FORECAST OF EMISSION CONTROL TECHNOLOGY AND STRATEGY FOR LIGHT-DUTY VEHICLES

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1. INTRODUCTION

Future estimates of the contribution of mobile source emissions to air quality are dependent on emissions factors estimates for the future fleet. The Air Resources Board (ARB) has recognized that these emission factors are sensitive to the technology employed in automobiles for emission control. At any particular level of stringency of the emission standard, compliance is possible by a number of alternative technological approaches, and this is evident from the differences in each manufacturer's approach to emission control. Even under unchanging standards, there is continuing evolution of emission control technology. While some of this evolution is initiated by the increasing stringency of other requirements (such as new high altitude standard or new emission warranty regulations), it also reflects manufacturers increased knowledge about the cost, durability, and performance tradeoffs between different emission control systems. Forecasts of the evolution of emission control technology are, therefore, required in order to accurately estimate future emissions factors.

Different emission control technologies behave differently under in-use conditions, especially if there are malperformances present in the vehicle. The emission factor programs have clearly shown that malperformances in the fleet of cars are <u>the</u> cause of "excess" emissions. An understanding of the current and future trends in emission control technology and their potential malperformances is, therefore, also required before emission factors can be forecast with accuracy. Although the role of the emission control hardware has been emphasized, an equally important role is played by the strategy used by the emission control system when one or several of its components malperform. The current generation of "closed-loop" emission control systems have many of their components working in synergy, so that the failure of any one component can cause what is termed as "a system failure." In some systems, such failure can cause a hundredfold rise in emissions.

In this report, EEA has provided detailed forecasts of the emission control technology used in the 1982-1990 time frame as well as discussion of the "malperformances strategies" peculiar to each system and manufacturer. These forecasts are for gasoline-fueled light duty vehicles only, as diesel technology does not vary by manufacturer and there are no major considerations of strategy required. Although some of the basic differences in gasoline emission control technology, -- e.g., oxidation catalyst, three way catalyst -- have been previously identified and documented, this report provides a considerably more detailed analysis, so that complex issues related to topics such as I/M effectiveness or the impact of emission warranty requirements can also be analyzed in the future by the ARB.

This report is an interim report under Task 2 of the work effort being conducted by EEA for the ARB. Recommendations provided in this report will be used in upcoming subtasks in this work effort and the final product under Task 2 will be a forecast of emission factors for light-duty vehicles. The Environmental Protection Agency has also contracted EEA to perform a similar study on Federal (49-state) cars, and the combined resources have allowed a much more detailed analysis than would have been possible if the work effort were not jointly funded.

Accordingly, Section 2 details the hardware that is or will be utilized by manufacturers for emission control in California during the 1982-1990 time frame. These forecasts were based upon information provided by the manufacturers in support of this project, as well as EEA's independent determination of trends in emission control technology usage by manufacturer. This determination is based upon the actual data for 1982 and 1983, as well as published reports in the popular and trade press on future emission control systems. A detailed breakdown of every major manufacturer's (four domestic manufacturers' and four major importers') emission control technology mix is provided in this section as well as a detailed forecast for the new car fleet that was derived by a sales weighted aggregate of the individual manufacturer specific forecasts. Every combination of fuel system type/catalyst type/secondary air system is listed separately; data for 1982 and 1983 is based on actual sales by engine family.

Section 3 discusses the strategy employed by each manufacturer under malperformance conditions. EEA has found that even for manufacturers using the same emission control hardware, the malperformance strategies diverge considerably. Our documentation of malperformance strategies is based on limited data supplied by the manufacturers, as well as from emissions data derived from intentional disablement testing programs conducted by the EPA and CARB. The combination of these data, as well as an understanding of technology performance, provides a guide to systems strategy likely to be used in the future. Since strategy changes can be implemented more simply than hardware changes, it must be recognized that the forecasts are subject to more uncertainty than the forecasts of technology provided in Section 2. The section concludes with a series of recommendations for the emissions factor analysis that will be performed in the next few months.

Appendix A provides a glossary of common abbreviations for emission control systems that are widely used in this report.

2. EMISSION CONTROL TECHNOLOGY FORECAST

2.1 OVERVIEW

Detailed examination of the 1984 Light Duty Vehicle Certification Lists shows that emission control hardware differences between Federal (49-state) and California vehicles have all but disappeared. Although the hardware is the same, calibration differences do exist; since California currently has a more stringent NO_x standard but a less stringent CO standard then the Federal standards, the same emission control hardware permits certification of vehicles if California vehicles are calibrated to a slightly richer air-fuel ratio than Federal vehicles. For a small handful of models, the less stringent CO standard in California has allowed their certification with only a single-bed three-way catalyst rather than dual-bed system used in Federal vehicles. Inspite of the fact that the individual car models utilize nearly identical emission control systems for Federal and California vehicles, the fleet mix of emission control technologies is very dissimilar since the market shares of the different models are very different in California in comparison to the other 49-states. For example, the market share of imports in California is nearly double that of the other 49-states.

In this section, EEA's forecasts of the fleet mix of emission control technology in California to 1990 is detailed. The fleet mix was derived from the forecasts of technology mix by manufacturer using a sales weighted aggregation. The technology mix by manufacturer was, in turn, derived from information obtained from publicly available literature and at meetings that EEA held with most major domestic and import manufacturers. This project was pursued in conjunction with a similar project for the EPA; while the manufacturer's discussed their plans primarily for Federal vehicles they also confirmed that the emission technologies used in their

California vehicles would be essentially similar to that used in their Federal vehicles under current standards. California may impose the 0.4 g/mi NO_x standard in the post-1987 time frame in which case the similarity between Federal and California emission control systems will end. Accordingly, EEA has separately derived a forecast for 1990 under a 0.4 g/mi NO_x standard at the fleet level based on information presented under an earlier task under this contract effort. All projections shown in this section are for gasoline powered light duty vehicles only; diesel penetration was set at actual values for 1982 and 1983 (6.4 and 3.3 percent), and assumed to be 4 percent for 1984 and 5 percent for the entire 1985-1990 time period. Current uncertainty about future diesel penetration led us to exclude its projection in this report, so that the results presented in this report are essentially insensitive to actual diesel penetration in future years.

Most manufacturers, other than Ford Motor Company, provided a discussion only of the general trends that they foresee in emission control technologies. Information provided by the manufacturers ranged from identification of specific emission control systems for some model lines to a discussion of generic groupings (e.g., carburetor, fuel injection) of different emission control technologies. Ford provided specific confidential information on their emission control technology mix, which, as a result, could not be revealed in this report. However, Ford's projections are utilized to estimate fleetwide emission control system penetration, which are also presented in this section.

Emission control system utilization by manufacturer, for all manufacturers other than Ford, were derived by starting with available data on historical model years 1982 and 1983, as well as data on the 1984 vehicles. Potential changes to emission control systems were estimated on an engine line specific basis, utilizing data obtained from the manufacturers as with published reports in the trade press and "sneak previews" provided to the enthusiast magazines such as "Car and

Driver" and "Road and Track." Since the tooling plans for the individual car lines are very nearly complete three years in advance of production, EEA believes that projection up to 1987 involve little uncertainty except in the forecast of sales mix of the different engine lines. EEA has derived sales mix forecasts based on previous work performed for the Department of Energy, and those forecasts are used in this analysis.

In this section of the report, information used to derive the manufacturer specific forecasts is detailed, and both the historical data (1982-1984) as well as projections through 1990 are shown. The analysis in this section breaks out emission controls by the combinations of:

- The fuel system
- The secondary air system
- The catalyst system

EGR systems are also documented, but not shown in combination with these systems since it has relatively little interaction with the failure modes that cause gross HC and CO emissions. EGR is used in all vehicles except in a fraction of vehicles with multi-point fuel-injection. The majority of these vehicles are currently of European origin, although some high performance (or turbocharged) domestic and Japanese vehicles may delete the use of EGR in the future.

The following subsections detail EEA's forecasts for the four major domestic manufacturers and the three major Japanese manufacturers. All European manufacturers currently utilize the same emission control system -- multipoint fuel injection and three-way catalyst with no secondary air (MPFI/3CL) -- with the exception of a very small number of luxury vehicles which utilize an air pump. Other than changing from mechanical fuel injection to electronic fuel injection, no changes in emission control technology are forecast for this group of cars through 1990. Forecasts for the domestic and major Japanese importers are detailed individually.

2.2 GENERAL MOTORS

General Motors certifies 14 gasoline engine lines and several of these feature different emission control technology depending on the car model they are used in. In order to provide the forecasts of the mix of emission control system, EEA has performed detailed predictions for each engine line, starting with historical data from 1982 and 1983. Using this data and the data provided by GM to EEA, we have arrived at long term forecasts of emission control technology. Conversion of these forecasts to fleet mix required the projection of sales by engine line through 1990. As a result of work being performed for the Department of Energy, EEA has developed a detailed forecast for new car product plans by GM and the knowledge of engine line/vehicle body conditions have allowed us to make a forecast of the mix of emission control technologies for GM.

In the meeting with GM staff, EEA learned the following:

- There are no new development programs underway for carburetted vehicles. This indicates that, other then the GM-Toyota program, new engines and new vehicle applications for old engines are likely to be fuel injected.
- The use of multi-point fuel injection for V-6 engines was found to be more effective than throttle-body fuel injection. Apparently the compact dimensions of the V-6 makes it easy to design a short fuel rail for the injectors and multi-point fuel injection allows the use of "ram-tuned" intake manifold that improves performance significantly.
- Although one would logically expect multi-point fuel injection in the most expensive cars first, it was indicated that this would not be the case. Multi-point fuel injection would be used to enhance the "high tech" image of Buick and of specific models such as the Camaro and Corvette.
- Because of recent recall actions, there is dissatisfaction with the current back-pressure EGR system. A large number of engine lines have begun to use electronic EGR in 1984 an most lines are expected to convert to this system by the late 1980s. The electronic EGR control fits well into the overall system strategy of the computer command control (C-3) system.

- Secondary air was not considered crucial to meeting the 7.0 g/mi CO standards in most engine lines. GM has been satisfied by the performance of its current throttle body injection systems with no secondary air, and has not been experiencing any higher than average failure rates in emission surveillance programs for these engine lines.

Because of the diversity of engine lines and the powertrain options for the different models, a discussion by engine line is first provided, followed by a discussion of new models offered and their powertrain options.

In four-cylinder engines, all lines except the 98 CID engine used in the T-body Chevette/T1000) utilize throttle body fuel injection. The T-body and the 98 CID engine is likely to be dropped and replaced by the GM-Toyota car, utilizing a Toyota engine now used in the Corolla. The Toyota engine is expected to utilize the emission control system currently used by the Corolla, i.e., the CARB/3CL/OXD/PLS system. In 1988, EEA expects GM to introduce the recently announced "GM-Saturn" car, which is known to have a throttle- body fuel injected engine. EEA anticipates that a small percentage of 4-cylinder engines, with and without turbocharging will make use of multi-point fuel injection for performance reasons.

All six-cylinder engines currently offered by GM utilize the CARB/3CL/OXD/PMP system, but a multi-point fuel injected version of the 231 V-6 (in turbo- charged and non-turbocharged form) is offered in limited quantity in 1984. The use of the fuel injected version will expand with the introduction of the front-wheel drive C-body in April 1984. GM has also unveiled the 1985 version of their 173 V-6 with multi-point fuel injection, and press reports state that the Pontiac Fiero and the GM A-body will utilize this version, while the X-body will continue to use the carburetted version. Based on GM's comments, it appears that the 181 V-6 and the 252 V-6 will also be converted to multi-point fuel injection in the 1986-1988 time frame. (The 181 V-6 will be fuel-injected for use in the new C-body for 1985).

Eight-cylinder engines, whose use is expected to decline in the late eighties as the different models are converted to front-wheel drive, are likely to be converted to multi-point fuel injection in high-performance models and as the Camaro, Firebird and Corvette. The enthusiast magazines report that a high performance multi-point fuel injection version of the 305 V-8 will replace the current throttle-body fuel injection version in 1985. It is likely that the more "standard" version will retain the carburetor through 1990, although its influence will decline. The Cadillac 249 V-8 may be converted to multi-point fuel injection in 1988-1989.

Plans for each individual engine-line and new engines are summarized in Table 2-1.

In the 1985-1990 time frame a number of new models will be introduced to alter the mix of engines. They are:

- The new front-wheel drive C-body that will utilize the 181 and 231 V-6 engines in the Buick and Oldsmobile versions, and the 249 V-8 in the Cadillac version.
- The N-body to be introduced in 1985 as a coupe and in 1986 as Sedan replacing the X-car. It will utilize the 151 4-cylinder and 173/181 V-6 engines.
- The B-body which will convert to front-wheel drive in 1986 for Buick and Oldsmobile and possibly 1988 for Chevy and Pontiac.
- The phase-out of the G-body and replacement with a new car -- the GM-10 -- in 1987 and 1988.

By 1988, EEA expects that all GM models except the Camaro/Firebird and the Corvette will be front-wheel drive (Chevrolet may retain the rear-wheel drive Caprice). Based on the above product actions, EEA has derived a composite forecast of the mix of emission control technologies as shown in Table 2-2, that will be used by GM. The very large change in emission control technology mix between 1984 and 1985 is attributable to the introduction of multi-point fuel injection in the popular V-6 lines (the 173 and 231 V-6) as well as conversion of the throttle-body fuel injected 305 V-8 to multi-point fuel injection. By 1990, EEA expects that GM sales mix will be:

TABLE 2-1

GM ENGINE LINES

Displacement	1982 System	Changes Through 1990
98*	(M) CARB/3CL/OXD/PMP (A) CARB/3CL/PLS	3CL/PLS system phased-out in 1983. Engine phase-out in 1987.
110	TBI/3CL	Turbo version uses MPFI/3CL in 1984.
112/121	CARB/3CL/OXD/PMP	Partially converted to TBI/3CL/PLS in 1983, fully converted in 1984.
151	TBI/3CL	No changes forecast.
173 V-6	CARB/3CL/OXD/PMP	Converted to MPFI/3CL in 1985 except in X-car.
229 V-6	CARB/3CL/OXD/PMP	Phased-out in 1985/86?
231 V-6	CARB/3CL/PMP	Converted to CARB/3CL/OXD/PMP in 1983, partially to MPFI/3CL in 1984.
252 V-6	CARB/3CL/OXD/PMP	Potential conversion to TBI/3CL/OXD/PMP in 1985 or in 1986.
305 V-8	CARB/3CL/OXD/PMP	No changes likely as volume declines.
305 V-8**	TBI/3CL/OXD/PMP	Dropped for 1984. Converted to MPFI/3CL in 1985.
249 V-8	TBI/3CL/OXD/PMP	Likely to convert to MPFI/3CL in 1987+.
350 V-8 (Corvette)	TBI/3CL/OXD/PMP	To be phased out in 1985 (replaced by 305 V-8).
		NEW ENGINES
98 I-4 (GM-Toyota)	CARB/3CL/OXD/PLS	To be introduced in 1985/86.
181 V-6	CARB/3CL/OXD/PMP	Likely to be converted to MPFI/3CL by 1988.
61 I-4 (GM-Suzuki)	CARB/3CL/PLS	To be introduced in 1985/86.
231 V-6 Turbo	CARB/3CD/OXD/PMP	Converted to MPFI/3CL in 1984.
90 I-4 (GM-Saturn)	TBI/3CL	Introduction in 1988.
195 V-6	MPFI/3CL	Chevy introduction in 1986/87.

*M - Manual Transmission; A - Automatic Transmission.

**Used in Camara/Firebird only.

TABLE 2-2

FORECAST OF MIX OF EMISSION CONTROL SYSTEMS - GM

	1982	1983	1984	1985	1987	1990
CARB/3CL/PMP	23.3	25.6	-	-	-	-
CARB/3CL/PLS	-	-	-	-	4	5
CARB/3CL/OXD/PMP	52.3	39.5	50.8	30.0	12.5	6
TBI/3CL*	15.2	19.7	33.1	34.4	35.0	35
TBI/3CL/OXD/PMP	9.1	15.2	11.0	9.4	8.5	-
MPFI/3CL	-	-	5.1	20.2	44.0	54

*About 1/3 equipped with PLS after 1982.

- 40 percent 4-cylinder engines, of which 30 percent will be TBI, 6 percent will be carburetted and 4 percent will utilize MPFI
- 45 percent 6-cylinder engines, all of which will feature multi-point fuel injection
- 15 percent 8-cylinder engines, about half of which will be carburetted and the other half fuel injected.

2.3 FORD

The number of engine lines sold by Ford is relatively small. Currently, Ford markets only five different engines, three of which are offered in two versions with different emission controls. Press reports indicate that a new V-6 of 3 liters displacement will be launched in 1986. The use of only a limited number of engine lines makes it relatively easy to project emission control technology.

Although Ford provided confidential data on the mix of emission control technology that they will utilize in the 1985-1990 time frame, engine specific information was not provided. Ford representatives have, however, publicly remarked that most of its engines would be fuel injected by the late 1980's*, and engine specific information on several lines have been made public. Based on these remarks, our forecasts use the assumption that throttle body fuel injection will more likely be utilized in the lower priced vehicles with four cylinder engines, and multi-point fuel injection in the higher price and higher performance (turbocharged) vehicles. This strategy is already evident in 1984 models, with all turbocharged engines using multi-point fuel injection and the V-6 and (most) V-8s using throttle body fuel injection.

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*e.g., J.J. Rivard, speech at Convergence '82, as reported in Ward's Engine Update, 10/15/82.

Table 2-3 summarizes EEA forecasts of product actions by Ford. Press reports* indicate that the current 1.6 liter engine used in the Escort/Lynx will be upsized to 1.9 liters in 1986, and potentially converted to throttle body fuel injection. Similarly, the 2.3 HSC engine used in the Tempo/Topaz will be upsized to 2.5 liters and converted to TBI in 1985/86. The popular press reports that a high performance multi-point fuel injection version of the 302 V-8 is being readied for 1985 and the new 181 V-6 will utilize multi-point fuel injection. EEA anticipates that most V-8 and V-6 engines will be converted to multi-point fuel injection in order to compete effectively with GM.

Unlike GM, Ford did not show a radical change between 1982 and 1984 in the engine mix towards V-8s; rather, the V-6 engines gained market share at the expense of the 4-cylinder engines. By 1990, EEA expects only small changes in the engine mix, primarily because Ford's product plans do not emphasize front-wheel drive (fwd) vehicles. The only rear-wheel drive vehicle stated for conversion to fwd is the LTD/Marquis. Since the V-8 is currently not available in this model, no major changes in engine mix (by number or cylinders) will occur even after conversion to front-wheel drive. However, the increased use of turbocharging, as well as CAFE standards will result in some decline in the use of V-8, with accompanying increases in the use of V-6s and four cylinder engines.

More recently, Ford has announced that it will source both the Mustang replacement and a small sporty car from Toyo Kogyo starting in MY 1988. Then vehicles will be assembled in the U.S. and Mexico, and it appears likely that the small car will utilize the CARB/3CL/PLS system found on current Toyo Kogyo vehicles. Based on announced production volumes**,

*Ward's Engine Update, 1/15/84.

**Ward's Automotive Reports, 1/23/84.

TABLE 2-3

FORD ENGINE LINES

Displacement (CID)	1982 System	Changes Through 1990
98	CARB/3WY/OXD/PMP	May be converted to TBI/3CL/OXD/PLS by 1986/87.
140	CARB/3WY/OXD/PMP	3WY version dropped in 1984.
	CARB/3CL/OXD/PMP	Turbo version to MPFI/3CL converted to TBI/3CL/OXD/PLS in 1985/1986.
200	CARB/3WY/OXD/PMP	Dropped in 1984.
231	CARB/3WY/OXD/PMP	Converted to TBI/3CL/OXD/PMP in 1985.
302	TBI/3CL/OXD/PMP	May lose sales share to 302HO in late 1980s.
302 HO	CARB/3WY/OXD/PMP	To be converted to MPFI/3CL/OXD/PMP in 1985.
	NEW ENGINES	
181 V-6	MPFI/3CL	To be introduced in 1986.
140 HSC	CARB/3CL/OXD/PMP	Introduced in 1984; may be increased to 151 CID and converted to TBI/3CL/OXD/PLS in 1985/86.
98	MPFI/3CL/OXD/PLS	Introduced in 1983; low volume option likely to be dropped.

we estimate that by 1990 this vehicle will account for 8-10 percent of Ford sales in North America. Since these recent announcements were not included in Ford's forecasts provided to EEA, we have independently derived estimates of emission control technology mix for Ford in 1990. For 1990, EEA projects the engine mix to be: 4-cylinder - 40 percent; 6-cylinder - 35 percent, 8-cylinder - 20 percent, and turbocharged 4-cylinder - 5 percent.

Since Ford provided confidential data, we are unable to show the emission control technology usage in model year 1985 and 1987. The mix of emission controls used in 1982, 1983 and 1984 as well as our independent estimate for 1990 are shown in Table 2-4.

2.4 CHRYSLER

Chrysler certifies only five different engines, of which one has been dropped (the 225 CID six cylinder) in 1984, while a second (the 156 CID four cylinder) is imported from Mitsubishi. Accordingly, it is relatively easy to project the mix of emission control technologies sold.

In 1982, only the imported 156 four cylinder used oxidation catalysts. All other engine lines employed the CARB/3CL/OXD/PMP system. Chrysler has, however, publicly stated that all front-wheel drive vehicles will be fuel injected by 1987. Product plans reveal that all four-cylinder engines sold in the post-1985 will be derivatives of the current 2.2 liter engine -- the new 1.8 liter as well as the 2.5 liter engine to replace the imported 2.6 liter. Since Chrysler has introduced a throttle body fuel injection system (TBI/3CL/OCD/PLS) in the 2.2 liter in 1984, EEA anticipates that all of the new engine derivatives will utilize essentially the same system when they are introduced.

Although the 225 CID 6-cylinder was discontinued in 1984, and Chrysler had planned to phase out all rear-wheel drive cars in 1986, the resurgence of the large car market has changed product plans. Ward's

TABLE 2-4

FORECAST OF EMISSION CONTROL TECHNOLOGY - FORD

	1982	1983	1984	1985/87	1990
CARB/3WY/OXD/PMP	67.2	67.5	30.3	C O	-
CARB/3WY/PMP	-	4.6	-	N F	-
CARB/3CL/PLS	-	-	-	I D	10
CARB/3CL/OXD/PMP	29.7	4.5	32.4	E N	-
TBI/3CL/OXD/PMP PLS	3.1	26.0	32.8	T I	30
MPFI/3CL/OXD/PMP PLS	-	1.0	2.5	A L	30
MPFI/3CL	-	2.7	2.0		30

Automotive Reports indicated that Chrysler is now planning to "reskin" the rear-wheel drive M-body, and a new V-6 derived from the 318 V-8 is being readied for production. Although the new V-6 may use the CARB/3CL/OXD/PMP version initially, conversations with Chrysler personnel revealed that conversion of all engines to TBI/3CL/OXD/(PMP or PLS) is only a matter of time.

Turbocharged 2.2 liter engines use the MPFI/3CL system. EEA anticipates that this will continue to 1990, and the MPFI/3CL system may be used for high performance/luxury vehicles with the 2.5 liter non-turbocharged engines as well. Our forecasts by engine line are summarized in Table 2-5.

Recent changes in Chrysler's sales mix from 1982 to 1984 were not large, and EEA expects that the rear-wheel drive cars using the new V-6 and the 318 V-8 will have a 20 percent market share in 1987, half of them with throttle-body fuel injection. In addition, EEA expects that in mid-1987, the Chrysler/Mitsubishi vehicle will be introduced as a replacement for the Omni/Horizon. Based on Mitsubishi's use of emission controls, we anticipate that the vehicle will be equipped with a CARB/3CL/PLS system. EEA forecasts for Chrysler's mix of emission control technology are shown in Table 2-6. In order to protect Ford's confidental data, we have not shown Chrysler's mix of dual-bed and single-bed catalyst systems in the fuel injection category, as only Ford and Chrysler are expected to utilize the dual-bed fuel injected system.

2.5 TOYOTA, NISSAN AND HONDA

Unlike the domestic cars, most imports do not offer engine options. Hence, knowledge of vehicle sales by model is usually adequate to estimate the mix of emission control technology for these manufacturers.

Toyota offered fuel injection in only the Celica Supra line in 1982. Most vehicles, with the exception of the Starlet line offered a unique emission control system -- CARB/3CL/PMP -- where the "closed loop" was

TABLE 2-5

CHRYSLER ENGINE LINES

Displacement (CID)	1982 System	Changes Through 1990
105	CARB/3CL/OXD/PMP	Dropped in 1986/1987.
135	CARB/3CL/OXD/PMP	Converted to TBI/3CL/OXD/PLS in 1984-1985.
156	CARB/OXD/PLS	Converted to CARB/3CL/PLS in 1984, dropped in 1986.
225	CARB/OXD/PMP	Dropped in 1984.
318	CARB/3CL/OXD/PMP	Converted to TBI/3CL/OXD/PMP in 1987-1988, MPFI version may follow.
	NEW ENGINES	
135 Turbo	MPFI/3CL	Introduced in 1984.
151	TBI/3CL/OXD/PLS	To be introduced in 1986 MPFI/3CL version may follow.
244	CARB/3CL/OXD/PMP	Introduced in1986; may be converted to TBI/3CL/OXD/PMP in 1988, MPFI version may follow.
98	CARB/3CL/PLS	Mitsubishi-Chrysler replacement for Omni/Horizon in 1986.

TABLE 2-6

FORECAST OF EMISSION CONTROL TECHNOLOGY - CHRYSLER

	1982	1983	1984	1985	1987	1990
CARB/OXD/PLS/PMP	31.2	31.4	-	-	-	-
CARB/3CL/OXD/PMP	68.4	68.3	55.4	26	15	-
CARB/3CL/PLS	-	-	15.6	16	5	10
TBI/3CL/OXD/PLS/PMP	0.4	0.3	19.0	38	65	70
MPFI/3CL	-	-	C	C	C	C
MPFI/3CL/OXD/PLS	-	-	C	C	C	C

accomplished by modeling the air pump's output. In 1983, however, Toyota dropped this system in favor of the more conventional closed-loop carburetor. Toyota also converted all of their higher priced models -- Celica, Supra, Cressida, Camry and Starlet -- to fuel injection, leaving only the Corolla/Tercel models with a carburetor.

Nissan has featured fuel injection in the popular 280 Z-X prior to 1982, but a majority of their popular low priced models (particularly the 210/Sentra and the Stanza) featured oxidation catalysts. In 1984, the Sentra/Pulsar lineup was converted to CARB/3CL/PLS while all other models are now equipped with multi-point fuel injection.

In meetings with their staff, both Toyota and Nissan confirmed that closed-loop carburetors would be utilized for at least the next few years (in 1987) in their low priced cars. They have also decided to retain backpressure EGR on their lower priced vehicles while converting to electronically controlled EGR on their fuel injected models. (Only the top-of-the-line vehicles currently feature electronic EGR control). In the 1987+ time frame, both Nissan and Toyota may utilize throttle-body fuel injection (TBI/3CL/PLS) and they have stated that such systems are being investigated by their research division. EEA's forecasts for Toyota and Nissan are shown in Table 2-7. We show a slight decline in the multipoint fuel injection system penetration to compensate for the expected introduction of low priced cars following the end of import restrictions.

Honda offers only low- and mid-priced models currently in the U.S. Until 1984, Honda used oxidation catalyst systems on all of their vehicles; starting in 1984, Honda converted to the CARB/3CL/PLS system for all engines except the smallest 1300 cc engine which utilizes the CARB/3WY system. In the future, Honda has announced potential introduction of an upmarket model built in England in 1987/88 and the automotive press reports that a sporty fuel injected model is likely to be introduced in

TABLE 2-7

FORECASTS OF EMISSION CONTROL TECHNOLOGY - TOYOTA/NISSAN/HONDA

	1982	1983	1984	1985	1987	1990
Toyota						
CARB/OXD/PLS	4.1	-	-	-	-	-
CARB/3CL/PMP	80.3	-	-	-	-	-
CARB/3CL/PLS	-	51.7	46	45	45	30
TBI/3CL/OXD/PLS	-	-	-	-	-	20
MPFI/3CL	15.6	48.3	54	55	55	50
Nissan						
CARB/OXD/PLS	54.6	11.6	-	-	-	-
CARB/3CL	-	54.6	56.3	55	50	30
TBI/3CL/PLS	-	-	-	-	-	20
MPFI/3CL	45.4	34.2	43.7	45	50	50
Honda						
CARB/OXD/PLS	100	100	-	-	-	-
CARB/3WY	-	-	7.6	10	15	15
CARB/3CL/PLS	-	-	92.4	90	75	55
MPFI/3CL	-	-	-	-	10	30

1986. EEA anticipates that the current CARB/3CL/PLS system is likely to continue in the Accord and Civic model lines through 1990. Forecasts of technology for Honda are also shown in Table 2-7.

2.6 OTHER MANUFACTURERS

American Motors (AMC) has dropped all of its older passenger car lines, and, starting in 1984, offers only the Renault Alliance/Encore. This model is equipped with a MPFI/3CL system although a throttle body fuel injection system is offered as an option in California. AMC plans to offer a larger engine (1700 cc) in 1985 equipped with the same emission control system as the current 1400 cc engine. In 1986, AMC/Renault is expected to introduce a midsize car that will also probably offer a multi-point fuel injection system. EEA believes that the multi-point system may be used in turbocharged versions of the AMC/Renault vehicles as well, and MPFI/3CL system will account for about 70 percent of production, while the TBI system will account for the rest.

Other Japanese manufactures include Isuzu, Mazda, Mitsubishi (including sales by Chrysler) and Subaru. Mitsubishi offered oxidation catalyst systems across all their model lines until 1983, and switched to the CARB/3CL/PLS system in 1984. Mitsubishi offers a MPFI/3CL system in the Starion, a new (for 1984) sports car. Isuzu has used the CARB/3CL/PMP system in their I-Mark since 1982, and has recently (1984) introduced the Impulse with a MPFI/3CL system. Mazda was the only foreign manufacturer to utilize the open-loop three-way catalyst system (CARB/3WY/OXD/PMP) on all of their models through 1982, but converted all except the GLC Wagon to CARB/3CL/PLS system in 1983/84. On the other hand, Subaru used the CARB/3CL/PLS system till 1983, and have added an oxidation catalyst to their system in 1984.

In future, we anticipate that most Japanese manufacturers will utilize the CARB/3CL/PLS or CARB/3CL/OXD/PLS system in their lower priced vehicles and the MPFI/3CL system in their higher priced vehicles. Minicars not yet available in this country are likely to use the CARB/3WY system as evidenced by the Honda CRX. All of the Japanese manufacturers are moving in the direction of higher priced vehicles; for example, Subaru has recently introduced a turbocharged version of its popular 4WD vehicle and Mazda is contemplating an "upmarket" sports sedan. Accordingly, our forecasts have been adjusted to account for an increasing penetration of MPFI/3CL systems in the "other Japanese" manufacturer category. Forecasts for AMC and "other Japanese" manufacturers are shown in Table 2-8.

2.7 FLEETWIDE EMISSION CONTROL TECHNOLOGY FORECASTS

The individual manufacturer specific forecasts were aggregated up to the fleetwide level by sales weighting the mix of emission control technologies listed for each manufacturer. Note that, as in the manufacturer specific forecasts, diesel engines are not included in these projections. For 1982 and 1983, actual sales share by manufacturers were used. For 1984 and later years, we have used a sales share forecast that envisages some loss of market share by GM in this future as well as modest gains in market share for Japanese manufacturers in the post-1985 (after import quotas expire) time frame. However, in order to protect confidentiality of the Ford emission control technology mix, we have not shown the manufacturer market shares. Table 2-9 details the total fleet mix of emission control technology. It is obvious that fuel injection essentially displaces carburetted systems by 1990.

In order to provide a better understanding of the change in this mix of emission control technologies of particular interest to EPA, the mix of fuel systems, catalyst technologies, secondary air systems and EGR systems were plotted separately. Figure 2-1 shows this mix of fuel systems. The large reduction in the share for open loop carburetors in 1984 is due to Japanese manufacturers and Ford converting most of their open-loop systems to closed loop systems. At the same time the growing market

TABLE 2-8

FORECAST OF EMISSION CONTROL TECHNOLOGY - AMC/OTHER JAPANESE

	1982	1983	1984	1985	1987	1990
AMC						
CARB/3CL/PMP PLS	100	26.5	-	-	-	-
TBI/3CL	-	1.6	32.9	30	30	30
MPFI/3CL	-	71.9	67.1	70	70	70
OTHER JAPANESE						
CARB/OXD/PLS	16.7	32.2	-	-	-	-
CARB/3WY/OXD/PMP	29.5	22.5	12.6	10	-	-
CARB/3WY	23.6	-	-	-	5	10
CARB/3CL/PLS (PMP)	29.8	38.7	50.0	49	40	30
MPFI/3CL	-	6.8	23.2	28	45	50

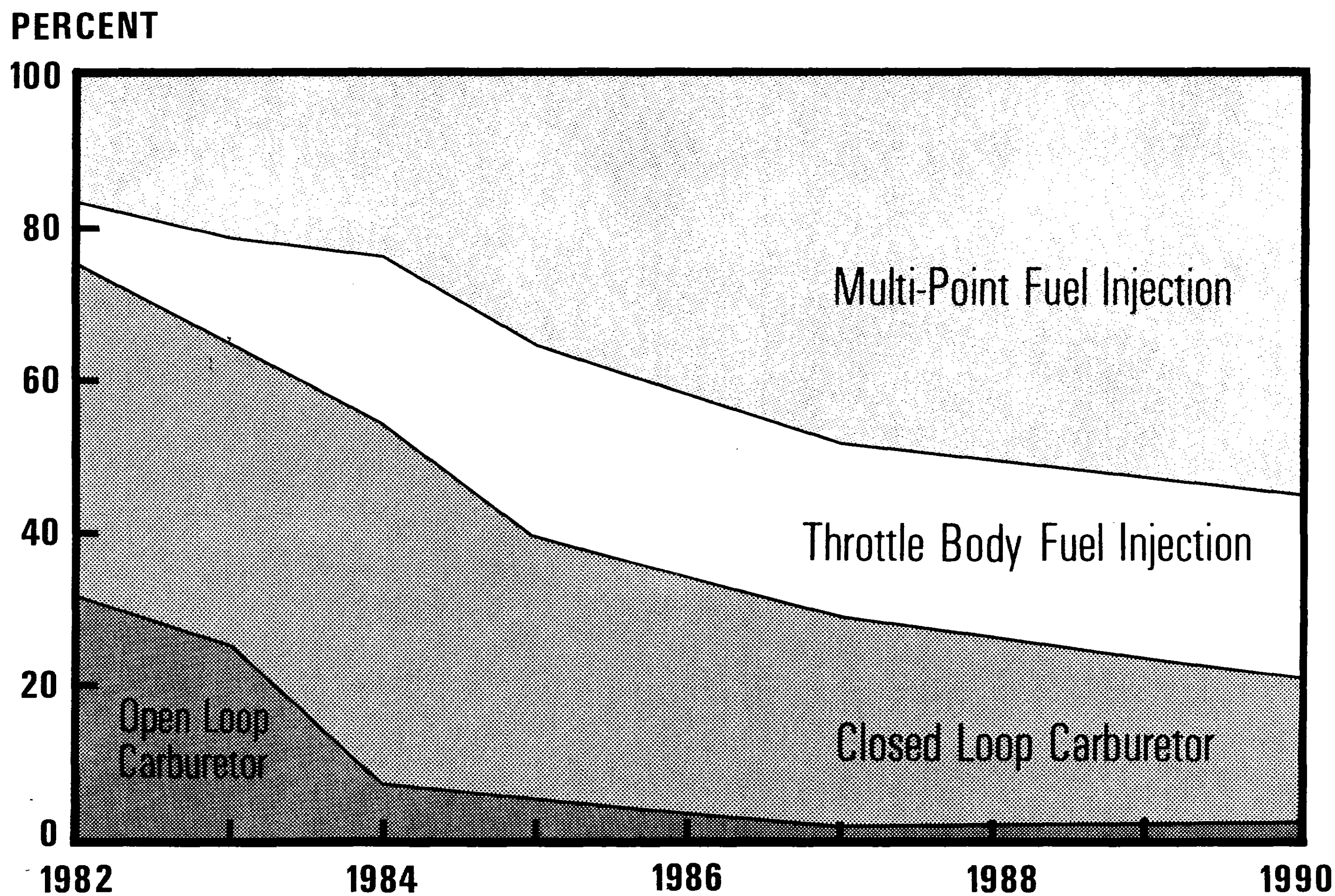
TABLE 2-9

FLEETWIDE FORECASTS OF EMISSION CONTROL TECHNOLOGY

	1982	1983	1984	1985	1987	1990	1990 (0.4 NOx)
Open Loop Carb.							
CARB/OXD/PLS	17.7	13.7	-	-	-	-	-
CARB/3WY/OXD/PMP	11.7	10.6	6.3	4.0	-	-	-
CARB/3WY	2.4	0.7	0.6	0.8	1.6	2.0	-
Closed Loop Carb.							
CARB/3CL/PMP	17.6	7.8	0.1	-	-	-	-
CARB/3CL/PLS	3.3	9.9	16.8	17.3	16.3	12.5	4.8
CARB/3CL/OXD/PLS	-	-	1.2	0.8	0.6	0.6	-
CARB/3CL/OXD/PMP	22.7	16.9	25.5	11.5	6.0	3.2	-
CARB/3CL	-	4.9	3.8	5.1	4.6	2.8	-
Throttle Body FI							
TBI/3CL	4.7	3.7	8.9	8.3	8.4	8.4	8.4
TBI/3CL/PLS	-	2.3	2.6	2.5	2.5	7.0	15.0
TBI/3CL/OXD/PMP (PLS)	3.2	8.0	10.4	14.2	11.5	8.6	-
Multi-Point FI							
MPFI/3CL	16.7	21.4	23.5	34.6	44.5	50.5	71.8
MPFI/3CL/OXD/PMP PLS	-	0.2	0.5	0.8	4.0	4.3	-

FIGURE 2–1

Fuel System Mix



share for fuel injected systems -- both MPFI and TBI is due primarily to the domestic manufacturers converting to fuel injection in the 1984-1987 time frame.

Figure 2-2 shows the mix of catalyst systems. Since oxidation catalysts were phased out in 1984, the main battle for market share is between the single-bed and dual-bed three-way catalyst system. The increased use of fuel injection is expected to bring about decreased use of the dual-bed system, as the primary reason for the additional oxidation catalyst was due to the inability of carburetors to control the air-fuel ratio closely enough to meet the CO standard with just a 3-way catalyst. Secondary air systems, shown in Figure 2-3, follow the trends in catalyst technology closely. While the dual-bed systems require secondary air, single-bed systems, do not, for the most part, require secondary air. There is some uncertainty over the use of secondary air due to potentially more stringent enforcement by the EPA of in-use emissions. Some engine lines that may meet the 7.0 g/mi CO standard for California with only a small margin of safety may switch to pulse air systems under stricter enforcement of in-use emissions.

Figure 2-4 shows the trends in EGR systems. This was not discussed previously primarily because all (with the exception of only 2 models) models of domestic and Japanese vehicles use EGR while all European vehicles do not use EGR. Both domestic and Japanese manufacturers indicated that they are considering deleting EGR to improve driveability in some limited line luxury or sports cars. The modest increases in the no-EGR category reflects this trend. On the other hand, GM has indicated widespread dissatisfaction with its back pressure EGR (this has been the object of several recall actions) and is currently converting most of its vehicle lines to electronic EGR control. (This term refers to the fact that vacuum modulation of the EGR valve is accomplished by electrical rather than mechanical means.) Ford and Chrysler have indicated that they will change their EGR systems to electronic control as well.

FIGURE 2–2
Catalyst Mix

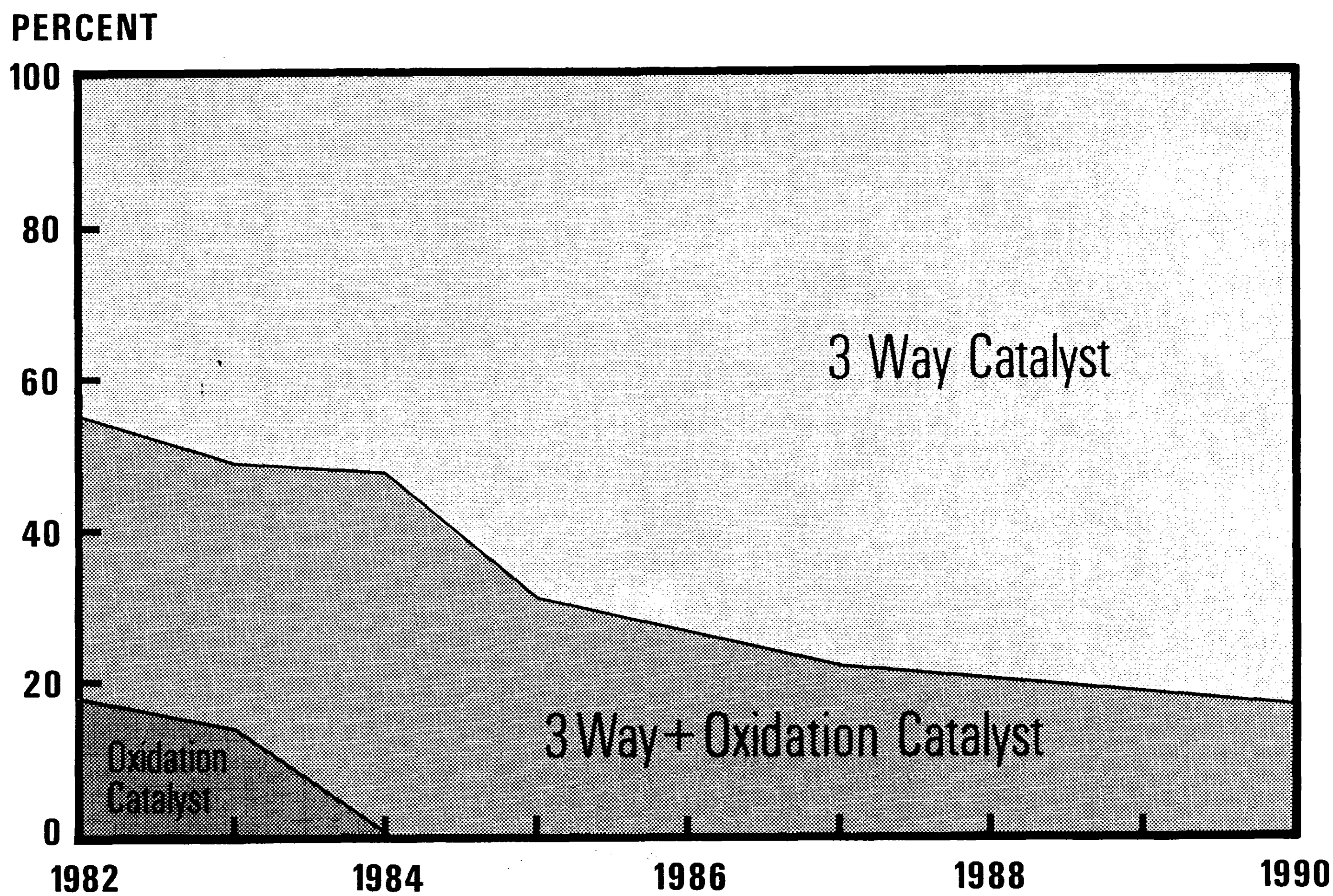


FIGURE 2–3

Secondary Air System Mix

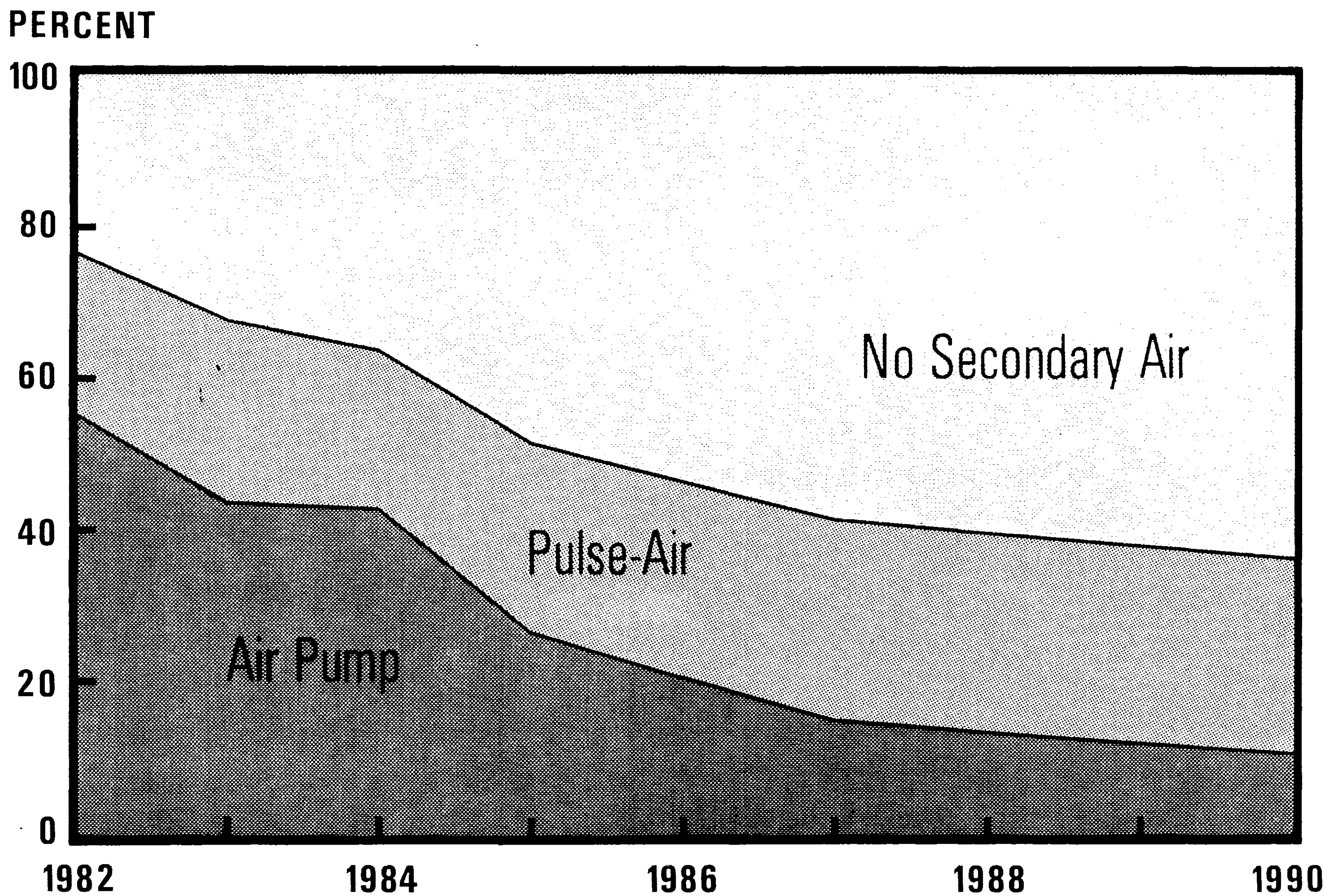
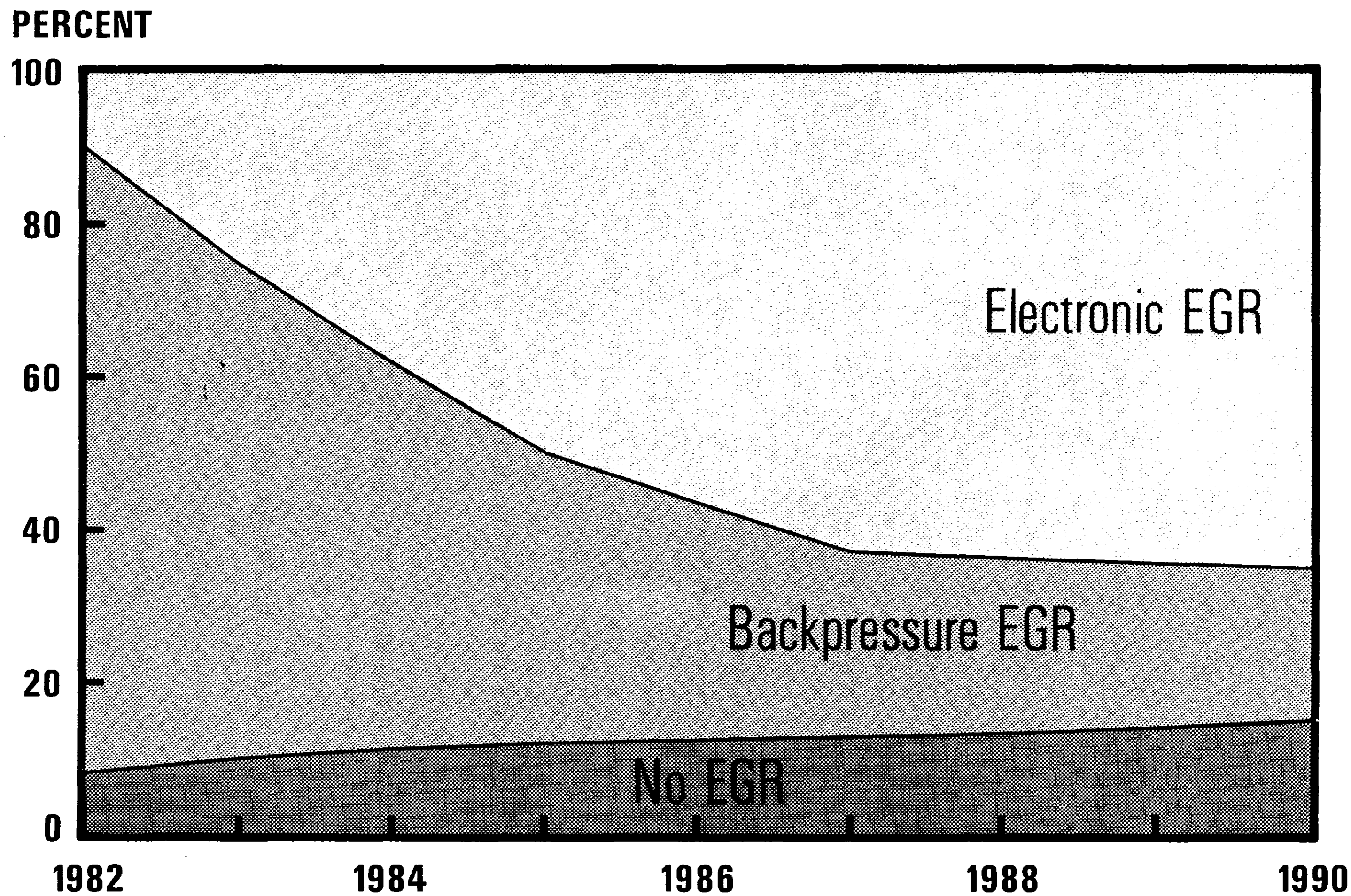


FIGURE 2–4

EGR System Mix



Japanese manufacturers have already converted their EGR systems to electronic control in their luxury fuel injected vehicles; however, Nissan and Toyota stated that their back pressure EGR systems on their lower priced carburetted vehicles was adequate and EEA expects that other Japanese manufacturers have had the same experience. As a result, EEA forecasts shown that even in 1990, over 15 percent of the fleet will continue to use back pressure EGR systems.

2.7.1 Stringent NOx Standard Scenario

The ARB is currently contemplating the imposition of a 0.4 NOx g/mi standard in the late 1980's. In view of the fact that no notice of proposed rulemaking has been issued, EEA believes that the earliest that this standard will be imposed is MY 1988. Accordingly, an additional forecast of emission control technology mix for 1990 under the 0.4 NOx scenario is provided. We have analyzed this scenario only at the fleetwide level and estimate that the following product actions will occur:

- All carburetted open-loop vehicles and vehicles with CARB/3CL systems will utilize the CARB/3CL/PLS system, using secondary air and increased catalyst loading as well as a slightly richer calibration to meet 0.4 NOx/7.0 CO.
- All other carburetted vehicles will be altered to utilize TBI/3CL/PLS systems or the MPFI/3CL system, depending on whether they are domestic or imported, to meet the 0.4 NOx standard.
- Vehicles featuring throttle-body fuel injection with dual-bed catalyst systems will utilize multipoint fuel injection and a single-bed catalyst system.
- Since single-bed catalysts provide greater NOx reduction than dual-bed systems, EEA believes that most MPFI/3CL/OXD/PMP(or)PLS systems will convert to MPFI/3CL using a catalyst with higher precious metal loading.

Based on these estimates, we have altered the forecast for 1990 under the 0.7 g/mi NOx scenario to provide an equivalent forecast under a 0.4 g/mi NOx scenario. This forecast is also shown in Table 2-9.

3. CLOSED LOOP SYSTEM STRATEGY WITH COMPONENT MALPERFORMANCES

3.1 OVERVIEW

The wide variety of emission control systems described in the previous section of this report have one major common function -- under proper operating conditions, the tailpipe emissions are close to or meet the applicable emission standards. However, a major concern is in-use vehicle emissions, which, especially at higher mileages, are dominated by a relatively small group of malperforming vehicles that have been labelled as "gross emitters." The continuing evolution of emission control systems as well as the forecasts that shows a trend towards increased market penetration of fuel injection systems makes it necessary to examine how emission control systems can fail in modes that cause "gross emissions", and whether such failures will be present in the future.

Unfortunately, the answers to these questions are by no means simple. Even within a technology specific category of emissions control, manufacturers can use a variety of malfunction mode strategies that can result in significantly different emission impact. The simple act of diverting the secondary air during malfunction changes tailpipe emissions of HC and CO by 500 percent; yet this diversion strategy can be changed through a programming change in the electronic control unit. As a result, there is the potential for sudden and unexpected shifts in strategy. On the other hand, it appears from the data that such sudden shifts have rarely occurred in the past, and manufacturer strategy appears to change only moderately with time. Thus, it is likely that strategies can be forecast with accuracy in spite of the fact that strategy changes can be implemented easily.

Control strategy is important only for closed-loop emission control systems, as the open-loop systems do not have what are known as "system failures." In the case of closed-loop systems, the malperformance of any one of several components can lead to failure of the entire system, with attendant loss of emission control. Under such malperformance conditions, manufacturers have adopted a number of different strategies so as to minimize the impact of the malperformance or retain the ability of the vehicle to "limp home." These strategies principally can affect the fuel system in different ways. The EGR and secondary air system fail only in "on" of "off" conditions. Failure mode of the spark control systems are generally only in "retarded spark" condition which results in favorable impact on emissions and are, hence, not considered in this report.

Malfunction strategies for the different systems types are outlined in this section and differences between manufacturers are highlighted. We have utilized data supplied by the manufacturers on their emission control system malfunction strategy as well as the results of emission tests on various cars with intentional disablements that were conducted by the EPA and the ARB. For any given emission control system, there is usually little or no difference in malfunction strategy between Federal and California vehicles for any manufacturer, and hence data from both Federal and California cars can be used. Since the CARB/3CL/OXD/PMP is the most commonly used system and there is large body of data available on its malfunction modes, this system's malperformances are described in some detail. The strategies employed by all other systems are then considered in terms of the <u>differences</u> between the strategies employed by the CARB/3CL/OXD/PMP system with the system under consideration. Additionally, a general discussion of system failure modes is provided so that failures may be grouped by failure type.

3.2 SYSTEM FAILURES

Individual component failures can lead to system failures for all closed-loop systems because of the interactive nature of such systems. Because these system failures are common to all closed-loop systems, the descriptions of system failures and the possible causes are common to all closed-loop systems identified below. Emission impacts for system failure are specific to each type of closed-loop system; these impacts are described in the appropriate subsections detailing emissions under malperforming conditions.

All closed-loop systems rely on continuous correction of the air/fuel ratio in a majority of driving modes to utilize the three-way conversion capability of the catalyst. Loss of control due to any component malfunction will lead to several possible system failures, all of which result in some change in the controlled air/fuel ratio.

Full rich failure occurs when the air/fuel ratio is at the rich limit of its authority range at all times due to loss of control. This happens, for carburetted vehicles, when:

- The mixture control solenoid fails or is disconnected
- The electronic control unit (ECU) fails catastrophically or is disconnected
- The coolant temperature sensor or the engine RPM sensor fails (in some cases)

Such failures cannot occur in fuel-injected vehicles since loss of control results in a no fuel condition. Similarly full lean failures can occur in some carbureted vehicles due to ECU malfunction or faulty solenoid connection.

Control rich failure occurs when the ECU sets the control value of the air/fuel ratio to a rich calibration. This is similar to the full rich failure; however, it does not imply loss of control but control at a rich air/fuel ratio. In general, this air/fuel ratio is somewhat leaner than that caused by a full rich failure. Typical reasons for such a failure are:

- Loss of coolant temperature sensor signal
- Throttle switch malfunction (at "wide-open" position)
- Oxygen sensor malfunction (sensor short to ground)
- Defective ECU.

Most modern ECU's (like the GM C-3 system) can automatically sense some of the above failures after a few minutes of operation. It then will revert to the open-loop mode, described below. Such a failure mode can occur in both fuel-injected and carbureted vehicles.

Control lean failure can occur due to ECU malfunction, defective oxygen sensor, or defective wiring harness. This failure resembles the full lean failure in much the same way as the two rich failures resemble each other, i.e., it represents an air/fuel ratio leaner than stoichiometric but somewhat richer than the full lean failure case. Such failures occur primarily in Bosch K-Jetronic fuel injection systems.

Open-loop failure is not a true failure but a result of recent efforts by the manufacturers to avoid the severe emission impacts of rich failures. The open-loop mode (rather than failure) occurs when the ECU diagnoses a component failure and then reverts to a fixed control value for air/fuel ratio. This fixed control value will result in operation that is nominally stoichiometric; however, production tolerances will result in some engines being slightly richer and the others being slightly leaner than stoichiometric. Also, during transients, air fuel ratios will oscillate much more violently than under closed-loop conditions. Open-loop modes can be caused by:

- Loss of coolant or air temperature sensor signal
- EGO sensor defects or disconnection
- Wiring harness defects.

Partial loss of control also can be caused by EGR malfunctions or tampering with the carburetor mixture adjustments or the intake air preheat.

The open-loop mode can result in very different emission impacts from vehicle to vehicle. This is because production tolerances could bias the carburetor or fuel-injection system slightly rich or lean, resulting in a large change in conversion efficiency for the three-way catalyst. However, the open-loop mode usually occurs only after the ECU recognizes some failure; thus, during the FTP, only a fraction of the time will be spent in the open-loop mode and the rest of the time under some failure condition. This fraction of time varies from model to model depending on ECU calibration. The open-loop mode dominates the emission impact. For example, an open-loop mode due to control rich failure will result in increased HC and CO emissions even if, during the open-loop mode, the air/fuel ratio is biased slightly lean. The open-loop modes will have emission impacts depending on whether they arise from a control lean failure or control rich failure.

The "limp-home" failure mode is used primarily in fuel injected systems to allow vehicles from being disabled completely. Usually, the computer provides a fixed fuel quantity (fixed injector opening time) to allow vehicle movement when catastrophic system failures have occurred.

3.3 THE CARBURETTED, DUAL-BED CATALYST SYSTEM (CARB/3CL/OXD/PMP)

This system accounts for over a third of all emission control systems sold in the 1981-1984 time frame and is used almost exclusively by the three domestic manufacturers. Although the market share for this system is projected to decline in the future, a discussion of the emission control strategy used provides an excellent guide to the differences in strategies between manufacturers. There is also a wealth of data available from various intentioned disablement testing programs conducted by the EPA, CARB and the manufacturers.

The GM system, implemented in about 70 percent of GM cars, utilizes a sophisticated fault recognition system with specific malperformance diagnostics and a malperformance strategy. Table 3-1 shows a comprehensive listing of system operation during malfunction modes for the fuel system, spark system, idle speed control system (ISC), the secondary air system (AIR), the EGR system, the torque converter clutch (TCC) and the evaporative carbon canister purge (CCP) system. Note that for almost every malperformance mode, secondary air is diverted to atmosphere (ATM). The strategy for no reference pulses, "PROM" error and failure of the carburetor mixture control solenoid puts the system in the full-rich failure mode. For failures of the coolant temperature sensor or the short circuited oxygen sensor, the system is in the control-rich failure mode. Since the air-fuel ratio control is effected by a solenoid controlling fuel flow, the failure pattern is relatively consistent. Eight GM vehicles utilizing this system have been subjected to a wide variety of disablement tests and the test results are summarized in Table 3-2. The typical disablements tested are:

- Oxygen (O_2) sensor short/ground
- Oxygen sensor open
- Coolant Temperature Sensor (CTS) open
- Mixture Control Solenoid (MCS) open
- Throttle Position Sensor (TPS) open
- Electronic Spark Timing (EST) disconnected.

Although not all disablements were tested on all cars, the trends are quite consistent (for the most part) with the system operation strategy shown in Table 3-1. O_2 sensor short and TPS open conditions appear to lead to control rich failures, whereas the "O_2 sensor open" and "CTS open" lead to open-loop failures. The MCS disconnect and EST disconnect lead to full-rich failures. Note, however, that the "full rich" failure in V-8 engines usually results in CO emissions of over 200 gm/mi vehicles while emissions are below 200 g/mi for V-6 and 4-cylinder engines. This observation is also supported by in-use failure data where all of the 200+ g/mi CO emitters have V-8 engines.

TABLE 3-1

STRATEGY FOR GM CARBURETTED EMISSION CONTROL SYSTEM

			TYPICAL SYSTEM OPERATION DURING MALFUNCTION						
CODE	DESCRIPTION	TYPICAL ERROR CRITERION	FUEL	SPARK	ISC	AIR	EGR	TCC	CCP
12	NO REF PULSES	NO SIGNAL	RICH	BACKUP	FIXED	ATM	ON	OFF	ON
13	OPEN CIRCUITED OXYGEN SENSOR	SIGNAL STAYS WITHIN 300-600 M VOLT	OPEN LOOP	NORMAL	NORMAL	ATM	NORMAL	NORM	NORMAL
14	COOLANT TEMPERATURE TOO HIGH ERROR	RESISTANCE LESS THAN 37 OHMS (SHORT OR TEMP. > 150°C)	CLOSED LOOP	HOT CAL.	HOT CAL.	ATM	ON	OFF	ON
15	COOLANT TEMPERATURE TOO LOW ERROR	RESISTANCE GREATER THAN 9K OHMS (OPEN OR TEMP. < 0°C)	OPEN LOOP	NORMAL	COLD CAL	ATM	OFF	OFF	OFF
21	THROTTLE POSITION SENSOR ERROR	AT IDLE, TPS GREATER THAN 50%	RICH	NORMAL	NORMAL	ATM	OFF	OFF	NORMAL
23	CARBURETOR SOLENOID	OPEN/SHORT	RICH/LEAN	NORMAL	NORMAL	ATM	OFF	OFF	OFF
24	VEHICLE SPEED	NO OUTPUT (ZERO MPH), ABOVE IDLE SPEED AND LOAD	CLOSED LOOP	NORMAL	NORMAL	ATM	NORMAL	OFF	NORMAL
32	BARO SENSOR	PRESSURE LESS THAN 40 KPA (>15,000 FT.)	CLOSED LOOP	HIGH ALT.	NORMAL	ATM	NORMAL	NORM	NORMAL
34	PRESSURE SENSOR (MAP OR VAC)	AT IDLE, PRESSURE LESS THAN 4 KPA OR GREATER THAN 80 KPA	CLOSED LOOP	HIGH LOAD	NORMAL	ATM	OFF	NORM	NORMAL
35	ISC NOSE SWITCH	SWITCH CLOSED W/TPS > 50%	CLOSED LOOP	NORMAL	NORMAL	ATM	NORMAL	NORM	NORMAL
42	EST BY-PASS	BY-PASS LINE IS SHORTED TO GROUND	CLOSED LOOP	BACKUP	NORMAL	ATM	NORMAL	NORM	NORMAL
44	LEAN EXHAUST AIR-FUEL RATIO	SENSOR VOLTAGE LESS THAN 300 MV	INDET.	NORMAL	NORMAL	ATM	NORMAL	NORM	NORMAL
45	RICH EXHAUST AIR-FUEL RATIO	SENSOR VOLTAGE GREATER THAN 600 MV; TPS > 12%, < 75%	INDET.	NORMAL	NORMAL	ATM	NORMAL	NORM	NORMAL
51	ECM	PROM ERROR	RICH	BACKUP	FIXED	ATM	ON	OFF	ON
52-55	ECM	SOLENOID DRIVER ERROR, A/D ERROR, LSI ERROR, M/C	INDET.	INDET.	INDET.	INDET.	INDET.	INDET.	INDET.

TABLE 3-2

INTENTIONAL DISABLEMENT DATA ON 1981 GM CARB/3CL/OXD/PMP SYSTEMS
FTP EMISSIONS (g/mi)

	Camaro V-8			Capric V-8			Riviera V-8			Bonneville V-8		
	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
Base	0.20	1.40	0.69	0.31	2.00	0.89	0.44	4.17	1.00	0.40	1.34	0.99
O_2 short/gnd	0.57	37.13	0.34	-	-	-	1.35	89.37	0.26	1.45	89.87	0.18
O_2 open	0.22	1.75	2.57	0.24	2.65	1.74	-	-	-	0.31	1.46	3.02
CTS open	-	-	-	1.86	71.60	0.55	2.31	60.54	1.70	3.18	89.53	1.91
MCS open	6.29	209.10	0.24	8.34	229.81	0.14	7.40	250.78	0.12	12.92	304.60	0.18
TPS open	6.20	213.40	0.25	-	-	-	-	-	-	-	-	-

TABLE 3-2 (cont'd)

INTENTIONAL DISABLEMENT DATA ON 1981 GM CARB/3CL/OXD/PMP SYSTEMS
FTP EMISSIONS (g/mi)

	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
		Citation V-6			Citation 4			Citation 4			Citation 4 (Calif)	
Base	0.25	2.73	0.48	0.26	2.74	0.79	0.14	1.05	0.78	0.05	0.63	0.34
O_2 open	-	-	-	0.31	2.80	1.83	0.10	1.03	2.14	0.15	2.05	1.04
O_2 short/gnd	1.90	81.28	0.28	-	-	-	-	-	-	-	-	-
CTS open	2.07	53.61	0.70	0.95	36.81	1.00	0.95	49.72	0.64	1.25	55.40	0.54
MCS open	5.41	190.87	0.11	0.75*	17.74*	0.68*	2.17	102.65	0.39	-	-	-
EST	-	-	-	-	-	-	1.93	168.89	0.12	-	-	-
Vac.Sensor Open	-	-	-	-	-	-	-	-	-	0.40	19.13	0.09

*Results suspect, malperformance potentially incorrectly identified.

Table 3-3 shows the data on intentional disablement testing of Ford's 1981 closed-loop dual bed systems. Unlike GM, Ford has used a variety of different electronic control units as well as different carburetors on their vehicles. For example, Ford employed a variable venturi carburetor on the V-8 engine, a stepper motor driven mixture control system on some of the carburetors for four cylinder vehicles as well as mixture control solenoid system on other four-cylinder vehicles. Additionally, two types of electronic control units -- the MCU and the EEC-II were used in conjunction with these carburetors. As a result, no consistent pattern of failure modes is evident, although EEA has learned that, in general, the MCU system is not capable of failure recognition. As a result, there is no secondary air diversion during malperformance with MCU systems and, in systems utilizing the stepper motor mixture control, the failure mode is indeterminate since the mixture control system can fail at any intermediate setting. The EEC-II system used on the V-8, appears more to like the GM system from emission data.

Table 3-4 shows the data on intentional disablements of Chrysler vehicles with the carburetted dual-bed system (which accounts for over 75 percent of Chrysler's sales). Chrysler utilizes a feedback carburetor that that is very similar to that used by GM. Chrysler vehicles are unique among domestic manufacturers in that they never divert secondary air. Emissions of CO, therefore, rarely exceed 35 g/mi even with the mixture control solenoid disconnected. The only high emitter in the group appears with an oil pressure switch disconnection. EEA was not able to ascertain why this causes high emissions. An examination of in-use data confirms the fact that Chrysler vehicles rarely (if ever) exceed the 35 g/mi CO level. It must be noted that none of the disablement testing was performed with the oxygen sensor shorted, although the emissions with the mixture control solenoid disconnected would represent the worst case full-rich failure. The 1981 Horizon in Table 3-4 shows extraordinarily low emissions with any disablement, but this may be due to the fact that the catalyst was relatively new.

TABLE 3-3

INTENTIONAL DISABLEMENT DATA ON FORD CARB/3CL/OXD/PMP SYSTEMS
FTP EMISSIONS (g/mi)

	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
	1981 Mustang 4-cyl			1981 Mustang 4-cyl			1981 Granada (Calif) 4-cyl			1981 LTD (Calif) (V-8)		
Base	0.63	6.58	1.24	0.97	8.12	0.67	0.27	3.05	0.65	0.23	1.57	0.61
O_2 open	0.74	9.95	0.41	1.00	14.67	0.45	0.42	4.67	0.67	0.46	3.82	0.68
CTS open	0.48	5.99	1.00	0.69	5.18	1.29	0.30	3.88	1.42	3.58	85.47	0.75
MCS open	0.93	17.96	0.32	0.79	15.31	0.39	0.30	5.06	0.65	0.32	2.42	0.50
ECU disconnect	-	-	-	-	-	-	2.92	109.81	0.67	No Start		
ECU gnd disconnect	-	-	-	-	-	-	3.31	268.46	0.64	3.41	77.70	1.08

TABLE 3-4

INTENIONAL DISABLEMENT DATA ON CHRYSLER CARB/3CL/OXD/PMP SYSTEMS
FTP EMISSIONS (g/mi)

	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
Base	0.24	1.72	1.12	0.50	9.21	0.80	0.72	9.73	1.00	0.34	4.67	0.61
O_2 open	0.25	3.28	0.64	0.87	32.90	0.30	1.52	31.25	0.37	0.26	9.40	0.38
CTS	0.22	1.59	1.12	0.68	20.17	0.34	2.01	25.25	0.59	0.33	4.01	0.52
MCS	0.22	4.00	0.58	1.16	24.75	0.28	1.06	17.47	0.43	0.91	28.94	0.28
Oil pr. sw.	-	-	-	-	-	-	-	-	-	2.39	73.23	0.19

More recently, Subaru has introduced carburetted dual-bed systems, although the secondary air is supplied through a pulse air system. Secondary air using the pulse air is totally uncontrolled so that there is no possibility of secondary air diversion. Hence, EEA anticipates that at worst, the malperformance emissions of Subaru carburetted system will equal that of Chrysler vehicles. It is likely to be better than the Chrysler system because of the inherently low emissions at light load. No in-use data is available on such vehicles as Subaru has introduced these systems only in 1983.

3.4 CARBURETTED, SINGLE-BED CLOSED-LOOP SYSTEMS

This type of emission control system is used primarily by Japanese manufacturers although a number of GM models with CO waivers also utilized such systems. No other domestic manufacturer offered the CARB/3CL/PMP or PLS systems. Table 3-5 provides the intentional disablement emissions data on GM 231 V-6 for Federal and California models. GM staff informed us that failure strategies for single bed systems were identical to those used for dual-bed systems (except for the air pump). The data in Table 3-5 appears to confirm that observation with one exception -- the "TPS open" malperformance does not seem to affect emissions noticeably. The emissions impact of the "CTS open" malperformance also appears to vary between California and non-California cars. EEA is unable to explain this difference although they may have arisen from differences in the method of disconnection. The full-rich failure emissions (MCS open) does confirm that for the most part, V-6 engines should have CO emissions below 200 g/mi in this worst case failure mode.

Table 3-6 shows intentional malperformance data on two GM four-cylinder vehicles equipped with a CARB/3CL/PLS system. There are no major differences between the emissions of these systems and those of the CARB/3CL/PMP system, except for the lower emissions under the full-rich failure mode (MCS open) attributable to the smaller engine size.

TABLE 3-5

INTENTIONAL DISABLEMENT DATA ON GM CARB/3CL/PMP SYSTEMS
FTP EMISSIONS (g/mi)

	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
	'81 Cutlass			'81 Cutlass			'81 Cutlass (Calif)			'81 Regal (Calif)		
Base	0.23	2.94	0.58	0.22	5.24	0.49	0.39	5.68	0.94	0.30	5.04	0.89
O_2 short/ground	3.12	98.89	0.36	5.56	161.32	0.43	-	-	-	-	-	-
O_2 open	-	-	-	-	-	-	0.39	2.34	2.35	0.41	4.66	2.30
CTS open	1.75	65.92	1.24	3.21	133.64	0.22	1.02	25.70	2.48	0.88	16.11	0.38
MCS open	3.53	121.64	0.52	11.80	219.79	0.15	3.44	112.20	0.62	3.70	139.91	0.26
TPS open	-	-	-	-	-	-	0.43	5.97	0.85	-	-	-

TABLE 3-6

INTENTIONAL DISABLEMENT DATA ON GM CARB/3CL/PLS SYSTEMS
FTP EMISSIONS (g/mi)

	HC	CO	NOx	HC	CO	NOx
	1980 Citation (Calif)			1981 Chevette		
Base	0.22	3.20	0.53	0.27	2.96	0.42
O_2 short/ground	2.07	95.62	0.13	-	-	-
O_2 open	0.29	6.85	0.64	0.21	2.33	1.76
CTS open	0.22	5.18	0.69	1.05	31.21	0.24
MCS open	2.36	111.24	0.06	3.11	85.06	0.15
TPS open	0.20	4.21	0.45	-	-	-

The Japanese manufacturers have also utilized the CARB/3CL/PLS system on many of the smaller vehicles. Both Nissan and Mitsubishi utilize carburetors that control air-fuel ratio by modulating the fuel flow, whereas Honda and Toyota utilize modulation of air flow to control air-fuel ratio. Although no intentional disablement test data is available, EEA believes that Nissan and Mitsubishi vehicles are likely to be quite similar to those found in GM vehicles. Nissan engineering confirmed that:

- Oxygen sensor open or short is recognized by the ECU, and the system reverts to the open-loop mode
- "Coolant temperature sensor open" is recognized after a few minutes following start, and the system goes to open-loop mode. "CTS short" is not recognizable by the system, and closed-loop mode is utilized even during warmup.

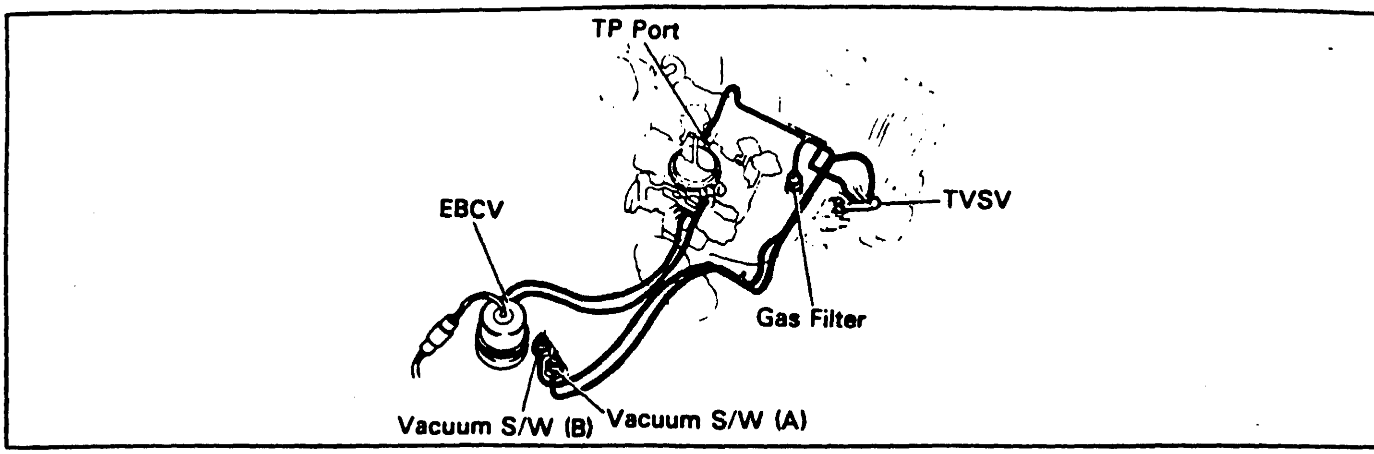
Unlike the Nissan system, Toyota's closed-loop carburetor utilizes different operating principles. The control of air-fuel ratio is <u>not</u> implemented by means of modulating fuel; rather, the Toyota system uses an <u>air-bleed</u> that does not operate at

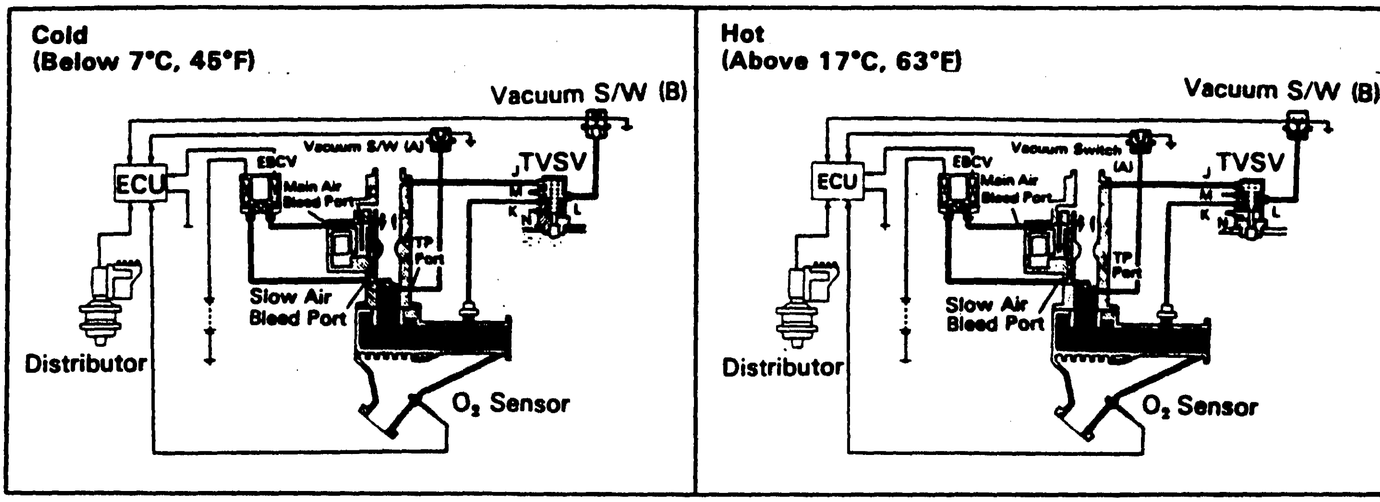
- Cold temperature (vacuum to air bleed is cut off by temperature controlled vacuum switch)
- Idle, (vacuum cut off by computer)
- Under heavy load as indicated by (absence of) engine vacuum.

These are illustrated in Figure 3-1 from the Toyota service manual. Note that the idle cut-off of air bleed requires that the carburetor be calibrated slightly lean at idle and light load conditions.

The lack of secondary air during malperformance modes could lead to higher emissions than for those dual-bed systems, i.e., emissions equivalent to those of the GM system shown in Table 3-6. However, since both Honda and Toyota do not utilize feedback control at low load/idle conditions, the HC and CO impact should be considerably lower than that on GM's CARB/3CL/PLS systems.

AIR BLEED WITH FEEDBACK SYSTEM
(USA Vehicles and Canada 3A-C Engine 4-Speed)





By means of a signal from the O_2 sensor, carburetor primary side main air bleed and slow air bleed volume are controlled to maintain optimum air-fuel mixture in accordance with existing driving conditions, thereby cleaning HC, CO and NOx. In addition, drivability and fuel economy are improved.

Coolant Temp.	TVSV	Condition	Engine rpm	Vacuum S/W A	Vacuum S/W B	Air-fuel Ratio for TWC	O_2 Sensor Signal	Computer	EBCV	Air Bleed
Below 7°C (45°F)	OPEN (J–L)	—	—	—	OFF	—	—	OFF	CLOSED	OFF
Above 17°C (63°F)	OPEN (K-L)	Idling	Below 1,300 rpm	—	—	—	—	OFF	CLOSED	OFF
		Cruising	Above 1,500 rpm	ON	ON	RICH	RICH	ON	OPEN	Feedback air bleed
						LEAN	LEAN	OFF	CLOSED	
		Heavy loads intake vacuum below 85 mm Hg (3.35 in.Hg)	—	ON	OFF	—	—	OFF	CLOSED	OFF
		Deceleration	Above 1,500 rpm	OFF	ON	—	—	ON	OPEN	ON

FIGURE 3-1

TOYOTA CLOSED-LOOP CONTROL STRATEGY

3.5 THROTTLE-BODY FUEL INJECTION

These systems were first introduced in 1981 on the Cadillac and the Lincoln Continental, and both systems were of the TBI/3CL/OXD/PMP type. GM has provided the typical operation of their TBI system under the different malperformance modes used in the V-8-6-4 engine, as well as in the 249 V-8, in 1982. In general, Table 3-7 shows that strategy is essentially equivalent to the strategy used by the carburetted systems, with the exception of conditions of "no reference pulses" and ECU failure, which results in no fuel rather than a rich condition. The manifold pressure sensor (MPS) is the primary input used in both the Ford and GM TBI systems to compute that fuel quantity delivered. (Such systems are referred to as speed-density systems.) Disconnection of the MAP sensor or its malperformance leads to what GM describes as a "reduced performance" control, whereas Ford systems employed in 1981/82 do not have such a backup mode.

Table 3-8 shows the results of intentional disablement testing of both the Cadillac and Lincoln systems. For the Cadillac the disconnection of the MPS appears to cause emissions of 200-230 g/mi CO whereas in the Lincoln, the CO emissions are in excess of 450 g/mi. However, disconnection of the speed sensor ground connection caused CO emissions on the Cadillac to rise to the 400+ g/mi level. It must be noted that for both the Cadillac and Lincoln, malperformances having very high emissions (400+g/mi CO) resulted in the car being barely driveable. Presumably, the electronics trigger maximum fuel flow for those malfunctions regardless of the operation mode.

It is known that GM has recently improved their strategy for cars when the MPS is open, so that the computer now utilizes the throttle position sensor and crank position sensor inputs to compute fuel quantity.

TABLE 3-7

STRATEGY FOR GM TBI EMISSION CONTROL SYSTEM

			TYPICAL SYSTEM OPERATION MALFUNCTION MODES						CAD. ONLY
CODE	DESCRIPTION	TYPICAL ERROR CRITERION	FUEL	SPARK	ISC	AIR	EGR	CCP	MOD/DISP.
12	NO REF PULSES	NO SIGNAL	NO FUEL	BACKUP	FIXED	NORM	ON	ON	NORM
13	(HIGH IMPEDANCE) OXYGEN SENSOR	SIGNAL STAYS WITHIN 300-600M VOLT	OPEN LOOP	NORM*	NORM	NORM	NORM	NORM	NORM
14	COOLANT TEMP. TOO HIGH ERROR	RESISTANCE LESS THAN 37 OHMS (SHORT OR TEMP 150°C)	CLOSED LOOP	HOT CAL.	HOT CAL. FAILSOFT	ATM	OFF	ON	OFF
15	COOLANT TEMP. TOO LOW ERROR	RESISTANCE GREATER THAN 38°C 9K OHMS (OPEN OR TEMP. 3°C)	OPEN LOOP	NORM	COLD CAL FAILSOFT	AIM	OFF	OFF	OFF
16	OVER/UNDER VOLT	VOLTAGE 10^{V}., 16^{V}	NORM	NORM	OFF	ATM	OFF	OFF	OFF
17	CRANK DISCRETE HIGH	CRANK DISCRETE STAYS HIGH	NORM AFTER TIME OUT	NORM	NORM	NORM	NORM	NORM	NORM
18	CRANK DISCRETE	CRANK DISCRETE NEVER GOES HIGH AFTER START	NORM	NORM	NORM	NORM	NORM	NORM	NORM
19	FUEL PUMP VOLT HIGH	VOLT 9 (ie., ON WHEN SHD. BE OFF)	—	--	--	--	—	—	—
20	FUEL PUMP VOLT LOW	VOLT 1.5	NO FUEL	NORM	NORM	NORM	NORM	NORM	NORM
21	THROTTLE POS. SENSOR ERROR LOW	AT IDLE, TPS MORE THAN 50%	RICH	NORM	NORM	ATM	OFF	NORM	
23	EST BYPASS HIGH/ LOW	BYPASS FEEDBACK LOW/HIGH	NORM	NORM/ BACKUP	NORM	NORM	NORM	NORM	NORM
24	VEHICLE SPEED	NO OUTPUT (ZERO MPH), ABOVE IDLE SPEED & LOAD	NORM	NORM	NORM	NORM	NORM	NORM	OFF
25	MOD.DISPL FAIL.	4-CYL FEEDBACK DOES NOT MATCH COMMAND	NORM	NORM	NORM	NORM	NORM	NORM	OFF
26	THROTTLE SWT.LOW	NOSE SWITCH FAILURE CLOSED	NO TIP-IN FUEL	NORM	INOP PULLS BACK	NORM	NORM	NORM	OFF
27	THROTTLE SWT. OPEN	NOSE SWITCH FAILURE OPEN	NO TIP-IN FUEL	NORM	INOP	NORM	NORM	NORM	OFF
30	ISC TEST	ISC MOTOR TEST	NORM	NORM	OFF	NORM	NORM	NORM	NORM

*"NORM" = NORMAL

TABLE 3-7

STRATEGY FOR GM TBI EMISSION CONTROL SYSTEM
(Continued)

CODE	DESCRIPTION	TYPICAL ERROR CRITERION	TYPICAL SYSTEM OPERATION MALFUNCTION MODES: FUEL	SPARK	ISC	AIR	EGR	CCP	CAD. ONLY MOD/DISP.
31.	MAP HIGH	MAP FAIL HIGH	REDUC. PERF. C/L	REDUC. PERF.	NORM	REDUC.	REDUC.	REDUC.	OFF
32.	MAP LOW		"	"	"	"	"	"	"
33	MAP/BARO COR.		"	"	"	"	"	"	"
34	MAP HOSE OFF		"	"	"	"	"	"	"
35	BARO HIGH		"	"	"	"	"	"	"
36.	BARO LOW		"	"	"	"	"	"	"
44	LEAN EXHAUST AIR/FUEL RATIO	SENSOR VOLTAGE LESS THAN 300 MV	INDET	NORM	NORM	ATM	NORM	NORM	OFF
45	RICH EXHAUST AIR/FUEL RATIO	SENSOR VOLTAGE MORE THAN 600 MV; TPS 12%, 75%	INDET	NORM	NORM	ATM	NORM	NORM	OFF
51	ECM	PROM ERROR	RICH	BACKUP	FIXED	ATM	ON	ON	OFF

TABLE 3-8

INTENTIONAL DISABLEMENT DATA ON TBI/3CL/OXD PMP SYSTEMS
FTP EMISSIONS (g/mi)

	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
	'81 Cadillac			'82 Cadillac			'81 Lincoln			'81 Lincoln		
Base	0.30	3.01	0.71	0.27	3.09	0.48	0.30	3.40	0.88	0.31	2.56	0.82
O_2 short/gnd	0.87	27.62	0.39	-	-	-	-	-	-	-	-	-
O_2 open	0.49	10.39	0.71	0.27	3.06	0.84	0.27	3.71	1.26	0.39	5.94	0.97
CTS open	0.76	1.72	2.82	0.64	3.75	8.21	Not driveable			Not driveable		
MPS open	14.80	204.92	0.24	15.93	229.99	0.50	-	-	-	19.55	472.41	0.13
ATS open	1.28	19.64	0.38	0.73	10.85	0.55	-	-	-	29.25	447.13	0.13
TPS open	0.31	4.12	3.94	0.30	2.77	0.78	-	-	-	No start		
TPS short	0.28	2.14	3.90	-	-	-	-	-	-	-	-	-
Speed Sensor (open)	-	-	-	2.12	26.87	0.35	-	-	-	-	-	-
Speed Sensor (gnd)	-	-	-	23.44	406.21	0.37	-	-	-	-	-	-

Table 3-9 shows the behavior of the TBI/3CL systems used on the X-cars. With these systems, disconnection of the MAP sensor leads to the reduced performance mode that appears to have far lower emissions impact than on the Cadillac. The larger engine on the Cadillac, as well as the secondary air diversion on that system, are probable causes of this difference. However, the TBI/3CL systems show very high emissions with an "O_2 sensor short" or with connection of the O_2 sensor lead to ground. Inexplicably, the Cadillac system did not produce high emissions with the O_2 sensor grounded -- it is possible that secondary air was not diverted during this malperformance in the particular vehicle tested.

A study of Ford's emission control strategy confirmed that Table 3-8 provides representative impact of the different malperformances. In addition, it appeared that a TPS short or an oxygen sensor short would have relatively small effect on emission. However, EEA cautions that the oxygen sensor short requires correct identification by the ECU to mitigate emissions and there is no test data available to support the statement that the ECU will, in fact, correctly diagnose such a fault.

In MY 1984, Chrysler introduced a throttle body fuel injection system that is expected to be utilized across most of their front wheel drive vehicles by 1987. This system differs from the GM and Ford TBI systems in that it has a dual-bed catalyst with uncontrolled pulse air. As a result, there is no secondary air diversion during malperformance and emissions in most malperformance modes is expected to remain low. (This is similar to the Chrysler system using an air pump with no diversion during malperformance.) Chrysler has also incorporated a fault recognition mode to accomplish the following:

- If the MPS is disconnected or receives no vacuum signal after start, the ECU utilizes the throttle position signal and the RPM signal to generate a modified manifold pressure signal.
- If the TPS fails (open or short), the MPS signal is used by logic moduls to generate a modified TPS signal that is utilized for enrichment.

TABLE 3-9

INTENTIONAL DISABLEMENT DATA ON GM TBI/3CL SYSTEMS
FTP EMISSION (g/mi)

	'82 Citation			'82 Skylark			'82 Citation			'82 Phoenix		
	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
Bas	0.09	1.35	0.50	0.15	3.56	0.54	0.14	4.03	0.37	0.12	1.59	0.69
O_2 short/gnd	-	-	-	3.19	157.66	0.22	4.17	175.08	0.11	4.53	170.29	0.30
O_2 open	1.58	59.71	0.39	-	-	-	-	-	-	0.53	16.34	0.26
CTS open	0.13	2.14	0.36	0.14	4.14	0.48	0.23	5.52	0.39	-	-	-
MPS open	-	-	-	-	-	-	1.90	82.52	0.13	1.72	76.64	0.21
TPS open	-	-	-	-	-	-	-	-	-	0.16	2.27	0.35

- Failure of the oxygen sensor is recognized not by an impedance check but by absence of sensor signals for over five seconds. However, this defect is evaluated only when engine temperature is above 180°F and engine speed is over 1500 RPM for six minutes. This indicates that the diagnostic may not be useful over the FTP.
- Recognition of the coolant temperature sensor malperformance is based on impedance being between pre-specified limits and the rate of change of impedence being below a threshold. Failure results in operation using the "warm calibration" for fuel.

Thus, it appears that Chrysler's on-board diagnostics and strategy may lead to lower emission during malperformances than either the GM or Ford strategy.

3.6 MULTIPOINT FUEL INJECTION SYSTEMS

Until 1984, no multipoint systems were utilized by the domestic manufacturers and all of the multipoint systems were built by Bosch (or its licence, Nippondenso).

Bosch offers two basic types of MPFI systems, one featuring mechanical fuel injection with an add-on electronic control (the Bosch K-E Jetronic) and the other, an all electronic system where fuel delivery is controlled by electrically operated injectors (the Bosch L-Jetronic). The Bosch K-E Jetronic was used by all European imports, but in 1983, BMW and Volvo began using the L-Jetronic. The Japanese manufacturers utilize systems essentially similar to the L-Jetronic.

The Bosch K-E Jetronic is a very simple system with no fault recognition and diagnostics capability. A key feature of this system is that computer malfunction or disconnection of the air-fuel ratio modulator (called frequency valve) leads to control-lean failure with low HC and CO emissions but high NOx emissions. However, grounding of the oxygen sensor can lead to a control-rich failure. Intentional malperformance tests of VW Rabbits equipped with this system confirmed these trends, and the emissions data from these tests are shown in Table 3-10. Although the O_2 sensor short does produce high HC/CO, it must be noted that in-use data does not indicate that such failures occur in actual practice, whereas the lean failure seems more common. The Bosch K-E Jetronic does not utilize either a coolant temperature sensor or a throttle position sensor as input devices for its ECU.

The Bosch L-Jetronic system is all electronic, and features control strategies similar to the domestic TBI systems, with fewer malperformance modes. The Japanese manufacturers, Toyota and Nissan utilize essentially similar systems with more advanced electronics. Table 3-11 shows emissions data from two Toyota's, a BMW and a Datsun 280 Z-X, all of which feature essentially similar emission controls. Note that, as with the GM system, the grounding of the oxygen sensor results in a control-rich failure. Note also that multiple malperformances (oxygen sensor and air temperature sensor open) leads to a similar control rich failure. Emissions from most other malperformance modes are very low, or else the malperformances result in a no start condition. Only the BMW produced very high emissions with the coolant temperature sensor disconnected, but the driveability was reportedly very poor.

Both Toyota and Nissan have begun upgrading their electronics. For example, both the 1981 and 1982 Supra featured analog electronics but the 1984 Supra features an all digital ECU, whereas the Camry, Celica and Starlet feature hybrid electronics. All of the 1984 models also feature built in diagnostics, with an inspection lamp to indicate malfunctions. Toyota provided a detailed chart of the malperformance strategy used by both the digital and the hybrid ECU. These are provided in Tables 3-12 and 3-13. The indication of "bad" emission impact is expected to be in the range of 40-50 g/mi CO, typical of the control-rich failure. Detailed discussions with Nissan revealed that the strategy used in 280 (now 300) Z-X and Cressida are very similar.

TABLE 3-10

INTENTIONAL DISABLEMENT DATA ON MECHANICALLY FUEL-INJECTED SYSTEMS
1981 VW RABBITS

	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
Base	0.33	5.17	1.00	0.11	1.38	0.32	0.32	1.68	0.33
O_2 sensor short/gnd	10.70	186.06	0.11	-	-	-	-	-	-
O_2 sensor open	-	-	-	2.41	109.59	0.70*	0.13	1.38	4.62
Thermo switch open	0.26	3.48	1.28	0.13	1.31	0.27	0.22	1.76	0.30
MCS open	-	-	-	-	-	-	0.20	1.40	3.02

*Results indicate grounding of harness.

TABLE 3-11

INTENTIONAL DISABLEMENTS ON ELECTRONICALLY FUEL-INJECTED SYSTEMS (MPFI/3CL)

	'81 Toyota Supra			'82 Toyota Supra			'82 BMW 528e			'81 Datsun 280z-x		
	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
Base	0.19	1.46	0.38	0.29	2.98	0.46	0.31	2.00	0.23	0.24	1.15	0.35
O_2 short/gnd	2.82	84.15	0.38	-	-	-	-	-	-	-	-	-
O_2 open	0.28	2.01	2.38	0.49	6.74	0.58	0.66	5.37	1.59	0.34	2.10	1.21
CTS open	-	-	-	No start			20.82	336.97	0.43	No start		
TPS open	0.16	1.32	0.36	0.30	2.10	0.28	0.46	2.13	0.17	0.42	2.42	0.32
EGR disconnect	0.22	2.21	0.55	-	-	-	-	-	-	1.87	5.24	0.23*
ATS disconnect	-	-	-	0.31	3.38	0.47	0.37	2.45	0.16	0.36	3.10	0.25
Air flow sensor disconnect	No start			No start			No start			Not driveable		
O_2 + ATS open	-	-	-	1.92	82.28	0.17	4.03	51.66	0.25	-	-	-

*Idle speed control disconnected as well.

TABLE 3-12 5M-GE (Supra & Cressida) ECU Failure Mode Operation

10/05/83

Computer Terminal	Failure Mode	A/F Control	Effect on Emission	Overt Indication	Diagnostic Lamp
Igniter	Open	No injection	N/A	Can't drive	
Air Flow Meter (Vs)	Open	Lean Operation	N/A	↑	ON
	Short	Rich Operation	N/A	↑	ON
Air Flow Meter (Vc)	Open	Rich Operation	N/A	↑	ON
	Short	Lean Operation	N/A	↑	ON
Inlet Air Temp. Sensor	Open	No compensation	O~Δ	Can't detect	
	Short	Lean (~10%)	O~Δ	Can't detect	
Coolant Temp. Sensor	Open	No compensation	O~Δ	Can detect at cold cond.	ON
	Short	No compensation	O	Can detect at cold cond.	ON
Oxygen Sensor	Open	Open Loop Operation*	X	Can't detect	ON
	Short	Open Loop Operation*	X	Can't detect	ON
Throttle Position Sensor (VL)	Open	No power enrichment at acceleration	O	Can't detect	
	Short	Rich (10%)	X	Can't detect	
Throttle Position Sensor (LL)	Open	No Fuel Cut	X	Poor fuel economy	
	Short	Fuel Cut at High RPM	N/A	Easy to detect	
Vehicle Speed Sensor	Open	ISC operate at any time	Δ	Engine stall at deceleration	
	Short	ISC operate at any time	Δ	↑	
Clutch Sensor	Open	No fuel reduction at deceleration	O~Δ	Can't detect	
	Short	No fuel reduction at deceleration	O~Δ	↑	
Battery (Backup)	Open	Clear the leaned parameter	Δ	Can't detect	
(Main)	Open	No operation	N/A	Can't drive	
Crank Angle Sensor	Open	No operation	N/A	Can't drive	

Note: *Hot Start Condition
Rich (~15%)

O [illegible]
Δ [illegible]

TABLE 3-13

83 2S-E (Camry) ECU Failure Mode Operation 10/05/83

Computer Terminal	Failure Mode	A/F Control	Effect on Emission	Overt Indication	Diagnostic Lamp
Igniter	Open	No injection	N/A	Can't drive	
Air Flow Meter (Vs)	Open	Lean Operation	N/A	↑	ON
	Short	Rich Operation	N/A	↑	ON
Air Flow Meter (Vc)	Open	Rich Operation	N/A	↑	ON
	Short	Lean Operation	N/A	↑	ON
Inlet Air Temp. Sensor	Open	Rich (~10%)	O~Δ	Can't detect	
	Short	Lean (~10%)	O~Δ	Can't detect	
Coolant Temp. Sensor	Open	Rich (-40°C condition)	X	Easy to detect	ON
	Short	No compensation	O	Can detect at cold cond.	
Oxygen Sesor	Open	Open Loop Operation	X	Can't detect	ON
	Short	Open Loop Operation	X	Can't detect	ON
Throttle Position Sensor (VL)	Open	No power enrichment at acceleration	O	Can't detect	
	Short	Rich (~10%)	X	Can't detect	
Throttle Position Sensor (LL)	Open	No Fuel Cut	Δ~X		
	Short	Fuel Cut at High RPM	N/A	Easy to detect	
Voltage Supply	Open	No operation	N/A	Can't drive	
			O=good Δ=so so X=bad		

All major domestic manufacturers indicated that the strategy utilized by their multipoint systems will not differ appreciably from those being used in their TBI systems. EEA expects that, since most multipoint fuel injected systems will have no secondary air, the emissions impact of malperformances will resemble those of the TBI/3CL system shown in Table 3-9. The high emissions of the "oxygen sensor short" malperformance is not likely to occur in Ford or Chrysler systems. GM, however, expects that this malperformance may result in high emissions even in their advanced multipoint fuel injected systems. A new feature of these systems however is their "keep alive" memory that allows the ECU to remember a failure once diagnosed even after the key is turned off. Thus, emissions may be high immediately after occurrence of a malperformance but once the computer has diagnosed the fault and takes remedial action, the malperformance strategy will result in only modest increases in emissions. This features' effect can be seen in disablement testing only if a car with a disablement is tested at least twice. Emissions during the first test will be dominated by the high emissions from the time period before the ECU diagnoses the malperformance; once the malperformance is diagnosed, emissions will be reduced and the emissions during the second test are likely to be much lower. Unfortunately, no test data is available to illustrate the point but the potential of the "keep alive" memory should be recognized.

3.7 RECOMMENDATIONS FOR EMISSION FACTOR ANALYSIS

Previous analysis of data generated from emissions tests of in-use cars have been sensitive only to the most obvious changes to emission control technology and not at all to strategy. Based on data presented in Sections 2 and 3 of this report, it is clear that emission control technology and strategy are of great importance in determining in-use emissions, and especially of emission during malperformance modes. EEA recommends that the data on in-use cars be stratified prior to analysis as explained below:

- At minimum, the in-use data sample must be stratified by types of fuel system: open-loop carburetors, closed-loop carburetors, throttle-body fuel injection and multipoint fuel injection.
- Closed-loop carburetted vehicles (the single largest group in the data base stratified by fuel system type) must be further stratified by the presence or absence of secondary air during malperformance modes. Toyota and Honda vehicles should be excluded because of their unique "air-bleed" closed loop control.
- Throttle-body fuel injected may be combined with electronic multipoint fuel injected vehicles if they have similar catalyst systems.
- Multipoint fuel injected vehicles (the second largest group in the in-use emissions data base) must be further stratified into groups for mechanical fuel injection (Bosch K-Jetronic) and electronic fuel injection.
- Future fleet emission factors should be derived from in-use data at the level of disaggregation recommended above and the technology specific emission factors can be reaggregated using data presented in Table 2-9.
- It is likely that fleet emission factors derived using this method will overstate emissions because of the influence of the "keep alive" fault detection systems being introduced in new cars. The potential reduction in emissions from such systems cannot yet be evaluated, but must await data from intentional malperformance testing of such new cars.
- Future intentional malperformance testing should be sensitive to the effects of the "keep alive" fault diagnostics; repeat tests of vehicles with intentional malperformances will be required to quantify the effect of such systems.

APPENDIX A
LIST OF ABBREVIATIONS

FTP	Federal Test Procedure
CARB	Carburetor
FI	Fuel Injection
MPFI	Multipoint Fuel Injection
TBI	Throttle Body Fuel Injection
3WY	3-way Catalyst with Open Loop Control
3CL	3-way Catalyst with Closed Loop Control
OXD	Oxidation Catalyst
PMP	Air Pump
PLS	Pulse-Air
O_2	Oxygen Sensor
CTS	Coolant Temperature Sensor
TPS	Throttle Position Sensor
ATS	Air Temperature Sensor
MCS	Mixture Control Solenoid
MPS	Manifold Pressure Sensor
EST	Electronic Spark Timing Unit
ECU	Electronic Control Unit (Fuel)
PROM	Programmable Read-Only Memory

EMISSION FACTORS FOR
1980 AND LATER MODEL YEAR CALIFORNIA
PASSENGER CARS AND LIGHT-DUTY TRUCKS

prepared for:

California Air Resources Board

prepared under:

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1. SUMMARY

Results of tests from 552 1980 and later model year California motor vehicles were reviewed to determine the best techniques for estimating future year vehicle emissions. The data were first subjected to a number of quality control checks to ensure that they were internally consistent. Items such as engine displacement, fuel system, emission control components, and make/model designations were checked with certification summaries to assure the accuracy of these entries. In addition, bag test results were compared with composite FTP (Federal Test Procedure) results for each test to ensure that both sets of entries were correct. The final analyses were performed on the corrected data sets.

Linear regressions were conducted separately for gasoline-powered passenger cars (PC), gasoline-powered light-duty trucks, and light-duty Diesel vehicles. The gasoline car regressions were the most detailed, since the other two vehicle categories had much smaller data sets. The gas PC data were divided into subfleets based on model year, fuel system, air injection system, fuel/air system combinations, exhaust gas recirculation system, vehicle manufacturer, and domestic/imports. An analysis of the residual sum of squares associated with each group of subfleets, combined with some engineering analysis of probable statistical relationships, indicated that the best predictions would be based on separating the data into two model year categories (1980, and 1981 and later), and into fuel/air subfleets within each model year group. This is generally consistent with the recommendations made by EEA in their "Forecast of Emission Control Technology and Strategy for Light-Duty Vehicles", also prepared under this contract. Some of the subfleet sample sizes were small (<10 vehicles); however, the methodology described in this report can be reapplied as CARB collects more data through its annual vehicle surveillance programs.

The recommended emission factors for gasoline passenger cars are shown in Table 1. The data suggest a slight increasing trend in CO and NOx emissions in future model years. This is associated with the

Table 1

Summary of
Recommended Emission Factors
Gasoline Passenger Cars

Pollutant	Model Year	Zero Mile Level (gm/mile)	Deterioration Rate (gm/mile/10K miles)
HC	1980	0.4719	0.1010
	1981-82	0.1673	0.1913
	1983	0.2032	0.1757
	1984	0.2087	0.1856
	1985-86	0.2626	0.1641
	1987-89	0.2964	0.1532
	1990+	0.3243	0.1445
CO	1980	8.9937	1.5674
	1981-82	2.4334	2.9617
	1983	2.6648	3.0426
	1984	2.5498	3.4601
	1985-86	2.9247	3.5620
	1987-89	3.1329	3.6967
	1990+	3.3334	3.7909
NOx	1980	0.8741	0.0675
	1981-82	0.5704	0.0818
	1983	0.5534	0.0933
	1984	0.5299	0.1169
	1985-86	0.5198	0.1214
	1987-89	0.5120	0.1262
	1990+	0.5109	0.1259

increasing trend towards the use of fuel injection systems during the 1980's. The data reported here do not agree well with engineering expectations of the performance of fuel injected vehicles in future years. This may be due to the fact that the analysis was based on tests of only 41 1981 and 1982 model cars with fuel injection. More advanced fuel injection systems, featuring onboard diagnostic capabilities and improved schemes for handling malfunctions, were not introduced until the 1983 and later model years. Thus, it will be important for CARB to reassess these projections as soon as additional data become available.

The recommended emission factors for gasoline light-duty trucks (LDT's) are shown in Table 2. Due to the relative paucity of LDT data, two approaches were used. Under the first approach, the projections are based solely on LDT test data. The factors for 1980 are based on 1980 data, and the factors for 1981 and later model years are based on 1981-82 data. (The zero mile levels for the latter case are adjusted in 1983 to reflect changes in the applicable standards.) The second option uses PC data, adjusted by model year, to forecast future LDT emissions. There are more data available under this approach; however, it relies on the assumption that LDT control technology and emissions levels correspond to PC levels of a few years earlier. The final recommended factors rely on actual LDT data for 1980-82, and extrapolated PC data for subsequent model years.

The recommended emission factors for Diesel passenger cars are shown in Table 3. The factors are shown separately for vehicles with and without exhaust gas recirculation. They should be combined for 1980-83 model years based on actual California sales of the two types of technologies. For 1984 and later model years, full use of EGR can be assumed. Once again, these factors should be updated as soon as possible when additional data become available.

Table 2

Summary of
Recommended Emission Factors
Gasoline Light-Duty Trucks

Pollutant	Model Year	Zero Mile Level (gm/mile)	Deterioration Rate (gm/mile/10K miles)
HC	1980	0.3794	0.1729
	1981	0.3169	0.0771
	1982	0.5804	0.0458
	1983+	0.2673	0.1913
CO	1980	3.926	3.231
	1981	4.509	0.9225
	1982	12.55	0.9099
	1983+	2.4334	2.9617
NOx	1980	1.334	0.1903
	1981-82	0.6889	0.1235
	1983+	0.8704	0.0818

Table 3

Summary of
Recommended Emission Factors
Diesel Passenger Cars

Pollutant	Model Year	Zero Mile Level (gm/mile)	Deterioration Rate (gm/mile/10K miles)
HC	1980-83		
	w/o EGR	0.1075	0.0444
	w/EGR	0.1333	0.0393
	1984+	0.1333	0.0393
CO	1980-83		
	w/o EGR	0.6505	0.0982
	w/EGR	1.105	0.0296
	1984+	1.105	0.0296
NOx	1980-83		
	w/o EGR	1.246	0.0241
	w/EGR	1.246	0.0612
	1984+	0.746	0.0612

2. METHODOLOGY

A. Data Sources

Two computer tapes, containing emission test data from the light-duty vehicle surveillance programs 1 through 7 (including Diesel program 3) conducted by the California Air Resources Board between 1976 and 1983, formed the initial database. The vehicles tested in the surveillance programs were selected at random, and therefore, should have been representative of the actual vehicle population. A subset containing as-received tests only for 1980 and newer model year vehicles was extracted from the initial database to perform the emission factor analysis. The principal characteristics of the gasoline passenger car fleet which formed the basis for the bulk of the analysis are shown in Table 4.

B. Data Checking/Quality Control

Numerous data checks and quality control algorithms were applied to the surveillance data to ensure consistent, accurate data. The CARB used two different formats to store vehicle test data collected in surveillance programs 1-6 and 7, respectively. The data was combined in a single, consistent format. Detailed data checking was especially critical to the analysis of gasoline passenger cars which, as described later, were stratified into small-sized subsets in which data errors could significantly alter the statistical results. A brief description of each data checking procedure is given below.

Reformatting

As indicated above, the surveillance data for program 7 (and Diesel program 3) were stored in a different data format than test results in previous programs. In addition, several data fields were reported in different units in each of the two formats. For example, in the vehicle description portion of a test record, engine size was reported in liters in the 'new' (program 7) format and in cubic inches

Table 4

Gasoline Passenger Cars - Fleet Characteristics

Sample Size = 435
Min. HC = 0.10 Max HC = 5.90
Min. CO = 0.76 Max CO = 159.09
Min. NOx = 0.08 Max NOx = 5.55
Min. Odometer = 999 Max Odometer = 83,606

	Model Year			
Manufacturer	80	81	82	Totals
GM	82	51	23	156
Ford	38	22	7	67
Chrysler	12	8	2	22
Toyota	17	19	7	43
Nissan	18	16	7	41
Honda	10	8	5	23
Mazda	8	8	3	19
Volkswagen	8	6	1	15
Mitsubishi	6	7	1	14
Other Imports	18	14	3	35
TOTAL	217	159	59	435

Emission Controls	80	81	82	Totals
Open Loop Carb.	68 (31%)	55 (35%)	24 (41%)	147 (34%)
Closed Loop Carb.	110 (51%)	72 (45%)	26 (44%)	208 (48%)
Electronic Fuel Injection	17 (8%)	19 (12%)	3 (5%)	39 (9%)
Mechanical Fuel Injection	22 (10%)	13 (8%)	2 (3%)	37 (9%)
Throttle Body Fuel Injection	0 (0%)	0 (0%)	4 (7%)	4 (1%)
TOTAL	217	159	59	435

in the 'old' (program 1-6) format. Unit conversions were performed on each of the necessary data fields, and the data was reformatted to a new consistent format.

Manufacturer Name Checks

Vehicle manufacturer names reported in each of the two data formats decribed above were coded with inconsistent conventions. For example, some vehicles manufactured by British Leyland (e.g. MG, Jaguar, Triumph) were coded as 'JRT' in programs 1-6 and 'BRIT' in program 7. A consistent naming convention was adopted and used to correct the differences in manufacturer names as described.

Domestic/Import Checks

All vehicles tested were coded as 'D' (domestic) or 'I' (import) based on the vehicle manufacturer. After checking and cleaning the manufacturer name field for each test vehicle as decribed above, the domestic/import data field was checked against the vehicle manufacturer field to ensure consistent coding of the domestic/import field.

Emission Control System Check

The vehicle description records identified the type of fuel systems used (carbureted or fuel injected); whether the vehicle used closed-loop control systems; the type of catalyst used (oxidation, three-way, none); and whether air injection (pulse or pump) and exhaust gas recirculation were used. These records were checked for internal consistency (e.g., vehicles with oxygen sensors must have closed-loop fuel systems), consistency with other similar vehicles (e.g., all 1980 Honda Civics with automatic transmission should have the same fuel and emission control systems) and with certification documents. Errors were identified and corrected, with the exception of some catalyst codes. This is because different naming conventions have been used by both CARB and EPA to describe oxidation, oxidizing-reducing, dual-bed, three-way, and three-way plus oxidation catalyst systems. These inconsistencies appeared in the certification summaries released by the two agencies as well as in the surveillance data itself. These errors could be corrected only through a detailed search of the confidential catalyst descriptions in each manufacturers' certification application, as well as establishment of consistent naming conventions. This effort was beyond the scope of this study; consequently, catalyst type was not used in the regression analyses. However, the remaining emission control system descriptions captured sufficient information about this variable so that the lack of consistent catalyst names was not considered a problem.

Test Condition Check

As-received vehicle tests were coded with a 'B' (baseline) in the test condition field. Vehicles which failed the underhood or initial emission inspection were repaired and re-tested. These retests were assigned different letter and number codings indicating the type and number of retests conducted. Since each vehicle was subject to a baseline test during the surveillance programs, each vehicle in the database was checked to verify that the initial test conducted on it was coded as a baseline test. In addition, the "last test" fields were checked to ensure that they properly indicated the last test in a series (e.g., baseline) and/or last test for the vehicle.

Engine Displacement Check

To uncover errors in the entry of data for the engine displacement field, a listing of unique engine sizes stratified by vehicle manufacturer, make, model and model year was generated. Inspection of this listing revealed several obvious errors in the coded engine sizes, which were corrected.

Bag Data/FTP Checks

The CVS emission test data were error checked by comparing the reported composite HC, CO and NOx emissions with the pollutant emissions recorded for the individual bag data, assuming the standard FTP driving distances of 3.59 miles for bags 1 and 3 and 3.91 miles for bag 2. An error tolerance of 10% in the composite FTP numbers was assumed to be acceptable, in order to provide for differences in actual driving distances. A number of inconsistencies between the composite and individual bag emissions were identified with this test. These inconsistencies were reported to CARB on a detailed print-out, which was subsequently returned with corrections.

Sample Selection

The initial 'raw' test data, as received on computer tape from CARB, contained both before and after repair test results for 1968-1982 model year vehicles. Baseline (i.e., before repair) test data for 1980 and newer model year gasoline vehicles, and for all Diesel passenger cars, were extracted from the raw data. (In cases where there were multiple baselines, the last was used.) In addition, CARB's special enforcement test data was deleted from the sample.

C. Analysis Techniques

This section discusses the statistical methods used to develop emission factors as a function of mileage for a fleet of light-duty vehicles.

Ideally, the best dataset for determining a statistical relationship between emissions and mileage for a fleet of vehicles would contain a series of emissions tests conducted on a representative sample of vehicles throughout the lifetime of the vehicles. Such a dataset, containing multiple emission tests on a sufficient sample of individual vehicles, does not exist. The best available alternative is to use a large sample of test data such as that compiled in CARB's vehicle surveillance programs which test a completely random sample of vehicles of varying mileages. The inherent assumption in using data collected in this manner is that the much larger sample of data available would, in part, offset the error introduced by not rêtesting the same set of vehicles.

To this end, a linear least-squares regression analysis of composite CVS HC, CO and NOx emissions versus mileage was performed on each of the following as-received 1980 model year and newer vehicle fleets as extracted from CARB's surveillance data:

- gasoline passenger cars (PC)
- light-duty gas trucks (LDT)
- Diesel passenger cars (PD) (all model years)

In past fleet emission factor development work, small fleet sample sizes precluded meaningful statistical analyses of vehicle subfleets (e.g., fuel injected cars). However, there are sound engineering reasons for expecting that there are several distinct relationships between vehicle emissions and mileage <u>within</u> the total vehicle fleet. These differences are typically associated with differences in the type and frequency of malfunctions associated with different emission control strategies. These differences are discussed at length in EEA's "Forecast of Emission Control Technology and Strategy for Light-Duty Vehicles", prepared separately under this contract. EEA concluded by recommending the following subfleet stratifications, to the extent possible with the available data:

- o At a minimum, the in-use data sample should be stratified by type of fuel system: open-loop carburetors, closed-loop carburetors, throttle-body fuel injection and multipoint fuel injection.
- o Closed-loop carburetted vehicles (the single largest group in the data base stratified by fuel system type) should be further stratified by the presence or absence of secondary air during malperformance modes.
- o Throttle-body fuel injected vehicles may be combined with electronic multipoint fuel injected vehicles if they have similar catalyst systems.
- o Multipoint fuel injected vehicles (the second largest group in the in-use emissions data base) should be further stratified into groups for mechanical fuel injection (Bosch K-Jetronic) and electronic fuel injection.

- Future fleet emission factors should be derived from in-use data at the level of disaggregation recommended above, and the technology specific emission factors can be reaggregated using projections of future-year technology mixes.

The database compiled for this analysis contains more test data, especially for gasoline passenger cars, than has been available for previous work. Thus, this analysis represents the first attempt to sub-divide the passenger car fleet into fuel system subfleets and to develop individual regressions for each of these subfleets to better explain vehicle emissions as a function of mileage.

The residual sum-of-squares statistic (RSS) was used as a key indicator in determining the effectiveness of additional fleet stratifications posited based on engineering theory. In a linear least-squares analysis, the RSS is defined as the sum of the squared vertical deviations of each observed data point from least-squares regression line. Mathematically,

$$RSS = \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 = \sum_{i=1}^{n} [\, Y_i - (\hat{\beta}_0 + \hat{\beta}_1 X_i)]^2$$

where X_i = the i^{th} measurement of an independent variable (e.g., vehicle mileage)

Y_i = the i^{th} measurement of a dependent variable (e.g., vehicle emissions)

$\hat{Y}_i$ = the expected value of the dependent variable for observation X_i

$\hat{\beta}_0$, $\hat{\beta}_1$ = the least-squares line intercept and slope, repectively

n = the sample size.

Given a sample containing n observations of two variables and the "best fit" regression line for that sample of data, the sample can be divided into up to numerous sub-samples, each with individual regression lines. The comparison of the RSS for the initial sample with the summed RSS's for each sub-sample can provide an indication that individual relationships exist for each sub-sample. If the summed RSS's are significantly lower than the total RSS it could be concluded that the set of data is better represented by a <u>set</u> of regressions applied to each subset of the data. By sub-dividing the fleet based on theoretical engineering reasoning, reduced RSS's would likely represent a real improvement in describing the relationship between emissions and mileage rather than reflecting an "artifact" of the variance within the fleet data.

3. RESULTS

A. Gasoline Passenger Cars

The initial regression results for gasoline passenger cars are shown in Tables 5 through 7.

The analysis of RSS for these regressions indicated the following:

	Residual Sum of Squares		
	HC	CO	NOx
Fleet total regression	304.1	146,900	109.7
Stratification by:			
model year	300.0	143,970	100.6
fuel system	302.8	145,830	105.3
air injection system	303.9	146,820	109.4
EGR use	302.1	146,220	109.6
fuel/air combination	300.5	144,486	102.2
domestic/import	302.5	146,760	107.2

For each pollutant, stratification by model year yields the best, although still small, improvement in RSS. Work being conducted independently under this contract related to inspection and maintenance program benefits suggested that emissions performance during 1980 was significantly different than during 1981-82 due to the use of a number of early three-way catalyst system designs.

A two-step model year stratification (1980 and 1981-82) yielded the following:

	Residual Sum of Squares		
	HC	CO	NOx
Fleet total regression	304.1	146,900	109.7
Model year stratification	300.0	143,970	100.6
Two-step model yr. stratification	300.2	144,780	100.7

Table 5'

Technology Based Regressions
for
Gasoline Passenger Cars

HC REGRESSIONS

	N	ZM	DR	r^2	RSS (MS)
ALL VEHICLES	435	0.3137	0.1401	0.044	304.1 (0.702)
ALL MY 80	217	0.5119	0.0916	0.014	215.6 (1.003)
ALL MY 81	159	0.1668	0.1657	0.108	54.14 (0.3449)
ALL MY 82	59	0.2182	0.1795	0.051	30.23 (0.5303)
FUEL = CARB	147	0.2131	0.1530	0.121	39.84 (0.2748)
CARC	208	0.3490	0.1461	0.032	175.2 (0.8503)
FI/TBI	80	0.3812	0.1181	0.029	87.72 (1.125)
AIR = YES	325	0.3178	0.1448	0.048	208.1 (0.6441)
NO	110	0.2832	0.1361	0.037	95.84 (0.8874)
EGR = YES	386	0.3434	0.1193	0.036	231.7 (0.6035)
NO	49	0.1371	0.2513	0.077	70.41 (1.498)
CARB W/AIR	129	0.1846	0.1758	0.137	38.33 (0.3018)
CARB NO AIR*	18	0.3316	0.0461	0.104	0.6545 (0.0409)
CARC W/AIR	182	0.3480	0.1535	0.035	160.0 (0.8887)
CARC NO AIR**	26	0.3540	0.1015	0.018	14.87 (0.6194)
FI/TBI W/AIR***	14	0.7394	-0.0074	0.000	7.324 (0.6103)
FI/TBI NO AIR	66	0.2616	0.1638	0.044	79.29 (1.239)
GM	156	0.3328	0.0880	0.026	61.28 (0.3979)
FORD	67	0.2534	0.2673	0.064	79.25 (1.238)
CHRYS	22	0.6106	0.3019	0.070	31.52 (1.576)
DOM	245	0.3669	0.1397	0.033	184.9 (0.7610)
IMP	190	0.2213	0.1512	0.068	117.6 (0.6257)

*All Honda's
**Mostly 80 GM 2.5L & Fuji
***All GM, Nissan 2.0L

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
CARB = open-loop carburetted
FI = fuel injected (multi-point)
AIR = secondary air injection
DOM = domestic manufacturers
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year
CARC = closed-loop carburetted
TBI = throttle-body fuel injected
EGR = exhaust gas recirculation
IMP = import vehicle manufacturers

Table 6

Technology Based Regressions
for
Gasoline Passenger Cars

CO REGRESSIONS

	N	ZM	DR	r^2	RSS (MS)
ALL VEHICLES	435	4.870	2.465	0.028	146,900 (339.2)
ALL MY 80	217	9.109	1.539	0.009	97,710 (454.5)
ALL MY 81	159	2.226	2.342	0.047	26,230 (167.0)
ALL MY 82	59	0.6864	5.239	0.065	20,030 (351.5)
FUEL = CARB	147	2.923	2.387	0.086	14,200 (97.94)
CARC	208	5.903	2.348	0.023	64,650 (313.8)
FI/TBI	80	6.511	2.525	0.018	66,980 (858.7)
AIR = YES	325	4.978	2.324	0.036	71,860 (222.5)
NO	110	4.798	2.714	0.019	74,960 (694.1)
EGR = YES	386	4.957	2.224	0.032	90,940 (236.8)
NO	49	6.100	3.250	0.017	55,280 (1,176)
CARB W/AIR	129	2.492	2.904	0.109	13,480 (106.2)
CARB NO AIR*	18	3.582	0.1739	0.014	79.05 (4.941)
CARC W/AIR	182	5.792	2.447	0.025	56,370 (313.2)
CARC NO AIR**	26	7.016	1.580	0.008	8,249 (343.7)
FI/TBI W/AIR***	14	9.087	0.0408	0.000	1,208 (100.7)
FI/TBI NO AIR	66	4.980	3.480	0.025	65,100 (1,017)
GM	156	5.170	2.066	0.025	36,070 (234.2)
FORD	67	3.232	3.072	0.036	19,020 (297.1)
CHRYS	22	9.046	5.468	0.048	15,330 (766.3)
DOM	245	5.461	2.394	0.025	72,660 (299.0)
IMP	190	3.940	2.617	0.034	74,100 (394.1)

*All Honda's
**Mostly 80 GM 2.5L & Fuji
***All GM, Nissan 2.0L

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
CARB = open-loop carburetted
FI = fuel injected (multi-point)
AIR = secondary air injection
DOM = domestic manufacturers
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year
CARC = closed-loop carburetted
TBI = throttle-body fuel injected
EGR = exhaust gas recirculation
IMP = import vehicle manufacturers

Table 7'

Technology Based Regressions
for
Gasoline Passenger Cars

NOx REGRESSIONS

	N	ZM	DR	r^2	RSS (MS)
ALL VEHICLES	435	0.6754	0.0948	0.055	109.7 (0.2534)
ALL MY 80	217	0.8790	0.0682	0.023	73.32 (0.3410)
ALL MY 81	159	0.5829	0.0623	0.042	20.92 (0.1332)
ALL MY 82	59	0.5862	0.0859	0.055	6.373 (0.1118)
FUEL = CARB	147	0.8050	-0.0006	0.000	25.20 (0.1738)
CARC	208	0.6481	0.1236	0.095	39.72 (0.1928)
FI/TBI	80	0.5457	0.1670	0.114	40.42 (0.5182)
AIR = YES	325	0.6945	0.0823	0.041	78.31 (0.2424)
NO	110	0.6278	0.1223	0.088	31.13 (0.2883)
EGR = YES	386	0.6731	0.0932	0.053	94.80 (0.2469)
NO	49	0.7188	0.0942	0.053	14.82 (0.3153)
CARB W/AIR	129	0.7739	0.0106	0.001	21.60 (0.1701)
CARB NO AIR*	18	1.026	-0.0701	0.050	3.330 (0.2081)
CARC W/AIR	182	0.6573	0.1093	0.085	31.58 (0.1754)
CARC NO AIR**	26	0.5605	0.2225	0.153	7.323 (0.3051)
FI/TBI W/AIR***	14	0.8675	0.1776	0.072	20.45 (1.704)
FI/TBI NO AIR	66	0.4906	0.1592	0.162	17.90 (0.2796)
GM	156	0.7358	0.1043	0.070	31.18 (0.2025)
FORD	67	0.5256	0.2024	0.205	12.03 (0.1879)
CHRYS	22	0.8632	-0.0382	0.026	1.391 (0.0696)
DOM	245	0.6940	0.1184	0.089	46.08 (0.1896)
IMP	190	0.6074	0.0878	0.045	61.07 (0.3248)

*All Honda's
**Mostly 80 GM 2.5L & Fuji
***All GM, Nissan 2.0L

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
CARB = open-loop carburetted
FI = fuel injected (multi-point)
AIR = secondary air injection
DOM = domestic manufacturers
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year
CARC = closed-loop carburetted
TBI = throttle-body fuel injected
EGR = exhaust gas recirculation
IMP = import vehicle manufacturers

Since this combination lost little in RSS, and allowed us to maintain a reasonable sample size in the two model year groupings, it was selected as the first level stratification.

The analyses were then performed again for the 1980 model year fleet, and separately for 1981-82 model vehicles. The results for 1980 are shown in Tables 8, 9, and 10. The summary of RSS results is shown below:

	Residual Sum of Squares		
	HC	CO	NOx
1980 MY fleet total regression	215.6	97,710	73.32
Stratification by:			
fuel system	212.5	96,570	71.27
air injection system	214.3	97,620	73.10
EGR use	214.8	97,530	73.29
fuel/air combination	210.2	95,315	68.05
domestic/import	213.4	97,480	73.20

For each pollutant, fuel/air combinations provided the best (small) improvement in RSS.

The same is generally true for the 1981-82 analyses, shown in Tables 11, 12, and 13, and summarized below:

	Residual Sum of Squares		
	HC	CO	NOx
1981-82 MY fleet total regression	84.61	47,070	27.39
Stratification by:			
fuel system	82.70	45,807	25.33
air injection system	84.05	46,870	27.11
EGR use	79.92	46,350	27.37
fuel/air combination	80.86	45,543	24.51
domestic/import	82.91	46,670	25.39

EGR use provides a slightly better RSS for hydrocarbons; however, in view of the secondary relationship between EGR use and hydrocarbon emissions, and given the better performance of fuel/air combination in all other pollutants and model years, the latter stratification was considered more representative.

Table 8

Technology Based Regressions
for
1980 Model Gasoline Passenger Cars

Hydrocarbons

	N	ZM	DR	r^2	RSS (MS)
ALL MY 80	217	0.5119	0.0916	0.014	215.6 (1.003)
FUEL = CARB	68	0.2316	0.1720	0.1044	27.86 (0.4222)
CARC	110	0.7328	0.0331	0.0013	135.7 (1.257)
FI/TBI	39	0.3382	0.1237	0.0270	48.93 (1.322)
AIR = YES	155	0.5950	0.0716	0.0092	153.1 (1.000)
NO	62	0.2432	0.1614	0.0394	61.22 (1.020)
EGR = YES	185	0.5656	0.0698	0.0086	169.3 (0.9252)
NO	32	0.2397	0.1869	0.0515	45.48 (1.516)
CARB W/AIR	58	0.2159	0.1896	0.1112	27.05 (0.4831)
CARB NO AIR*	10	0.3260	0.0711	0.1685	0.3890 (0.0486)
CARC W/AIR	90	0.7743	0.0292	0.001	120.8 (1.372)
CARC NO AIR**	20	0.4922	0.0730	0.0069	14.37 (0.7984)
FI/TBI W/AIR***	7	1.013	-0.0739	0.0644	1.715 (0.3429)
FI/TBI NO AIR	32	0.1223	0.2100	0.0539	45.84 (1.528)
GM	82	0.4276	0.0541	0.0113	33.65 (0.4207)
FORD	38	0.9696	0.0036	0.00001	65.00 (1.806)
CHRYS	12	0.9598	0.3304	0.0756	25.93 (2.593)
DOM	132	0.6782	0.0398	0.0022	139.8 (1.076)
IMP	85	0.2368	0.1664	0.0595	73.59 (0.8866)

*All Honda's
**Mostly 80 GM 2.5L & Fuji
***All GM, Nissan 2.0L

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
CARB = open-loop carburetted
FI = fuel injected (multi-point)
AIR = secondary air injection
DOM = domestic manufacturers
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year
CARC = closed-loop carburetted
TBI = throttle-body fuel injected
EGR = exhaust gas recirculation
IMP = import vehicle manufacturers

Table 9

Technology Based Regressions
for
1980 Model Gasoline Passenger Cars

Carbon Monoxide

	N	ZM	DR	r^2	RSS (MS)
ALL MY 80	217	9.109	1.539	0.0090	97,710 (454.5)
FUEL = CARB	68	3.024	3.074	0.093	10,170 (154.0)
CARC	110	12.79	0.6296	0.0013	50,620 (468.7)
FI/TBI	39	9.674	1.334	0.0044	35,780 (967.2)
AIR = YES	155	9.798	1.373	0.0097	53,580 (350.2)
NO	62	6.882	2.119	0.0097	44,040 (734.1)
EGR = YES	185	9.421	1.283	0.0079	62,460 (341.3)
NO	32	8.564	2.359	0.0111	35,070 (1169)
CARB W/AIR	58	2.739	3.675	0.1188	9,425 (168.3)
CARB NO AIR*	10	4.669	-0.3259	0.0257	62.7 (7.839)
CARC W/AIR	90	13.17	0.6273	0.0013	42,620 (484.4)
CARC NO AIR**	20	10.76	0.7688	0.0014	7,929 (440.5)
FI/TBI W/AIR***	7	8.758	-0.0525	0.0004	148.3 (29.66)
FI/TBI NO AIR	32	7.230	2.724	0.0124	35,130 (1171)
GM	82	8.184	0.9882	0.0067	19,150 (239.3)
FORD	38	12.43	-0.0320	0.0000	16,620 (461.6)
CHRYS	12	17.31	5.443	0.0414	13,350 (1335)
DOM	132	10.90	0.7366	0.0020	52,670 (405.1)
IMP	85	6.420	2.541	0.0237	44,810 (539.9)

*All Honda's
**Mostly 80 GM 2.5L & Fuji
***All GM, Nissan 2.0L

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
CARB = open-loop carburetted
FI = fuel injected (multi-point)
AIR = secondary air injection
DOM = domestic manufacturers
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year
CARC = closed-loop carburetted
TBI = throttle-body fuel injected
EGR = exhaust gas recirculation
IMP = import vehicle manufacturers

Table 10

Technology Based Regressions
for
1980 Model Gasoline Passenger Cars

Oxides of Nitrogen

	N	ZM	DR	r^2	RSS (MS)
ALL MY 80	217	0.8790	0.0683	0.0233	73.32 (0.3410)
FUEL = CARB	68	1.075	0.0341	0.009	14.02 (0.2124)
CARC	110	0.8431	0.0819	0.039	26.74 (0.2476)
FI/TBI	39	0.7277	0.1459	0.0584	30.51 (0.8246)
AIR = YES	155	0.8930	0.0565	0.0163	53.64 (0.3506)
NO	62	0.8381	0.0975	0.0450	19.46 (0.3243)
EGR = YES	185	0.8829	0.0648	0.0202	61.47 (0.3359)
NO	32	0.8745	0.0791	0.0361	11.82 (0.3939)
CARB W/AIR	58	1.021	-0.0198	0.0030	12.07 (0.2154)
CARB NO AIR*	10	1.415	-0.1254	0.1317	1.615 (0.2019)
CARC W/AIR	90	0.8538	0.0652	0.0304	19.41 (0.2206)
CARC NO AIR**	20	0.6858	0.2018	0.1025	6.653 (0.3696)
FI/TBI W/AIR***	7	1.782	-0.0087	0.0001	18.57 (3.713)
FI/TBI NO AIR	32	0.6450	0.1405	0.10732	9.732 (0.3244)
GM	82	0.9734	0.0467	0.0135	20.97 (0.2621)
FORD	38	0.5315	0.2264	0.2019	8.712 (0.2420)
CHRYS	12	0.9298	-0.0339	0.0223	0.9822 (0.0982)
DOM	132	0.8609	0.0833	0.0406	32.31 (0.2485)
IMP	85	0.8927	0.0533	0.0116	40.89 (0.4927)

*All Honda's
**Mostly 80 GM 2.5L & Fuji
***All GM, Nissan 2.0L

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
CARB = open-loop carburetted
FI = fuel injected (multi-point)
AIR = secondary air injection
DOM = domestic manufacturers
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year
CARC = closed-loop carburetted
TBI = throttle-body fuel injected
EGR = exhaust gas recirculation
IMP = import vehicle manufacturers

Table 11

Technology Based Regressions
for
1981-82 Model Gasoline Passenger Cars

Hydrocarbons

	N	ZM	DR	r^2	RSS (MS)
ALL MY 81-82	218	0.1869	0.1656	0.0861	84.61 (0.3917)
FUEL = CARB	79	0.2199	0.1211	0.1327	11.33 (0.1471)
CARC	98	0.0336	0.2518	0.1496	32.64 (0.3400)
FI/TBI	41	0.3927	0.1250	0.0305	38.73 (0.9932)
AIR = YES	170	0.1313	0.1979	0.1277	49.68 (0.2957)
NO	48	0.3179	0.1046	0.0305	34.37 (0.7472)
EGR = YES	201	0.2238	0.1318	0.0753	57.66 (0.2898)
NO	17	-0.4209	0.5755	0.2124	22.26 (1.484)
CARB W/AIR	71	0.1884	0.1458	0.1601	10.76 (0.1559)
CARB NO AIR*	8	0.3124	0.0257	0.0678	0.1848 (0.0308)
CARC W/AIR	92	0.0179	0.2686	0.1585	32.14 (0.3571)
CARC NO AIR**	6	0.1929	0.0572	0.5286	0.0192 (0.0048)
FI/TBI W/AIR***	7	-0.2126	0.8138	0.1756	4.529 (0.9058)
FI/TBI NO AIR	34	0.3475	0.1285	0.0341	33.23 (1.038)
GM	74	0.2240	0.1462	0.0454	27.23 (0.3783)
FORD	29	-0.4364	0.5740	0.5629	7.304 (0.2705)
CHRYS	10	0.5511	0.0408	0.0134	0.8953 (0.1119)
DOM	113	0.0569	0.2688	0.1487	39.55 (0.3563)
IMP	105	0.2357	0.1212	0.0598	43.36 (0.4210)

*All Honda's
**Mostly 80 GM 2.5L & Fuji
***All GM, Nissan 2.0L

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
CARB = open-loop carburetted
FI = fuel injected (multi-point)
AIR = secondary air injection
DOM = domestic manufacturers
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year
CARC = closed-loop carburetted
TBI = throttle-body fuel injected
EGR = exhaust gas recirculation
IMP = import vehicle manufacturers

Table 12

Technology Based Regressions
for
1981-82 Model Gasoline Passenger Cars

Carbon Monoxide

	N	ZM	DR	r^2	RSS (MS)
ALL MY 81-82	218	2.370	2.742	0.0443	47,070 (217.9)
FUEL = CARB	79	3.410	1.369	0.0594	3,507 (45.55)
CARC	98	1.260	3.141	0.0725	11,430 (119.0)
FI/TBI	41	3.839	4.073	0.0402	30,870 (791.6)
AIR = YES	170	2.555	2.361	0.0606	16,050 (95.52)
NO	48	3.181	3.136	0.0306	30,820 (670.0)
EGR = YES	201	2.633	2.366	0.0542	26,410 (132.7)
NO	17	-1.329	6.676	0.0389	19,940 (1,329)
CARB W/AIR	71	3.205	1.630	0.0696	3,424 (49.62)
CARB NO AIR*	8	2.799	0.5594	0.4063	9.284 (1.547)
CARC W/AIR	92	1.100	3.365	0.0774	11,310 (125.7)
CARC NO AIR**	6	2.486	0.6397	0.4101	3.880 (0.9700)
FI/TBI W/AIR***	7	-2.489	10.77	0.1602	885.5 (177.1)
FI/TBI NO AIR	34	3.584	4.064	0.0377	29,910 (934.6)
GM	74	1.721	3.907	0.0530	16,520 (229.5)
FORD	29	-4.977	6.140	0.4577	1,276 (47.24)
CHRYS	10	4.749	2.025	0.1716	122.6 (15.33)
DOM	113	0.2121	4.379	0.0913	18,250 (164.4)
IMP	105	3.288	2.015	0.0261	28,420 (275.9)

*All Honda's
**Mostly 80 GM 2.5L & Fuji
***All GM, Nissan 2.0L

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
CARB = open-loop carburetted
FI = fuel injected (multi-point)
AIR = secondary air injection
DOM = domestic manufacturers
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year
CARC = closed-loop carburetted
TBI = throttle-body fuel injected
EGR = exhaust gas recirculation
IMP = import vehicle manufacturers

Table 13

Technology Based Regressions
for
1981-82 Model Gasoline Passenger Cars

Oxides of Nitrogen

	N	ZM	DR	r^2	RSS	(MS)
ALL MY 81-82	218	0.5893	0.0650	0.0430	27.39	(0.1268)
FUEL = CARB	79	0.6629	-0.0137	0.0035	6.285	(0.0816)
CARC	98	0.5393	0.1214	0.1141	10.36	(0.1080)
FI/TBI	41	0.5037	0.1305	0.1325	8.689	(0.2228)
AIR = YES	170	0.6289	0.0469	0.0215	18.60	(0.1107)
NO	48	0.4740	0.1052	0.1138	8.513	(0.1851)
EGR = YES	201	0.5871	0.0674	0.0457	25.65	(0.1289)
NO	17	0.6231	0.0381	0.0151	1.716	(0.1144)
CARB W/AIR	71	0.6592	-0.0061	0.0006	6.080	(0.0881)
CARB NO AIR*	8	0.6170	-0.0337	0.1635	0.1176	(0.0196)
CARC W/AIR	92	0.5456	0.1199	0.1055	10.23	(0.1136)
CARC NO AIR**	6	0.4368	0.1469	0.5623	0.1107	(0.0277)
FI/TBI W/AIR***	7	0.2918	0.5228	0.4433	0.4999	(0.1000)
FI/TBI NO AIR	34	0.4233	0.1454	0.1670	7.475	(0.2336)
GM	74	0.5920	0.1237	0.1045	7.945	(0.1103)
FORD	29	0.5801	0.1244	0.1334	2.869	(0.1063)
CHRYS	10	0.8472	-0.0837	0.1481	0.2492	(0.0312)
DOM	113	0.6040	0.1102	0.0927	11.37	(0.1024)
IMP	105	0.5020	0.0615	0.0482	14.02	(0.1362)

*All Honda's
**Mostly 80 GM 2.5L & Fuji
***All GM, Nissan 2.0L

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
CARB = open-loop carburetted
FI = fuel injected (multi-point)
AIR = secondary air injection
DOM = domestic manufacturers
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year
CARC = closed-loop carburetted
TBI = throttle-body fuel injected
EGR = exhaust gas recirculation
IMP = import vehicle manufacturers

This level of stratification (two model year groups, each with six fuel/air combinations) produced some small subfleet sizes. This was particularly true for open-loop carbureted vehicles without air injection (all Honda's); closed-loop carbureted vehicles without air injection (all GM 2.5 liter engines and Subaru's); and fuel-injected vehicles with air injection (all GM TBI and Nissan 2.0 liter engines). The regression lines calculated for the first two groups are not unreasonable from a technical perspective; in addition, the combined size of these two groups is less than 6% of the total fleet throughout the 1980's, meaning they will not play a dominant role in the technology-weighted results. However, the last category (FI with air) presents some anomalous results - such as initial (zero mile) emissions exceeding the applicable standards, with a significant drop in emissions as mileage increases (1980 MY); or a negative intercept with an unusually high slope (1981-82 MY). Although it is not uncommon to see a slight negative slope for NOx emissions on pre-catalyst and oxidation catalyst vehicles, there is no technical basis to explain this phenomenom for HC or CO emissions. Therefore, given these anomalous results, and given EEA's projection that this technology combination could represent 20% of California's new car sales by 1990, the data for all fuel-injected vehicles were combined into one category.

The final set of emission factors recommended for use is presented in Table 14 (for the 1980 model year), and in Tables 15, 16, and 17 (for 1981 and later models). The final RSS for these equations are as follows:

	Residual Sum of Squares		
	HC	CO	NOx
Total fleet	304.1	146,900	109.7
Final Stratification	293.4	141.434	95.5
Reduction in RSS	4%	4%	13%

Table 14

Summary of Results
1980 Model Year
Passenger Cars - Gasoline

CONTROL SYSTEM	FLEET FRACTION	ZERO MILE	DETERIORATION RATE	50 K VALUE	100 K VALUE
		Hydrocarbons			
OPEN LOOP CARB W/AIR	0.256	0.2159	0.1896	1.16	2.11
OPEN LOOP CARB W/O AIR	0.044	0.3260	0.0711	0.68	1.04
CLOSED LOOP CARB W/AIR	0.352	0.7743	0.0292	0.92	1.07
CLOSED LOOP CARB WO/AIR	0.078	0.4922	0.0730	0.86	1.22
FI (ALL)	0.270	0.3382	0.1237	0.96	1.58
FLEET AVERAGE		0.4719	0.1010	0.98	1.48
		Carbon Monoxide			
OPEN LOOP CARB W/AIR	0.256	2.739	3.675	21.11	39.49
OPEN LOOP CARB W/O AIR	0.044	4.669	-0.3259	3.04	1.41
CLOSED LOOP CARB W/AIR	0.352	13.17	0.6273	16.31	19.44
CLOSED LOOP CARB WO/AIR	0.078	10.76	0.7688	14.60	18.45
FI (ALL)	0.270	9.674	1.334	16.34	23.01
FLEET AVERAGE		8.9937	1.5674	16.83	24.67
		Oxides of Nitrogen			
OPEN LOOP CARB W/AIR	0.256	1.021	-0.0198	0.92	0.82
OPEN LOOP CARB W/O AIR	0.044	1.415	-0.1254	0.79	0.16
CLOSED LOOP CARB W/AIR	0.352	0.8538	0.0652	1.18	1.51
CLOSED LOOP CARB WO/AIR	0.078	0.6858	0.2018	1.69	2.70
FI (ALL)	0.270	0.7277	0.1459	1.46	2.19
FLEET AVERAGE		0.8741	0.0675	1.21	1.55

Table 15

Summary of Results
1981 and Later Model Years
Passenger Cars - Gasoline

Hydrocarbons

CONTROL SYSTEM	ZERO MILE	DET. RATE	FLEET FRACTIONS 1981-2	1983	1984	1985-6	1987-9	1990+
OPEN LOOP CARB W/AIR	0.1884	0.1458	0.294	0.243	0.063	0.040	0.000	0.000
OPEN LOOP CARB W/AIR	0.3124	0.0257	0.024	0.007	0.006	0.008	0.016	0.020
CLOSED LOOP CARB W/AIR	0.0179	0.2686	0.436	0.346	0.436	0.296	0.229	0.163
CLOSED LOOP CARB WO/AIR	0.1929	0.0572	0.000	0.049	0.038	0.051	0.046	0.028
FI (ALL)	0.3927	0.1250	0.246	0.356	0.459	0.604	0.709	0.788
			1.000	1.001	1.002	0.999	1.000	0.999

FLEET AVERAGES:	1981-2	1983	1984	1985-6	1987-9	1990+
ZERO MILE	0.1673	0.2032	0.2087	0.2626	0.2964	0.3243
DETERIORATION RATE	0.1913	0.1757	0.1856	0.1641	0.1532	0.1445
50K VALUE	1.12	1.08	1.14	1.08	1.06	1.05
100K VALUE	2.08	1.96	2.06	1.90	1.83	1.77

Table 16

Summary of Results
1981 and Later Model Years
Passenger Cars - Gasoline

Carbon Monoxide

CONTROL SYSTEM	ZERO MILE	DET. RATE	FLEET FRACTIONS 1981-2	1983	1984	1985-6	1987-9	1990+
OPEN LOOP CARB W/AIR	3.205	1.630	0.294	0.243	0.063	0.040	0.000	0.000
OPEN LOOP CARB W/AIR	2.799	0.5594	0.024	0.007	0.006	0.008	0.016	0.020
CLOSED LOOP CARB W/AIR	1.100	3.365	0.436	0.346	0.436	0.296	0.229	0.163
CLOSED LOOP CARB WO/AIR	2.486	0.6397	0.000	0.049	0.038	0.051	0.046	0.028
FI (ALL)	3.839	4.073	0.246	0.356	0.459	0.604	0.709	0.788
			1.000	1.001	1.002	0.999	1.000	0.999

FLEET AVERAGES:	1981-2	1983	1984	1985-6	1987-9	1990+
ZERO MILE	2.4334	2.6648	2.5498	2.9247	3.1329	3.3334
DETERIORATION RATE	2.9617	3.0426	3.4601	3.5620	3.6967	3.7909
50K VALUE	17.24	17.88	19.85	20.73	21.62	22.29
100K VALUE	32.05	33.09	37.15	38.54	40.10	41.24

Table 17

Summary of Results
1981 and Later Model Years
Passenger Cars - Gasoline

Oxides of Nitrogen

CONTROL SYSTEM	ZERO MILE	DET. RATE	FLEET FRACTIONS 1981-2	1983	1984	1985-6	1987-9	1990+
OPEN LOOP CARB W/AIR	0.6592	-0.0061	0.294	0.243	0.063	0.040	0.000	0.000
OPEN LOOP CARB W/AIR	0.6170	-0.0337	0.024	0.007	0.006	0.008	0.016	0.020
CLOSED LOOP CARB W/AIR	0.5456	0.1199	0.436	0.346	0.436	0.296	0.229	0.163
CLOSED LOOP CARB WO/AIR	0.4368	0.1469	0.000	0.049	0.038	0.051	0.046	0.028
FI (ALL)	0.5037	0.1305	0.246	0.356	0.459	0.604	0.709	0.788
			1.000	1.001	1.002	0.999	1.000	0.999

FLEET AVERAGES:	1981-2	1983	1984	1985-6	1987-9	1990+
ZERO MILE	0.5704	0.5534	0.5299	0.5198	0.5120	0.5109
DETERIORATION RATE	0.0818	0.0933	0.1169	0.1214	0.1262	0.1259
50K VALUE	0.98	1.02	1.11	1.13	1.14	1.44
100K VALUE	1.39	1.49	1.70	1.73	1.77	1.77

These reductions are quite small for HC and CO; were it not for the technical rationale for stratifying the data, it might be just as proper to use a single regression line for all 1980 and later model cars. This exercise should be repeated each year, as CARB collects additional data. Either a more significant reduction in RSS should be observed, or alternative stratification schemes should be evaluated.

B. Light Duty Trucks

The initial regression results for light duty trucks are shown in Table 18. The analysis of RSS for these regressions indicated the following:

	Residual Sum of Squares		
	HC	CO	NOx
Total fleet	32.67	15,770	47.47
Model Year Stratification	30.80	14,747	33.59
Two-Step MY Stratification	31.16	15,320	36.07

Table 18

Technology Based Regressions
for
Light-Duty Trucks

		N	ZM	DR	r^2	RSS	(MS)
ALL	HC	70	0.3741	0.1221	0.0822	32.67	(0.4805)
	CO	70	5.873	1.928	0.0442	15,770	(231.9)
	NOx	70	0.9092	0.1714	0.1083	47.47	(0.6981)
MY 80	HC	29	0.3794	0.1729	0.1151	21.64	(0.8017)
	CO	29	3.926	3.231	0.1014	8,717	(322.9)
	NOx	29	1.334	0.1903	0.1232	24.27	(0.8990)
MY 81	HC	27	0.3169	0.0771	0.1127	4.089	(0.1636)
	CO	27	4.509	0.9225	0.0664	1,047	(41.87)
	NOx	27	0.8354	0.0648	0.0814	4.146	(0.1658)
MY 82	HC	14	0.5804	0.0458	0.0050	5.069	(0.4224)
	CO	14	12.55	0.9099	0.0020	4,983	(415.2)
	NOx	14	-0.2087	0.5476	0.4135	5.171	(0.4309)
MY 81/82	HC	41	0.4109	0.0659	0.0442	9.515	(0.2440)
	CO	41	7.969	0.6204	0.0059	6,612	(169.5)
	NOx	41	0.6889	0.1235	0.1155	11.80	(0.3027)

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
MY = model year

Due to the small total sample size (only 70 vehicles), the only stratification possible was by model year. As the regression lines indicate, there seems to be significant differences between the three model years (see particularly the deterioration rates). A model year stratification reduces the RSS by 6% for HC and CO, and by 29% for NOx. However, due to the small sample size for the 1982 MY, the NOx regression intercept is negative for that year. Therefore, we recommend that the 1981-82 data for NOx be combined to develop a single factor for those years.

For future model years, we are confronted with two alternatives. The first is to use the 1981-82 truck regressions and adjust them for the change in emission standards which occurred in 1983. The alternative would be to extrapolate passenger car data from a period in which the standards were comparable to those in effect for 1983 and newer model trucks. Given the changes in technology which were observed in the 1983 truck fleet (especially the increasing use of closed loop three-way catalyst systems), the latter approach is recommended. The final emission factors for light duty trucks are shown in Table 19. The 1981-82 passenger car factors were used for 1983 and later model light duty trucks, with the HC intercept adjusted upward by 0.1 gm/mi and the NOx intercept adjusted upward by 0.3 gm/mi to reflect the differences in emission standards for the two types of vehicles.

C. Diesel Passenger Cars

The CARB data base included a total of only 48 Diesel passenger cars. The only meaningful stratification for these vehicles is based on the use of exhaust gas recirculation (EGR). The technology based regression for Diesels is shown in Table 20. The data indicate the following benefits to stratifying the sample for these vehicles:

	Residual Sum of Squares		
	HC	CO	NOx
Total fleet	1.183	5.323	8.225
EGR Stratification	1.182	4.933	7.834

Table 19

Summary of Results
Light-Duty Trucks

Model Year	Zero Mile	Deterioration Rate	50K Value	100K Value
		Hydrocarbons		
1980	0.3794	0.1729	1.24	2.11
1981	0.3169	0.0771	0.70	1.09
1982	0.5804	0.0458	0.81	1.04
1983+	0.2673	0.1913	1.22	2.18
		Carbon Monoxide		
1980	3.926	3.231	20.08	36.24
1981	4.509	0.9225	9.12	13.73
1982	12.55	0.9099	17.10	21.65
1983+	2.4334	2.9617	17.24	32.05
		Oxides of Nitrogen		
1980	1.3334	0.1903	2.29	3.24
1981	0.6889	0.1235	1.31	1.92
1982	0.6889	0.1235	1.31	1.92
1983+	0.8704	0.0818	1.28	1.69

Table 20

Technology Based Regressions
for
Diesel Passenger Cars

Oxides of Nitrogen

		N	ZM	DR	r^2	RSS	(MS)
ALL VEHICLES	HC	48	0.1275	0.0406	0.2706	1.183	(0.0257)
	CO	48	1.004	0.0439	0.088	5.323	(0.1157)
	NOx	48	1.249	0.0479	0.069	8.225	(0.1788
W/O EGR	HC	15	0.1075	0.0444	0.425	0.1748	(0.0135)
	CO	15	0.6505	0.982	0.280	1.623	(0.1249)
	NOx	15	1.246	0.0241	0.016	2.311	(0.1778)
W/EGR	HC	33	0.133	0.0393	0.2338	1.007	(0.0349)
	CO	33	1.105	0.0296	0.050	3.310	(0.1068)
	NOx	33	1.246	0.0612	0.118	5.523	(0.1782)

Legend:

N = sample size
DR = deterioration rate (gm/mile/10K miles)(slope)
MS = mean square
ZM = zero mile value (intercept)
r^2 = correlation coefficient
RSS = residual sum of squares
EGR = exhaust gas recirculation

For the 1980 through 1983 model years, EGR systems were gradually phased in by most Diesel car manufacturers. Using actual production data, CARB combined the two regression equations for each model year to develop the final emission factors.

For 1984 and later model years, all vehicle manufacturers used some kind of EGR system to meet California's standards. Consequently, the "with EGR" factors represent the final recommendation; the NOx factor intercept is reduced by 0.5 gm/mi to reflect the standard change which took effect in 1984.