groupings for light duty vehicles, light duty trucks and heavy-duty trucks to 2020. This report provides a review of historical and future technologies and suggests appropriate groupings for emission factor analysis. Based on these groupings historical distributions of market share were derived from CAFE and certification data, while forecasts of future distributions were derived from the expert opinion of manufacturers.

KEY WORDS/DESCRIPTORS: Mobile source, automotive technology, emission modeling.