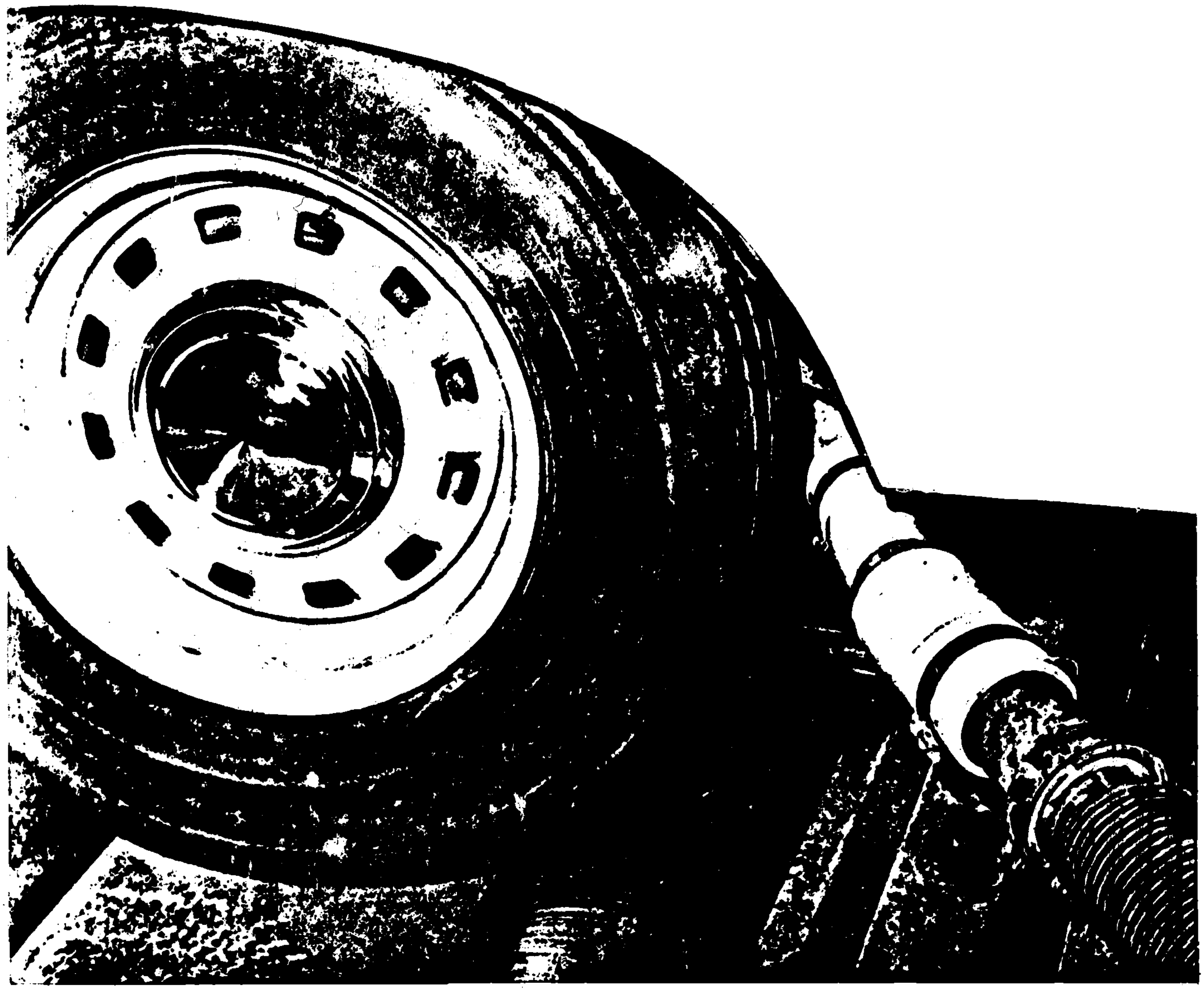
Automobile Emission Control - The State of the Art as of December 1972

a report to
the Administrator,
Environmental Protection Agency

prepared by
Division of Emission Control Technology,
Mobile Source Pollution Control Program,
Office of Air and Water Programs,
Environmental Protection Agency



AUTOMOBILE EMISSION CONTROL

THE STATE OF THE ART

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CONTENTS

CONTENTS (Continued)

SECTION 1

ABSTRACT

This report contains a summary and evaluation of information and data reported individually to EPA by 20 different automobile manufacturers and other organizations involved in the development of emission control technology.

This report describes the state of the art in automobile emission control technology as of the time frame in which the report was written and the data reported. Most of the information used to prepare this report came from status reports submitted to EPA by the 20 manufacturers in response to a letter sent to them from EPA on September 8, 1972. Most of the status reports were received in the time period of November-December 1972. Therefore, most of the data is characteristic of the state of the art at/or before December 1972.

This report covers the emission control systems planned for use in model year 1975 and 1976, results of the durability testing reported to date, the significant technical problem areas, and the development status of the industry with respect to model years 1975 and 1976.

This report is a companion document to a similar report 1/ prepared last year by the Division of Emission Control Technology. This report is somewhat different in scope than the earlier report, being essentially a description of the current state of the art and the progress made in the last year, while last year's report had, in addition to information similar to that included in this report, a description and explanation of various types of emission control devices. If the reader

1/ Automobile Emission Control--A Technology Assessment as of December 1971 of this report is unfamiliar with either the terminology used or the emission control devices discussed in this report, he is referred to Sections 2.2, 2.3, 4 and 5 of last year's report.

This report contains conclusions about the ability of manufacturers to certify vehicles in model years 1975 and 1976.

SECTION 2

SUMMARY AND CONCLUSIONS

The purpose of this report is to summarize and discuss the state of the art in automobile emission control technology.

The approach used in preparing this report was to obtain information from manufacturers concerning the status of their development programs; review and analyze the reported information; and, based on the review of the data, assess and report the state of the art in emission control technology. Discussion of the state of the art is reported on an industry-wide basis and on an individual manufacturer basis. A copy of the letter requesting the data from the manufacturers can be found in the Appendix. Twenty (20) manufacturers responded to the request for information.

2.1 Summary Estimate of Manufacturers' Ability to Meet the 1975 and 1976 Standards

The current state of the art of emission control technology is such that a wide range of both technical approach and technical achievement exists among the 20 manufacturers discussed in this report.

The technical approaches reported by the 20 manufacturers have been grouped into two classes, catalytic systems and non-catalytic systems. The manufacturers who are developing catalytic systems have been further subdivided into classes based on EPA judgment of their relative accomplishments as of the time the information was received. These subdivisions represent above average, average, and below average demonstrations of the technology necessary to certify vehicles for model year 1975 and 1976. The non-catalytic systems have not been subdivided and are judged to be equal demonstrations of technical accomplishment.

For model year 1975 the classes are:

75-1 Non-Catalytic Approach

Three manufacturers are in this class: Honda, with their CVCC engine, Toyo Kogyo with their rotary engine + thermal reactor and Daimler-Benz with their Diesel engine. None of these emission control systems use a catalyst or require unleaded gasoline. All have demonstrated emission levels below 1975 requirements, Honda and Toyo Kogyo having reported satisfactory 50,000-mile durability data. The manufacturers in this class are predicted to be able to certify the above-mentioned approaches for model year 1975. These manufacturers currently comprise less than 1% of the U. S. market. There is little information upon which to base predictions of their market share in 1975, but it will probably remain small.

75-2.1 Catalytic System Approach - Above Average Development Status

Three manufacturers were judged to be in this class, GM, Chrysler and Ford. These manufacturers have demonstrated emission control achievements with the "typical" 1975-type control system (engine mods, air injection, EGR and oxidation catalysts) that is superior to other manufacturers developing the same generic system. All of these systems require unleaded fuel. These manufacturers, in the judgment of the report team, will probably be able to certify for model year 1975. The manufacturers in this group currently comprise about 85% of the U. S. market. Their share of the U. S. market in 1975 is assumed to be very nearly the same. Their market share depends on the performance of the manufacturers in the next two classes, and what fraction of their model lines the three manufacturers are able to successfully certify for model year 1975.

75-2.2 Catalytic System Approach - Average Development Status

This class of manufacturers is the largest in number, 11 manufacturers being included. This class is also the most variable in technical achievement, with some manufacturers ranking close to class 2 and some ranking nearly in class 3. In alphabetical order, these manufacturers are AMC, BMW, Daimler-Benz (gasoline), Fuji, Mitsubishi, Nissan, Peugeot, Toyota, Saab, Volkswagen and Volvo. The ability of these manufacturers to certify for model year 1975, in the opinion of the report team, remains in question. Currently, these manufacturers constitute approximately 13% of the U. S. market. The market share of this class in 1975 will depend on the ability of the individual manufacturers to certify.

75-2.3 Catalytic System Approach - Below Average Development Status

There are three manufacturers in this class, Alfa Romeo, British Leyland (BLMC) and International Harvester. Their ability to certify for model year 1975 is considered unlikely. Currently these manufacturers constitute less than 2% of the U. S. market. What their market percentage will be in 1975 is not known as their projected ability to certify is presently highly uncertain.

For model year 1976 the classes are:

76-1 Non-Catalytic Approach

There are three manufacturers in this class, Honda, Toyo Kogyo and Daimler-Benz (Diesel). All three have demonstrated control below or very close to the 1976 levels without use of any catalyst but no durability data has yet been reported. Considering the poor performance of NO_x catalysts reported to date, this alone puts these manufacturers in a somewhat more favorable position than the other two classes. These manufacturers may be able to certify for model year 1976. Their share of the market is discussed under class 75-1.

76-2.1 Catalytic System Approach - Average Development Status

This class is representative of the current industry-wide capability. These manufacturers are developing systems that use catalysts to control HC, CO and NO_x. All of the manufacturers in classes 75-2.1 and 75-2.2 plus BLMC fall into this category. These sixteen manufacturers currently have 98% of the U. S. market. The ability of this class to certify for model year 1976 is judged questionable.

76-2.2 Catalytic System Approach - Below Average Development Status

This class includes Alfa Romeo and International Harvester. The same comments used for this class for 1975 apply for 1976 as well.

2.2 Conclusions on the Status of Technology for Meeting the 1975 and 1976 Standards

Implicit in the conclusions listed below are three assumptions:

1. Unleaded fuel averaging less than .05 grams per gallon (gpg) lead content will be available for model year 1975-76 vehicles.

2. The certification procedure for model year 1975 would remain the same as it is currently, with the following exceptions. In addition to catalyst replacement and EGR maintenance being allowed, the manufacturers will be required to run certification on fuel of a minimum of .03 gpg lead content, assumed to be representative of the average lead content in the field.

3. Vehicles owned and operated by the public will continue to receive the same maintenance, both in frequency and quality, as is the case today. This means that vehicle owners will continue to obtain vehicle maintenance that affects emission performance only when something is noticeably wrong with the vehicles and when the vehicles are maintained the owner will only be concerned about the things that are noticeably wrong. No assumptions about the possible success of state inspection plans in changing the habits of the average motorist were made, since those programs are as yet undeveloped.

The conclusions listed below apply at the time that this report was written. In an area such as emission control technology where such rapid progress is continually being made, the time frame in which conclusions are made must be kept in mind. New developments may be reported that would require the conclusions listed below to be modified. For example, the significant achievements obtained by Honda were announced during the preparation of this report. Very little was known about the concept prior to Honda's disclosure.

The EPA report team concludes:

1. If EPA does not adopt averaging of the emissions from vehicles for assembly line testing and warranty/recall purposes, then only one manufacturer (Honda) would be predicted to even have a chance to comply with all the emission requirements for model year 1975.

2. If EPA adopts the averaging of emissions from vehicles in a given engine family to determine compliance with the assembly line test and warranty/recall provisions of the

Clean Air Act, then manufacturers currently representing at least 85% of the current U. S. market will probably be able to certify vehicles that comply with all requirements related to meeting the 1975 standards.

3. The state of the art with respect to the dual catalyst emission control systems favored by most manufacturers being developed in an attempt to meet the 1976 standards, is not as advanced as was the development of 1975-type emission control systems last year at this time.

4. The major industry-wide technical problem with 1976 emission control system development is the same now as it was one year ago, the absence of an acceptable NO_x catalyst.

5. Three non-catalytic systems have demonstrated the emission control required to meet the 1975 standards. Two non-catalytic systems (Honda CVCC and Toyo Kogyo rotary) have demonstrated 50,000-mile durability at or below the 1975 emission requirements. The emission performance of these two systems has been verified by tests at the EPA laboratory in Ann Arbor. The three non-catalytic systems have potential to meet the 1976 standards. Some catalytic systems are expected to meet the 1975 standards. The dual catalyst approach favored by most manufacturers appears, at this point in time, to have less potential for meeting the 1976 standards than do the non-catalytic systems.

6. The catalytic emission control system that has so far achieved the 1976 emission levels for the greatest number of miles is not a typical dual catalyst system and is being developed and demonstrated by a supplier to the automobile industry.

7. The on-the-road emissions from 1975 vehicles may be somewhat higher than the standards against which prototype vehicles are certified, because of limited assurance, at this point in time, that vehicles will be maintained and operated as carefully as may be necessary to have them continue to meet the standards. This issue will become far more important as regards 1976 systems, since the HC and CO emissions from a 1976 system may even exceed the HC and CO emissions from uncontrolled vehicles, if catalytic control of emissions fails in service.

2.3 Discussion of Conclusions

Conclusions 1 and 2 reflect the difference that the averaging of emissions makes. It is recognized that there are important legal and policy implications in the ultimate EPA position on averaging, but those issues are beyond the scope of this report. Conclusions 1 and 2 indicate only what the assumptions of allowing or not allowing averaging mean with respect to the technical capability of the industry to comply.

Conclusions 3, 4, 5, and 6 indicate that significant improvements in the area of NO_x catalyst technology are still required if the dual catalyst approach favored at this point in time by most manufacturers is to be successful.

There are three main reasons for conclusion 7. First, the current EPA durability mileage accumulation schedule is probably not as rigorous a test for catalytic emission control systems as it is for non-catalytic emission control systems. Since catalytic systems are thus not subjected to the same degree of stress in certification testing that they may be in actual service, especially with respect to heavy loads and concurrent high exhaust temperatures, it must be assumed that the performance of catalysts on the road may not be as good. Second, there is less than complete assurance at this point in time that vehicle owners will be effectively required to perform all the maintenance that may be needed to keep 1975 emission control systems operating properly. Third, the actual average lifetime of automobiles is about 85,000 miles, as contrasted to the 50,000-mile "useful" life of the current regulations. There are no current Federal regulations for control of emissions from automobiles beyond 50,000 miles.

SECTION 3

INDUSTRY STATUS - 1975 DEVELOPMENT

3.1 Systems to be Used for Model Year 1975 Compliance and the Constraints Influencing Their Design

Systems to be Used

The predominant emission control system planned for use in model year 1975 by the automobile manufacturers is the system employing engine modifications, exhaust gas recirculation, air injection, and an oxidation catalyst.

The engine modifications planned for use in model year 1975, compared to an uncontrolled vehicle, involve modifications to permit operation with lead-free fuel, intake and carburetor system modifications, spark timing and control modifications, and combustion chamber and exhaust port modifications.

The modifications to permit operation on lead-free fuel are, primarily, lowering the compression ratio to allow use of 91-octane fuel which is assumed to be the principal octane level with unleaded fuel, and the introduction of hardened valve seats to prevent valve seal recession.

Many manufacturers have already incorporated these engine modifications, and virtually all manufacturers will have instituted these change by model year 1974.

The intake system and carburetion modifications involve three basic changes: quick release chokes, improved carburetors, and quick heat manifolds.

The purpose of quick release chokes is to provide just enough choking to get the engine started. This tends to minimize the CO emissions during the cold start portion of the emission test when most of the CO and HC are formed. Conventional chokes are not satisfactory because they are too erratic in operation and they maintain choking action for too long a period of time after the engine is started.

The carburetor improvements scheduled for model year 1975 are in the area of fuel metering. The air/fuel ratio must be controlled more precisely than current practice and some manufacturers are planning to employ altitude-compensated carburetors, which automatically adjust the mixture depending on the barometric pressure.

The quick heat or "stove" manifolds provide two advantages. They provide better fuel evaporation during the cold start portion of the emissions test, thus helping to minimize CO emissions, and they also tend to improve cold engine drive-ability by providing a better mixture to the cylinders quicker than conventional systems.

The advanced induction and carburetion systems are not yet in production. Because of the long lead times necessary for the casting of intake manifolds, current prototype durability fleets of the manufacturers are not all equipped with quick heat manifolds. The advanced carburetors are also just becoming available in a production-like form. Many manufacturers are currently testing modified current production carburetors.

The spark timing and control modifications in many cases involve use of electronic ignition systems. These systems provide better and more reliable ignition. Some manufacturers are already mass producing these systems. The spark timing and advance will be similar to current (1973) model year calibrations.

The combustion chamber and exhaust port modifications, compared to an uncontrolled vehicle, are made to optimize the surface-to-volume ratio and to conserve exhaust heat, respectively.

Manufacturers have already made the combustion chamber changes, but the exhaust port changes, for example, shorter exhaust ports or exhaust ports with liners, are not generally in production now.

The exhaust gas recirculation systems planned for use in 1975 are for the most part, similar to those in use on current (1973) models. Some manufacturers are developing more sophisticated systems that match engine air flow requirements in a proportional manner, but since these type systems may not be necessary to meet the 1975 Federal NO_x standard of 3.1 grams per mile they may not be used nationwide.

The air injection systems for 1975 are similar to the existing systems but may differ in application. Since the catalytic converters may need more air than can be provided by conventional pumps, designers have two options: drive the existing pumps faster or use pumps with greater displacement. Since most development vehicles use current pumps with a greater drive ratio and have had durability problems,the trend at this time is to favor larger pumps.

The oxidation catalyst is the component of the 1975 emission control system that is the most different from current (1973) emission control systems. The most favored type of oxidation catalyst for use in 1975 systems is the precious metal monolith. Precious metal refers to the type of active material (the actual catalyst). These metals include the chemical elements of the platinum group: Platinum, palladium, osmium, iridium, rhodium and ruthenium. Most catalyst active materials for automobile application mainly contain varying proportions of platinum and palladium as active materials. The term "monolith" refers to the structure of the substrate upon which the washcoat and active material are placed. Monolithic structures are one piece, with passages through which the exhaust passes. They differ from the bead type, which are a large number of separate beads or pellets around which the exhaust gas flows. Some manufacturers are still considering bead catalysts with base (non-precious) metals as active materials, but most manufacturers now consider the precious metal monolith as a more optimum choice.

There is another kind of catalyst being considered for application in 1975. This type of catalyst is known as "promoted base metal." Typically, this is a base metal pellet catalyst containing a very small amount of precious metal to promote the catalytic reaction. These types of catalysts may offer some advantages over other types of catalysts. They may be more efficient than base metal catalysts, and they may be cheaper than precious metal catalysts. General Motors is the manufacturer doing the most extensive development and testing work in this area.

The above-mentioned components and subsystems constitute what will be referred to in this report as a typical 1975-type emission control system.

Some manufacturers are not planning to use typical 1975-type emission control systems on all their vehicles. These systems are discussed in section 6 in the individual manufacturers' reviews. The manufacturers are Honda, Daimler-Benz (Mercedes), and Toyo Kogyo.

The costs for 1975 emission control systems, and the fuel economy penalties associated with their use vary greatly. Cost estimates from the manufacturers range from a low of $100 to a high of $1500, compared to a 1973 vehicle. The fuel economy penalty anticipated by the manufacturers ranges from none to a 45% increase. Discussion of the manufacturers'cost and fuel economy estimates can be found in the individual manufacturer's reviews. Part of the reason for the wide spread in the anticipated fuel economy penalty reported may be the lack of a standardized industry-wide procedure for measuring and reporting fuel economy.

Constraints Influencing the Design of 1975 Emission Control Systems

Acceptable emission performance is not the only requirement that the modern automobile must meet. Federal safety requirements and other requirements imposed by the manufacturers themselves must also be met by the vehicle designers. It is beyond the scope of this report to discuss all of the constraints involved in the design of the modern automobile. For example, there are constraints placed on the vehicle designer for the purposes of making the ultimate vehicle more attractive to the potential buyer. These constraints should not be considered unimportant, however, since the safest and cleanest automobile would be of no use if the buying public rejected them in preference to older, presumably less safe and less clean vehicles.

The constraints that are within the scope of this report are the constraints that affect the design of the emission control system.

The major 1975 design constraints are: Cost, performance, driveability, packaging, fuel economy, compatibility with 1976 requirements, applicability to all models, and lead time. When emission performance and system durability affect the above-mentioned parameters greatly, compromises have to be made.

The automobile industry is extremely cost conscious. The types of costs that are considered most important are the projected manufacturing costs and retail price. The projected manufacturing costs are pertinent to this discussion. Automobile manufacturers have staffs whose sole job is to estimate production costs for items. These cost estimates are quite detailed, involving estimating costs down to fractions of a cent per part. Considering the total number of parts produced yearly, (pistons, for example, are produced in quantities of greater than 50 million annually), the need for accurate cost predictions is clear. Cost information of this type is considered highly confidential by the industry.

No manufacturer has indicated to EPA that an absolute cost ceiling has been placed on the 1975-type emission control system. However, cost is certainly one major constraint on the acceptability of any given design. Non-precious metal catalysts have received much attention for this reason.

Vehicle performance and driveability are other parameters than can impose constraints on the emission control system. For example, the desire to maintain vehicle acceleration and driveability at or near current levels can cause compromises in such emission control system areas as EGR flow rate, carburetor calibration, spark advance, and catalyst design (backpressure), among others.

Packaging is a constraint that currently primarily affects the design of the catalytic converter. Because of the desire of most manufacturers to make as few changes as possible to the existing vehicles, the design of the catalytic converter has been constrained to a great degree by the space available. This has influenced the choice of the catalyst material, and the size, shape and positioning of the catalyst relative to the exhaust manifolds.

Fuel economy is a design constraint that affects the EGR system design, the spark advance and timing selection, the choice of the air pump and catalytic converter design. Most manufacturers appear to have accepted as inevitable the small losses due to the air pump and the increased exhaust backpressure due to the catalyst but are still working to minimize the losses due to the EGR and spark retard.

Compatability with the requirements for both 1975 and 1976 is another constraint. Systems which have promise to meet the 1975 standards, but which, in the opinion of the manufacturers, have little or no chance to meet the 1976 NO_x requirement, have been abandoned, or not fully investigated. It makes little sense to the manufacturers to have a "one year" system. Such an approach would be very expensive and disruptive to the normal design, development and production cycle.

Another more recent constraint on the design of emission control systems is related to EPA's recent policy decisions regarding defeat devices and emission control system modulating devices. Since the information supplied by the manufacturers on the status of their 1975/76 developments was submitted before the public hearings on emission control system modulating devices, little specific information regarding these types of devices was included. It is the opinion of the report team, however, that the manufacturers are now carefully reviewing their 1975/76 designs in the light of the EPA policy on defeat devices, especially catalyst bypass systems.

Manufacturers are extremely interested in systems that can be applied across their current model line. They are reluctant to develop systems that have limited application, especially if the systems cannot be used on some of their current models.

Lead time is also another constraint. Better systems, if they cannot be produced in time to meet the statutory deadline, have received little or reduced emphasis. One of the results of this time constraint is that the manufacturers have not seriously considered unconventional propulsion systems for model year 1975, except for the rotary engine.

How and why a given manufacturer gives more or less weight to each of these constraints results in a design philosophy for the emission control system. Which contraints are considered most important, which less important, and how much emission control capability is sacrificed because of these constraints varies from manufacturer to manufacturer. No manufacturer has provided quantitative information concerning how these tradeoffs are made, the reasons for making them, and how much emission control may have been sacrificed.

3.2 Durability Testing Programs

Durability of 1975-type emission control systems was identified as a major problem area over a year ago. The ability of emission control systems, especially the catalysts, to remain effective for the required 50,000-mile AMA durability schedule remains a major problem area for some manufacturers. For this reason, the experimental test programs that the manufacturers are conducting to assess the durability of their 1975 prototype vehicles are extremely important.

Generally, manufacturers have to undertake two types of durability testing. The first type is the AMA-type 50,000-mile schedule. This is the schedule that is used by EPA to calculate the deterioration factor from the manufacturer's durability fleet vehicles. This deterioration factor (DF) is then applied to the 4,000-mile emissions from the manufacturer's emission data fleet. Since the manufacturers must comply with the EPA requirements to be able to sell vehicles, the performance of the emission control systems on AMA durability has to be known. For this reason, many manufacturers conduct "mock certification" AMA durability runs prior to the official certification runs to be sure that their vehicles will be able to comply.

The second type of durability testing done by the manufacturers is the usual product acceptance testing. Automobile manufacturers have spent much time and money in trying to develop test procedures that will duplicate the wide range of usage that automobiles encounter once they are sold. In an attempt to duplicate the use (and abuse) to which customer-operated vehicles are subjected, the manufacturers perform many tests at high speeds and loads, under arctic and tropical temperature conditions, over many different road conditions, and under many different types of driver treatment. This type of testing has historically been performed to ensure customer acceptability and to uncover durability problems which might result in unacceptable warranty costs.

The warranty and recall provisions of the Clean Air Act have caused this type of testing to take on added importance. The manufacturers are concerned about the costs and negative publicity that might result from recall programs that may result from failures in the field. Recalls for emission control system failures may be even more expensive than the past recalls for safety-related items have been, since the causes may not be as evident and the labor, parts, and testing costs may be high.

The type of durability testing given the most emphasis in this report is the AMA durability. There is much more data available on this type of durability schedule, and data from the other types of durability schedules may not be directly comparable among manufacturers.

There is a wide spread in the scope and type of durability test programs on 1975 prototype vehicles that have been reported to EPA. While some manufacturers have not reported that any vehicles are currently being durability tested, other manufacturers have reported that extensive fleets of vehicles are running. Manufacturers also vary in the rate at which mileage is accumulated, some finishing the 50,000 miles in a period of time close to the minimum, others taking much longer.

The number and type of vehicles in any given manufacturer's durability fleet appear to be in most cases a result of cost constraints and prototype parts availability, rather than the result of a thorough and comprehensive analysis of what is actually needed to demonstrate the ability or inability of a system to certify for model year 1975.

3.3 Catalyst Screening Programs

The screening of oxidation catalysts for possible use in model year 1975 is not as active now as it was a year ago. The major reason is lead time. For a new catalyst to successfully pass the laboratory activity and aging tests, the dynamometer durability tests and the 50,000-mile vehicle tests, the amount of required time is sufficiently long to make it doubtful, at this point in time, that even the so-called "magic bullet" (a catalyst with no problems) could get through the testing process in time for use in model year 1975 with job one starting at the usual time.

Some manufacturers, however, may still be screening catalysts and/or substrates of their own preparation, because of the cost savings to them if either catalysts or substrates are made in-house. Since some manufacturers are also becoming more proficient in the catalyst/substrate art, they are seriously considering being their own source of catalyst or substrate.

3.4 Lead Time for 1975 Production and an Identification of the Critical Items

The lead time information in this report came primarily from two sources. The first source is a study done for EPA by the

Aerospace Corporation.[2/] This study is an independent analysis of the lead time issue with information concerning lead time being obtained from catalyst suppliers, substrate suppliers, parts suppliers, machinery suppliers, and tool suppliers. The major domestic automobile manufacturers also supplied information. The study was primarily limited to domestic manufacturers and suppliers. The other source of information concerning lead time was the responses sent to EPA by foreign and domestic manufacturers on the status of their 1975 development.

The period of time encompassing the last two months of 1972 appears to be a watershed period with respect to lead time. If certain commitments have not been made by about the first of the year (1973) then it will be very difficult for the manufacturers who have not made commitments to be able to meet the usual "job one" date (July-August) in 1974, for the 1975 models.

The main lead time problem for model year 1975 is the problem of creating an entirely new supplier industry for the automobile industry. This new supplier industry complex is the industry that will have to produce the needed components for the catalytic converters to be used by most of the automobile manufacturers. This group of suppliers can be subdivided into four functional groups. Some suppliers may perform more than one function.

The first group is the raw material producers. The most important raw material producers are those that produce precious metals, especially platinum and palladium. To

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2/ Assessment of Domestic Automotive Industry Production Lead Time for 1975/76 Model Years The Aerospace Corporation, 15 December, 1972.

meet the demand for the precious metals which are the active materials in the type of oxidation catalyst most likely to be used for model year 1975, the production of the platinum mines will have to be increased.

The second group is the catalyst substrate producers. These producers are going to be making an entirely new product, in very large quantities. The substrate manufacturers will most likely have to construct new manufacturing facilities, or extensively modify existing facilities.

The third group is the catalyst producers. These producers will also need new facilities to coat the substrates with a high surface area washcoat and then to apply the actual active catalyst materials.

The fourth group is the catalyst container producers. After the catalyst substrate has been washcoated and activated, it must be installed in a container that is inserted into the exhaust pipe. This group will also have to install new facilities to produce the required components.

It appears, at this point in time, that the single most important item affecting the lead time issue is the ability of the catalyst substrate manufacturers to produce substrate at the needed volume in time. This is based on lead time information furnished to EPA by the potential substrate suppliers. Since at least two of the major vehicle manufacturers are considering the production of their own substrate, the lead time for substrates may not be as critical as it now appears, but there is little information available on the plans and ability of the vehicle manufacturers with respect to substrate production in-house.

There are other emission control related components that may involve lead time problems, such as new carburetors and manifolds, but these problems are not considered as severe as the problems with the catalytic converters.

All of the lead time information submitted to EPA has been based on the conventional new model start-up time of July-August 1974. There is a period of approximately 4 months that could be used to extend the lead time available to the manufacturers. No manufacturer has indicated to EPA that they will definitely follow such an approach.

In summary then, on a production lead time basis, the automobile companies appear to have taken or have plans to take action to ensure the availability of all elements of the 1975 emission control system and to ensure the integration of these components into the vehicle. If those plans are carried out, they should be able to produce 1975 vehicles starting at the usual time.

3.5 Significant Problem Areas

For 1975 system development, there are three interrelated major problem areas: Durability testing, catalyst failures, and lead time.

Durability Testing

In general, the durability testing currently being conducted by the manufacturers is non-optimum as some or all of the following deficiencies can be found in most programs.

1. Insufficient numbers of vehicle are currently under test. More vehicles with the same emission control system should be accumulating mileage to allow sound decisions to be made on what to produce for model year 1975. Also, a full range of the manufacturers vehicle mix should now be on test, especially if there are major differences in the emission control system among models.

2. Mileage accumulation is too slow. Because of the common practice of developing emission control systems while mileage is being accumulated, the rate of mileage accumulation for many manufacturers is slow. For example, some manufacturers have taken over one year to run 50,000 miles while the minimum time for development testing can be about 4 1/2 to 5 months. (Certification testing has been done in a period of time as short as 3 1/2 months on an all-out 24 hour per day, 7 days a week basis.) Therefore, the important durability data is not being generated as fast as it could be, which is especially important when the lead time problems are considered.

3. Non-optimum systems are being tested. Many manufacturers are accumulating mileage on systems that are not completely representative of full 1975-type systems. It is common to have durability vehicles running without some of the advanced components that the manufacturers have developed and are planning to use for model year 1975. Advanced carburetors and intake manifolds are the most common missing components. The latest model or generation of catalysts is also frequently missing.

Premature Catalyst Failures

Premature catalyst failures are the second significant problem area. The problem is compounded by the fact that the reasons for the failures are, in many cases, not known. The durability mileage schedules call for periodic testing, usually in 4,000-mile increments. If a catalyst failure is diagnosed at one of these checkpoints, it is usually difficult to pinpoint exactly when and why failure occurred. The inability to explain failures (and conversely, the inability to explain success) is a serious problem especially since commitments to production will depend on the outcome of the tests.

The reason for many of the failures may be catalyst over-temperature. The usual results are failure of the substrate due to melting and/or cracking. Since cracking, for example, is not always followed by an immediate rise in emissions, diagnosis of the cause of catalyst failure is difficult. The judgment of the report team is that many failures are caused by an excess of combustible materials (either fuel (HC) or CO) entering the catalyst. This condition can be caused by many conditions, but the most likely cause is some form of failure to ignite the air/fuel mixture in the cylinder.

Poisoning of the catalyst by trace contaminants (lead, phosphorous and sulfur) is also a problem, but quantitative data on the exact effects from extensive vehicle tests is lacking. Control of lead contaminants to the proposed EPA certification level of .03 grams per gallon may not be as great a problem as was claimed earlier by some manufacturers.

<u>Lead Time</u>

Lead time is the third major problem area. Because of the somewhat less than ideal situation with respect to durability testing, the manufacturers are holding off their commitments to the last possible instant. Whether or not they are waiting too long is a controversial matter, but their potential suppliers have indicated that if decisions and firm commitments are not made at about the time of this report (November-December 1972), the "drop dead" dates may be passed.

One possible contributing factor to the need for the manufacturers to make decisions at the latest possible time may not be entirely within their control. One of the reasons why the decisions are being held up is the lack of durability testing on the advanced "second generation" catalysts. It appears that the supply of such catalysts to the manufacturers may have been slow in being made available and the quantities were limited. Therefore, the vital results from the durability testing have not been available to the decision makers in the industry as soon as both they and their potential suppliers would like.

3.6 Summary Discussion Model Year 1975

In summary, there is little doubt that Honda with their CVCC engine, Toyo Kogyo with their rotary engine and Daimler-Benz with their Diesel engine will be able to meet the 1975 standards.

A number of other manufacturers appear capable of meeting the 1975 standards with catalytic systems, although the durability of the catalytic systems appears to be poorer than the durability of the non-catalytic systems that can meet the 1975 standards. Catalyst durability is still a major problem for some manufacturers.

SECTION 4

INDUSTRY STATUS - 1976 DEVELOPMENT

4.1 Systems to be Used for 1976 Compliance and the Constraints Influencing Their Design

Systems to be Used

The typical 1976 emission control system includes all the components of the 1975 emission control system plus a reduction catalyst for NO_x control, switching controls for the air injection system, and possibly a more sophisticated EGR system.

The principal difference in the 1976 system is the addition of another catalyst. This catalyst, called a reduction or NO_x catalyst, is placed in the exhaust flow between the engine and the HC/CO catalyst. The NO_x catalyst must operate in an atmosphere that provides enough CO to reduce the NO. To achieve this CO level, the carburetion is adjusted to provide a mixture richer than in the 1975 systems.

Many catalysts have been considered for use as NO_x catalysts in the 1976 systems, but now there are two general types under serious consideration. The two types use platinum and/or other precious metals or some sort of nickel-containing alloy, such as stainless steel, as active material.

As is the case with the HC/CO catalyst, various substrates could be used for NO_x catalysts. At this point in time, the preferred substrate type appears to be the monolithic substrate.

1976 systems will also have provisions for controlling the location of the air injection. A valve and extra air injection lines will be needed. The purpose of this switching function is to enable the NO_x catalyst to operate as a HC/CO catalyst during the initial cold start period. During this period, air is injected upstream of the NO_x catalyst making it act as an HC/CO catalyst. When both the NO_x catalyst and the HC/CO catalyst are hot enough to begin converting, the air is injected between the NO_x catalyst and the HC/CO catalyst.

The EGR systems in 1976 may be different from those used in 1975. Because of the need to reach the 0.4 gram per mile NO_x level, all additional control to below the levels achieved by the 1975-type EGR systems is highly desirable. Getting substantially lower NO_x emissions with EGR may require the use of a proportional EGR system. Current (1973) and most planned 1975 EGR systems do a poor job of matching EGR flow to the requirements of the engine. Systems that offer proportional flow characteristics are under development. Whether they will be used may be interrelated with the NO_x catalyst status at the time at which decisions must be made.

There is another type of emission control system under development for possible application for model year 1976. This type of system uses a single catalyst to control HC, CO and NO_x.

It is known that some catalysts can efficiently convert HC, CO and NO_x simultaneously. The catalysts that use precious metals are an example. This feature has been used by Universal Oil Products (UOP) in the "Tri-component catalyst" (tri-component referring to the three gaseous emissions HC, CO and NO_x). The major drawback to the use of a single catalyst for control of HC, CO and NO_x is the requirement for very tight control of the exhaust oxygen level into the catalyst. If the air/fuel ratio is too rich, the catalyst loses control of

HC and CO and acts like a NO_x catalyst in a dual catalyst system. If the air/fuel ratio is too lean, the catalyst loses control of NO_x and acts like an HC/CO catalyst.

It is doubtful whether carburetors or fuel injection alone at the present state of the art can control the air/fuel ratio accurately enough to make the concept of a single catalyst work. However, the reason for the widespread interest in this type of system is due to an additional type of control which has been under development for the past year or so. This system is a feed-back loop that senses the exhaust gas oxygen level, and feeds back a signal that controls the air/fuel ratio of the engine. Most of the development on this system has been done by Bosch, in conjunction with various European automobile manufacturers, and by Bendix in this country.

The cost and fuel economy penalty predictions by the manufacturers show the same wide range for 1976 systems as for 1975 systems, the cost ranging from a low of $115 to a high of $1900 and the fuel economy penalty ranging from a 3% to a 50% increase, compared to 1973 vehicles.

Constraints Influencing the Design of 1976 Emission Control Systems

The constraints influencing the design of the 1976 emission control systems are much the same as the ones influencing the design of the 1975 systems. There are, however, some differences. Because of the different (richer) air/fuel requirements of the NO_x catalyst, the carburetion has to be even more closely controlled than the 1975 systems. The engine must be run rich, but not too rich, because the HC/CO baseline levels will be too high, and not too lean because then the NO_x catalyst will not reduce the NO under lean operation. Because having a NO_x catalyst upstream of the HC/CO catalyst delays the light-off of the HC/CO catalyst, the NO_x catalyst must work as an HC/CO catalyst during the cold start. This requires switching the air injection location.

4.2 Durability Testing Program

The durability testing programs currently being conducted by the industry on 1976 prototype systems are limited. The manufacturers claim that the present state of the art in NO_x catalyst durability has not advanced to the level at which extensive durability programs are warranted. For this reason, the number of vehicles currently undergoing durability testing with 1976 systems on them is quite small, compared to the number of 1975 prototypes currently being tested.

No vehicle has been reported to EPA that has successfully completed the 50,000-mile durability test at or below the 1976 emission requirements. Compared with the durability testing reported by the manufacturers on 1975 systems at this point in time last year, the 1976 durability testing is not as extensive.

4.3 Catalyst Screening Programs

The manufacturers are currently conducting extensive catalyst screening programs in an attempt to find the optimum NO_x catalyst for use in the 1976 systems. Thousands of tests have been performed on many different catalysts. Each manufacturer has a unique set of screening tests, but generally, they involve three types of tests: laboratory bench activity and aging tests, single or multicylinder engine activity tests, and vehicle tests.

The laboratory bench activity and aging tests are usually the first tests performed. The catalyst is checked for NO_x conversion efficiency, both as a function of temperature and CO, and for ammonia (NH_3) formation. The conversion efficiency of the NO_x catalyst, when used as an HC/CO catalyst, is another parameter that is measured.

The engine tests are usually performed on only the more promising catalysts. Activity, NH_3 formation, and some durability testing are important here.

Once a candidate catalyst has passed the first two screening tests, it is usually put on a vehicle and the entire system is optimized for low emissions. Depending on the results of these vehicle tests, the catalyst may or may not enter a durability testing program.

4.4 Lead Time for 1976 Production and an Identification of the Critical Items

Currently, lead time is not a major constraint for the production of 1976 emission control systems. The manufacturers have designed the 1976 systems to have a minimum number of changes from the 1975 systems.

The most critical item from the lead time standpoint is the reduction catalyst. Because there are so many unknowns about the eventual catalyst system to be used for the 1976 model year, very little can be done with respect to detailed contractual commitments for NO_x catalysts at this point in time.

If the commitments for the 1975 systems are made in time to ensure the existence of the catalytic converter supplier industry, the manufacturers will have approximately 12 months (until December 1973-January 1974) in which to screen, develop, and test NO_x catalysts. After that point in time, lead time for 1976 systems will become a critical issue.

4.5 Significant Problem Areas

The most significant problems currently being encountered by the manufacturers in their 1976 development programs all are related to the NO_x catalyst. The major problems are the general state of NO_x catalyst development, catalyst durability and efficiency, ammonia formation, and ruthenium oxidation.

NO_x Catalyst Development Status

When the Clean Air Act was passed, automobile and catalyst manufacturers already had some background in oxidizing catalysts. The development of HC/CO catalysts for California in the 1960's and the very extensive experience of the catalyst manufacturers in the use of oxidizing catalysts in other applications had already established a basis from which the catalyst technology for oxidation catalysts could start and be adapted to the legal requirements for 1975. This was not the case with NO_x catalysts. No automobile-related development work was done on NO_x catalysts in the California program in the 1960's and the use of NO_x reduction catalysts in other non-automobile applications was not as extensive as the use of oxidation catalysts. Therefore, the baseline for the application of NO_x catalysts was much less advanced than the baseline technology level for oxidation catalysts. The demonstrated emission control technology at this point in time reflects this difference.

Catalyst Durability and Efficiency and Ammonia Formation

Catalyst durability is another 1976 development problem. NO_x catalysts must generally be run at a higher temperature than

HC/CO catalysts. This makes over-temperature excursions more critical, and many NO_x catalysts have been destroyed due to over-temperature. Because the operating temperature is higher, the severity of the thermal shock problem is also greater, both for "upshock" and "downshock" (heating up and cooling off the catalyst).

Catalyst efficiency is also a problem. Initially, manufacturers attempted to have the NO_x catalyst do the entire NO_x clean up job without EGR. This requires very high efficiencies. The problem is that some NO_x catalysts do show very high test efficiencies (greater than 95%) and almost no NO_x comes through them, but not all of the NO_x is reduced to nitrogen and oxygen. Some NO_x catalysts are also very efficient in producing ammonia (NH_3) from NO and the hydrogen (H_2) present in the exhaust. Although ammonia is not currently regulated as a pollutant (it is objectionable and noxious), ammonia emissions are not the only problem. The oxidation catalyst is very effective in oxidizing the NH_3 back to NO_x. Thus, the net efficiency of a catalyst pair is important and a catalyst with lower gross efficiency and less NH_3 formation may be superior to one with higher gross efficiency and greater NH_3 formation.

Ruthenium Oxidation

Another catalyst-related problem area is a consequence of trying to find a NO_x catalyst that does not produce much ammonia. If ruthenium (Ru), one of the precious metal group, is added to a catalyst formula containing platinum, for example, the resulting catalyst produces little NH_3. However, the use of ruthenium as a catalytic material results in two problems: first, ruthenium is reported to be even more scarce than platinum; and second, ruthenium forms a volatile oxide. When the NO_x catalyst is operated as an HC/CO catalyst during the cold start, some of the ruthenium is oxidized and is lost. These two problems have caused some manufacturers to continue to try to find or develop other NO_x catalysts with low NH_3 formation characteristics.

Other Problem Areas

Other current problems in the development of 1976 systems are due to the richer air/fuel ratios needed for the NO_x catalyst. These problems are increased HC/CO loading to the oxidation catalyst and fuel economy.

The richer air/fuel ratios used in the 1976 systems can cause greater input HC/CO emissions to the oxidation catalyst. This implies that the overall HC/CO conversion efficiency of the 1976 dual catalyst system will have to be higher than the overall conversion efficiency of the 1975 system. Since maintaining high conversion efficiency at extended mileage is currently a problem with 1975 systems, it is likely to be an even more serious problem with 1976 systems.

Richer air/fuel ratios can mean poorer fuel economy. Many manufacturers have reported that they think that the 1976 model year vehicles will have poorer fuel economy than current (1973) systems. There is, however, little comparable data to quantify the extent of this projected loss.

4.6 Summary Discussion - Model Year 1976

No manufacturer has yet demonstrated the capability to meet the 1976 standards for 50,000 miles.

The three non-catalytic systems (Honda CVCC engine; Toyo Kogyo rotary engine; and Daimler-Benz Diesel engine) that have demonstrated the capability to meet the 1975 standards are all judged by the report team to have significant potential for meeting the 1976 standards.

The catalytic systems being developed for 1975 may, with the addition of a better reduction catalyst, evolve into successful 1976 systems. However, the performance to date of dual catalyst systems is such as to suggest, in the opinion of the report team, that the potential for success for such dual catalyst systems is less than the potential for success of the non-catalytic systems.

SECTION 5

NON-AUTOMOBILE MANUFACTURER DEVELOPMENT STATUS

5.1 Catalyst Manufacturers

Of the large number of catalyst manufacturers that are potential suppliers to the automobile industry, three manufacturers have reported that they have built and tested emission control systems on vehicles. The three manufacturers are Engelhard, Universal Oil Products (UOP) and Matthey-Bishop (a subsidiary of Johnson-Matthey).

5.1.1 Engelhard

Engelhard has built and tested several vehicles. The most important vehicle for the purposes of this report is a Ford Torino Station wagon, which was reported by Engelhard to have completed more than 50,000 miles of durability testing without a catalyst change. The vehicle was equipped with the Engelhard Type IIB catalyst (an improved "second generation" catalyst), air injection and EGR. Since there is very little durability data from the automobile manufacturers on this type of catalyst, the emission performance of this vehicle/catalyst combination is important.

What actually was demonstrated by the Engelhard durability results is difficult to determine. The fuel used was lead sterile, and thus significantly lower than the lead level that is expected to be used for model year 1975 certification. The mileage accumulation schedule was not strictly AMA, and the engine was replaced at 8,000 miles.

The Engelhard vehicle has been tested at the EPA laboratory at 58,000 miles. The test results were:

	HC	CO	NO_x
	.38	1.42	1.62
	.45	1.61	1.50
Average	.42	1.52	1.56

The EPA emission tests show that the Engelhard vehicle has excellent CO control and somewhat less satisfactory HC control, when compared to the 1975 standards. Both HC and CO control are very good for a system in which the catalysts have been exposed to exhaust gas for nearly 60,000 miles of vehicle operation.

No catalyst failures were reported in the mileage accumulation for this vehicle. Compared to reports of frequent catalyst failure from the manufacturers, this test was much more successful. The reasons for this are not known, but the fact that the mileage accumulation was less rigorous than the more stringent durability tests that the manufacturers perform (in addition to AMA durability), and the characteristics of the fuel and lubricant used by Engelhard, may have had a significant influence on the favorable result.

5.1.2 Matthey-Bishop

Matthey-Bishop is another catalyst manufacturer that has reported results on vehicle tests. Matthey-Bishop has reported results on two vehicles, one with a 1975-type emission control system, the other with a 1976-type emission control system. The vehicle with the 1975-type emission control system is the vehicle that received much attention during the Suspension hearings in the Spring of 1972. At that time, the vehicle had accumulated approximately 24,000 miles and was under the emission levels required for 1975. Additional information obtained since then indicates that there were some substrate and baseline emission problems with the 1975 control system vehicle after 24,000 miles. These problems caused Matthey-Bishop to reconsider whether they should do vehicle testing of 1975-76 prototypes or to continue to do research and development work on catalysts.

Matthey-Bishop has chosen the latter course, and their vehicle durability program is currently inactive.

5.1.3 Universal Oil Products (UOP)

UOP has reported successful completion of two 50,000-mile durability tests with catalyst systems. These results are considered significant, since the tests were run with conventional lubricating oil and fuel of .02 gpg lead content. On catalyst PZ 217, the 50,000-mile results were:

HC .15 gpm CO 1.2 gpm

On catalyst PZ 236 the results at 50,000 miles were:

HC .22 gpm CO 1.45 gpm

The results are considered good, especially for PZ 236 since the precious metal loading was .018 troy ounces, compared to the .07 troy ounces for PZ 217.

5.2 Other Manufacturers Development Status

Many non-automobile and non-catalyst companies have developed, or are developing, 1975-76 emission control systems. Of the many companies, four are the most significant: DuPont, Esso, Ethyl and Questor.

5.2.1 DuPont

DuPont has long been active in emission control development. They have been especially interested in emission control systems that are lead tolerant. Much of the recent development work has been with a rich thermal reactor and a sophisticated EGR system. The EGR system is a proportional one, controlled by exhaust gas back pressure with the exhaust gas introduced above the throttle plate.

Typical results with this type system on a full-size vehicle are:

	HC		CO		NO_x
Approx.	.15	Approx.	6.0	Approx.	.5 - .6

The above results indicate typical rich thermal reactor performance: good HC control, but CO and NO_x emissions above the 1976 levels.

DuPont also reported some results on a smaller vehicle with the same type of control system. In this case, the vehicle was a Ford Pinto currently on durability testing at 36,000 miles. The results were reported to be:

HC	CO	NO_x
.25	4.5	.6

Again, the characteristic performance of the rich thermal reactor is evident.

DuPont is continuing to develop their emission control system further. They also are developing particulate trapping systems for vehicles.

5.2.2 Esso

Esso has developed two distinct emission control systems aimed at achieving 1976 emission levels. The two systems are the Rapid Action Manifold (RAM) rich thermal reactor system and a dual catalyst system.

The RAM system has demonstrated good emission performance for a rich thermal reactor. Two tests at EPA gave the following results:

	HC	CO	NO_x
	.11	4.76	0.67
	.10	3.19	0.67
Average	.11	3.98	0.67

The CO control for the RAM is good, one of the two tests achieving 1975-76 CO levels. The NO_x, however, is above the 1976 level.

Esso reported that they have been able to achieve the 1976 emission levels at low mileage, as have many manufacturers using dual catalyst systems. Esso's development is important because they reported that up to 20,000 miles of durability on a chassis dynamometer the emission levels were below the 1976 levels. At 30,000 miles the emissions were above the 1976 levels on CO and NO_x. This durability performance is superior to that reported to date by the automobile manufacturers. Esso attributes the loss of NO_x control to a loss of active surface area of the catalyst. The fuel used in this test was lead sterile which may have influenced the favorable results. Esso reported that they are not yet ready to put vehicles on the road for mileage accumulation, since they are still developing the NO_x catalyst.

5.2.3 Ethyl

Ethyl, like DuPont, has been extremely interested in emission control devices that are lead tolerant. Ethyl has been involved for several years in the development of thermal reactor systems for automobiles. The system receiving the most attention has been the Ethyl Lean Reactor system, a lean thermal reactor, EGR, and special three venturi carburetor system. Emissions from this system have consistently been above the 1975-76 standards. Typical results in 1971 were:

HC	CO	NO_x
.52	6.2	1.37

More recent tests with a quick heat manifold, proportional EGR system, and a 17.5 to 1 air/fuel ratio setting for the carburetor yielded on an 8 test average basis:

HC	CO	NO_x
.27	3.6	2.3

Ethyl is continuing development on their system with approximately 5 cars in their development fleet. They have not reported any NO_x levels below the requirements for 1976, and since their system operates at a lean air/fuel ratio the use of a NO_x reduction catalyst is precluded.

5.2.4 Questor

Unlike DuPont, Esso and Ethyl, Questor is not as well known as an independent developer of emission control systems.

Questor Automotive Products is a diversified automotive parts supplier, making, among other things, exhaust systems and piston rings. Questor has been working for a few years on the emission control system that they call the "Reverter." Basically, the Reverter system is a rich thermal reactor followed by a metallic NO_x catalyst, followed by another thermal reactor. In order to maintain high reactor and catalyst temperatures, the system is carbureted very rich, typically 9-10% CO in the exhaust. No EGR or spark retard control is used with the system.

The Reverter system can operate on leaded fuel. Current prototypes, therefore, have compression ratios that correspond to this characteristic (9.2 to 1).

The high temperature promotes good HC and CO oxidation in the thermal reactors and also keeps the NO_x catalyst operating at a point where its efficiency is high. The high temperature operation of the NO_x catalyst may also be beyond the temperature range in which ammonia (NH_3) is formed. Also, the reason why the system does not appear to be strongly affected by the lead in the gasoline (at least at low mileage) is the fact that most of the lead is in the vapor phase at the higher temperatures of the Reverter system and does not deposit out on the catalyst and clog or poison it.

The high temperature of operation of the Reverter system is also responsible for its disadvantages. To keep the temperature high, the engine is run rich to provide the fuel (HC and CO) necessary to keep the temperature in the system high. This causes a loss in fuel economy. The high temperatures also require use of more expensive materials in the construction of the Reverter system, compared to conventional exhaust systems. The high temperatures also may cause problems related to excessive under-hood temperatures.

The Questor Reverter system has been tested by American Motors, Chrysler, Ford and General Motors. Although not every test was below 1976 levels, the Reverter system has demonstrated impressive emission control when tested by all four of the automobile manufacturers.

The Reverter system has also been tested at EPA. The emission levels were also below the levels required for 1976. All the tests, both at the manufacturers and at EPA, have been on low mileage (less than 8,000 miles) prototypes.

All four of the automobile manufacturers have expressed reservations about the Reverter system. In general, the aspects that the industry considers negative are the fuel economy penalty and the unproven durability. Of the four automobile manufacturers, only General Motors currently has a joint development program with Questor.

Another factor besides fuel economy and durability is that at the present time, it would be almost impossible to employ a Reverter system for model year 1975, due to lead time constraints. This means that the typical 1975 system now planned for use would be good for only one year. The manufacturers do not like to contemplate writing off the costs for a 1975 system in such a short time.

5.3 Summary Discussion Non-Automobile Manufacturer Development Status

The Questor Reverter system has not demonstrated durability success or failure. No vehicles have yet been run to 50,000 miles, although durability testing on the AMA durability schedule is now underway. Until such tests are completed, the feasibility or infeasibility of the Reverter system will not be demonstrated. However, it is the judgment of the report team that the Questor Reverter emission control system is at least as effective as the 1976 emission control systems currently under development by the automobile manufacturers.

In fact, the Reverter system may be superior to many 1976 dual catalyst systems, having completed 19,000 miles of durability testing at the time this report was written and remaining under the 1976 levels. Information from the vehicle manufacturers did not indicate that any results superior to the Questor results have yet been achieved.

As regards all of the other systems discussed in this section, it is the judgment of the report team that the potential of those systems for meeting the 1976 standards is much less than the potential of the Questor Reverter system.

SECTION 6

INDIVIDUAL MANUFACTURERS REVIEWS

6.1 DOMESTIC MANUFACTURERS

6.1.1 AMERICAN MOTORS (AMC)

6.1.1.1 1975 Development Status

Systems to be Used - '75

The AMC system for 1975 is planned to be a typical 1975 system employing engine modifications, air injection, exhaust gas recirculation and an oxidation catalyst. The engine modifications may include a quick heat intake manifold and breakerless ignition. AMC has done extensive development work in the engine modification area, primarily in combustion chamber design. They have worked extensively with both GM (AC) and Engelhard, and at this time, appear to favor the AC underfloor pellet catalyst. Since at the time of the writing of this report, GM had not finalized the catalyst active material type and loading, it is not too surprising that AMC has not done so either.

Although AMC mentioned development work on the breakerless ignition and quick heat intake manifold, little data was reported on those subsystems. In fact, it is not clear whether or not AMC has ever tested a complete 1975 system including the breakerless ignition, quick heat intake manifold and the rest of the system (including a good catalyst). AMC reported little information about design constraints that would permit some logical development pattern to be inferred from the information they did present. It can only be conjectured, for example, how the results on the GM catalysts that AMC has achieved can be construed to be better than the results with the platinum monolith catalysts. Possibly AMC is aware of the current encouraging results obtained by GM on their latest promoted base metal catalysts.

AMC shows a good example of the development problem faced by a relatively small manufacturer. Because of limitations caused by their small size AMC has not been able to do all of the in-house development work that they would probably like to. As a result, they have had to depend on outside suppliers for most of their components.

The American Motors status report indicated that 1975 AMC vehicles will have 9% poorer fuel economy than 1970 vehicles. This is about an additional 5% loss from 1973 vehicles. More development work may reduce this penalty since AMC works closely with GM which is not experiencing a penalty from 1973 to 1975 systems.

AMC estimated that the retail price increase required to meet the 1975 standards will be about $275 ('72 dollars) compared to 1970 vehicles. Catalyst replacement, if required, for a V-8 powered vehicle is estimated by AMC to cost $76. If catalyst replacement is not required, the maintenance cost of the 1975 vehicle may be less than '70-'74 vehicles, especially if a breakerless ignition is used.

Durability Program - '75

The American Motors vehicle durability program is designed to assess the degree of the various problem areas associated with preliminary system designs.

Three vehicles with 1975 prototype systems have been run to 50,000 miles by AMC:

DOO-24	3000 pound, 232 CID
D20-6D	3500 pound, 304 CID
D17-11	3000 pound, 258 CID

A fourth vehicle, D28-25D, suffered converter over-temperature and a resulting vehicle fire. With the exception of this last car, AMC considers their durability program to be on schedule. Several other vehicles are at relatively low mileage points. Currently only two of AMC's three engine families have been represented in the durability program. Vehicles using the third engine family have been prepared for low mileage testing. Thus, it appears that ultimately all of AMC's current engines will be represented.

The basic thrust of the AMC program is one of catalytic system evaluation. As such, the vehicles which have completed 50,000 miles of testing have not been equipped with full 1975 emission control concepts. Specifically lacking are quick heat intake manifolds and advanced carburetion. Testing has been performed in accordance with standard Federal procedures with the exception of maintenance. On vehicle D17-11, a cylinder head change was required at about 28,000 miles. It appears, however, from the data that this type of maintenance did not significantly affect the overall deterioration factor calculation. Fuel used had a lead content of less than .02 grams per gallon. Listed below are the HC and CO deterioration factors reported for the three vehicles which have completed 50,000 miles of operation:

Vehicle	HC DF	CO DF
DOO-24	1.96	2.66
D20-6D	2.03	2.11
D17-11	3.77	less than 1.0

At this point, AMC has demonstrated relatively severe deterioration of their systems under test. Low mileage data does not seem to be representative of a full effort on a complete 1975-type system.

Catalyst Screening Program - '75

The catalyst screening work used by AMC is done by GM and is described under the GM section.

Progress and Problem Areas - '75

Progress

AMC has made progress in the last year on catalyst system selection and component development.

In the area of catalyst system selection, AMC apparently now considers the AC division of GM to be one of their potential suppliers of both catalysts and containers. Their description of the system that they are concentrating their development on indicates that it is the same as the AC underfloor system. The catalyst choice, however, has not yet been made.

AMC also reported that they have done some development work on quick heat intake manifolds.

Problem Areas

AMC reported that their major problem area was that "...none of the systems tested to date has shown the ability to meet the 50,000-mile durability requirements of the certification test procedure." Lead time and an unexplainable vehicle fire were also reported as problem areas.

While the 1975 levels have been achieved with the GM underfloor-type system, AMC has not been able to demonstrate 1975 emission levels with their own catalyst system located inside the standard muffler and installed in the normal rear muffler location.

Conclusions - '75

The report team concludes that AMC's chances of certifying for 1975 are questionable. They have been grouped into class 75-2.2, Catalytic System Approach - Average Development Status. Data available on six-cylinder vehicles with noble metal monolith catalysts indicated that certification of part of AMC's product line is possible. Data on V-8 powered vehicles and vehicles using pelleted catalysts was less encouraging. Insufficient data on systems employing the advanced engine mod concepts being developed by AMC makes a more definite conclusions impossible at this time. AMC's chances of certification are highly dependent on GM's ability to supply them with acceptable catalysts and on AMC's ability to adapt the GM catalysts to AMC vehicles.

6.1.1.2 1976 Development Status

Systems to be Used - '76

The two systems planned for use by AMC appear to be virtually identical to those under consideration and development by GM for 1976. AMC, therefore, in the opinion of the report team, appears to be focusing most of their effort on adapting the GM-type system to their vehicles, rather than designing and developing one of their own.

Of the development tests reported, not one (of the total of 9 reported) met the 1976 levels. The only system that AMC has ever reported testing that met the 1976 levels was covered in their 1971 status report. That was the Questor Reverter system. No development work or testing has been reported by AMC on the Questor system with the exception of the one test reported in 1971.

Durability Program - '76

AMC has not initiated any durability testing of their 1976 prototype concept. No schedule was submitted to indicate when testing will be initiated.

Catalyst Screening Program - '76

AMC did not report any catalyst screening program for 1976.

Progress and Problem Areas - '76

Progress

The progress that AMC has made in the last year on 1976 systems has apparently resulted in a decision to use the GM system. Both possible 1976 systems described by AMC are the two systems given highest priority currently by GM.

Problem Areas

AMC reported that their three major problem areas were (1) they are unable to meet the emission levels required for 1976, (2) the over-temperature protection system is unsatisfactory, and (3) AMC has no durability test results.

AMC reported only 11 emission tests on 1976 systems. Apparently, having this small number of tests completed was not considered as serious a problem as the others listed above.

Conclusions - '76

The report team concludes that AMC's chances of certifying for 1976 are questionable. They have been grouped into class 76-2.1, Catalytic System Approach - Average Development Status. Not enough data was available on which any firmer conclusions could be based. As is the case for 1975, AMC's chances for 1976 are highly dependent on GM's ability to supply emission control systems which AMC could successfully adapt to their vehicles.

6.1.2 CHRYSLER

6.1.2.1 1975 Development Status

Systems to be Used - '75

The Chrysler first choice system consists of engine modifications, EGR, modified carburetion and a noble metal monolithic oxidation catalyst with air injection. As possible back-up systems, Chrysler is considering replacing the non-proportional EGR system of the first choice system with a proportional system and/or replacing the standard exhaust manifolds with partial thermal reactors. Some consideration is still being given to using pellet-type catalysts in place of the monolith units.

The precious metal monoliths, especially palladium-containing catalysts, are receiving the most attention at Chrysler currently.

Chrysler did not specify what they consider to be important design constraints; however, they seem to be concerned about fuel economy, performance and cost penalties. Chrysler reported an 8% power loss due to emission control is anticipated for 1975. An EPA test of one of Chrysler's 1975 prototypes indicated, however, that the acceleration times of the prototype were almost identical to the prototype car's 1972 counterpart which was rented by EPA for the purposes of comparison. Chrysler is also claiming an 8% fuel economy penalty comparing 1975 systems to 1972 systems. Limited data on the 1975 prototype tested by EPA does not support this claim as the fuel economy measured was as good as current vehicles. In the opinion of the report team, cost seems to be the major reason for the deletion of partial thermal reactors and proportional EGR from the first choice system. Apparently, the electronic engine control (EEC) concept was also deleted for cost reasons. Chrysler stated that the cold start retard feature did not provide enough improvement when using monolithic catalysts to justify including EEC in the first choice system.

Low mileage tests on Chrysler vehicles using complete systems have been as low as .12 gpm HC, .9 gpm CO, and 1.32 gpm NO_x. Tests run using the partial thermal reactors without catalysts resulted in emission levels as low as .56 gpm HC and 5.6 gpm CO. A major point of difference between the Chrysler systems and the systems of the other manufacturers has been in the development of partial thermal reactors rather than quick heat intake manifolds to lower the level of the emission reaching the catalyst. The Chrysler approach is just as effective but may be more expensive and for that reason, may not get into production.

Chrysler did not supply any information on the use of modulating devices. A catalyst by-pass system was formerly under development but is no longer being considered.

Chrysler estimated the cost of their first choice system for 1975 to be $363 more than no control system at all or about $260 more than the system for '73-74 vehicles.

Durability Program - '75

The primary thrust of the Chrysler durability program at this point is one of establishing catalytic deterioration information based on vehicle mileage accumulation. A 10 vehicle fleet is operating at the Chelsea proving ground.

At the time of the Chrysler submittal none of these had completed 50,000 miles, although several were nearing completion. One vehicle (car #333), which is not included in the current fleet but which previously completed 50,000 miles, will also be discussed in this section. Three out of the five 1972 Chrysler engine families are currently involved in the program. The 400 CID and small displacement Cricket vehicles have not been reported to be on mileage accumulation.

The test vehicles are equipped with several types of monolithic catalysts and most still use 1973 carburetion and exhaust gas recirculation. Thus, it cannot be assumed that these vehicles are typical of complete 1975 models.

Three major considerations of Chrysler's test procedures are necessary to fully evaluate the significance of their testing thus far. First, the fuel used for mileage accumulation is Indolene Clear. While trace lead level data on individual batches was not included, it must be assumed that some of the mileage may have been run on fuel with a level of less than 0.01 grams per gallon, considerably lower content than the assumed average lead-free fuel of 1975 - 0.03 grams per gallon. Second, Chrysler is basically using an accelerated mileage accumulation driving schedule which is more severe than the AMA schedule, and reportedly more typical of customer-type usage. The Power Plant Endurance test and the General Endurance test were used on at least seven out of the 10 reported vehicles. The use of this type of mileage accumulation, while certainly necessary prior to a production run, may have introduced so many non-catalytic problem areas as to have reduced the usefulness of the catalytic durability program. It is significant that four of the ten vehicles suffered rod or bearing failures, requiring engine replacement or rebuild during the mileage accumulation. Third, and somewhat related to the previous point, the maintenance procedure utilized on this fleet of vehicles cannot be considered to be the type of maintenance allowable during a certification run.

Of the 10 vehicles running and car #333, the following calculated or projected deterioration factors appear most significant. Included in the following table is the latest mileage reported and as close to a 4,000-mile data point as could be found in the submittal:

Deterioration Factors & 4000-Mile Emissions

Car #	Mileage	HC DF	HC gpm 4000	CO DF	CO gpm 4000	NO_x DF	NO_x gpm 4000
414	33096	1.82	.31	1.45	4.20	1.05	1.94
467	25814	1.03	.24	less than 1.0	9.40	2.26	1.17
333	49438	less than 1.0	.25	2.14	1.42	less than 1.0	2.17

While a number of assumptions as to data point selection had to be made due to numerous cases of unscheduled maintenance, it does appear that car #333, in light of its developmental character, did successfully demonstrate 50,000 miles of operation approximating the 1975 requirements. Car #467 had inordinately high low mileage carbon monoxide emissions but appears to be headed toward relatively low HC and CO deterioration factors. Car #414 thus far has demonstrated deterioration factors lower than the Chrysler design goal of HC DF of 2 and CO DF of 2.

Catalyst Screening Program - '75

Chrysler uses both a laboratory test apparatus (called a tube furnace) and a single cylinder engine test rig for catalyst screening.

The tube furnace is essentially a heated container in which catalyst effectiveness for an artificial exhaust gas can be measured. The catalyst is aged for 16 hours at each of the following temperatures:

1500^{o} F
1700^{o} F
1800^{o} F
1900^{o} F
2000^{o} F

The physical crush strength of the fresh and aged catalyst is compared. Catalytic activity is determined as described below on the fresh catalyst and after the 1900^{o} F and 2000^{o} F exposures. Chrysler feels this environment is similar to that encountered in a vehicle over 6,000 miles of gentle driving. However, Chrysler did not provide catalyst temperature or other data for vehicle operation to substantiate this claim.

After this aging, Chrysler measures steady state conversions for two hours under each of the following test conditions:

1500° F
1700° F
1800° F
1900° F
2000° F

The light-off temperature for 50% conversion of HC and CO, as well as the temperature for 90% conversions, is measured. A synthetic exhaust gas containing 2% CO, 200 ppm HC, 3% oxygen, and 3% water vapor is used.

Catalysts which remove 90% or more of the CO at 800° F when fresh are considered to have passed the test if the temperature for conversion of 90% of the CO does not increase more than 100° F upon aging. Platinum-and palladium-containing catalysts have performance superior to other catalysts on this test.

Successful candidates are moved to a single cylinder engine test. If the catalyst continues to perform well here, it then is a candidate for engine dynamometer and durability testing.

Progress and Problem Areas - '75

Progress

Chrysler has made significant progress in the last year. Some durability vehicles have run 50,000 miles although whether the tests were successful or not is somewhat unclear (see Problem Areas below). Chrysler has made progress in the area of catalyst screening. More information on catalyst screening was supplied by Chrysler than by any other manufacturer. Chrysler has also made progress in the area of catalyst selection, having secured a supply of precious metal for use in catalytic converters and also having reached an agreement with UOP in the area of catalyst production technology.

Problem Areas

Chrysler has reported serious problems in the area of catalyst substrate mechanical durability, particularly with the extruded Corning W-1 substrate. The problems are heightened because Chrysler reported that they do not know why the failures occur. The failures do not appear to happen as frequently with other types of substrates in the testing done by Chrysler.

Chrysler also may have some problems in the area of emission measurement. Recent correlation tests at EPA of two Chrysler prototypes that had completed 50,000 miles showed relatively large differences in the CO results, with the EPA results being lower. Discussions with Chrysler personnel revealed that the instruments, calibrations and procedures used by Chrysler were inadequate to accurately measure CO at the low levels that result from systems performing at or below 1975 CO levels. Chrysler indicated that they were in the process of installing better CO instruments in their facilities. It is not known how much of the CO data that Chrysler has presented to EPA was generated with the inadequate CO instrumentation. Chrysler's review of data collected using the inadequate instrumentation may have created undue pessimism on their part.

Conclusions - '75

The report team concludes that Chrysler will probably be able to certify for 1975. They have been grouped into class 75-2.1, Catalytic System Approach - Above Average Development Status. One Chrysler prototype has been tested by EPA in the Ann Arbor laboratory which was below the 1975 levels after a 50,000-mile durability run. This vehicle completed the 50,000 miles without a catalyst change. The vehicle was not a full effort system in our opinion, since partial thermal reactors were not installed and only a single catalyst was used.

Our analysis of data on another Chrysler prototype, still not equipped with a full effort system, which completed 50,000 miles, indicated that the 1975 standards were achievable. This vehicle, car #333, also achieved the 1975 levels in EPA's laboratory but one of the two catalysts installed on the vehicle had less than 50,000 miles on it at that time.

Other Chrysler prototypes which have completed or nearly completed 50,000-mile durability tests have demonstrated deterioration characteristics which indicate certification of full effort systems with lower "untreated" emission levels is probable.

6.1.2.2 1976 Development Status

Systems to be Used - '76

Chrysler's first choice system for 1976 is essentially the 1975 system with the addition of noble monolith NO_x catalysts on each side of the engine. This is the same approach being used by most other manufacturers. The EGR system may be more sophisticated than the 1975 version. No tests of the first choice system reported were below the 1976 levels.

Four back-up systems were reported:

1. Metallic NO_x catalysts
2. DUAC system, both NO_x and HC-CO catalysts in the same can.
3. Dual catalyst system used on one side of the engine only.
4. Questor system

Chrysler is currently seeing better durability with back-up system number one (metallic NO_x catalyst) than with the first choice system, but they reported: "...its required high operating temperature for both reducing and warm-up oxidation places heavy demands on other components." This is the only Chrysler system to meet the 1976 levels. The best test was .38 gpm HC, 2.1 gpm CO, and .26 gpm NO_x.

Back-up system number two (DUAC) is reported to aggravate temperature problems while back-up system number three has impaired performance due to excessive heat losses.

Concerning the Questor system, Chrysler reported: "We consider this system a less attractive back-up....because of the fuel consumption and durability problems." It should be noted that Chrysler compared the fuel economy of the Questor vehicle (5000 lb class) to the fuel economy of a lighter weight vehicle (4500 lb class). The fuel economy measured by Chrysler on the 1972 FTP was 8.46 mpg.

Compared to the average of all the 5000 lb 1973 certification vehicles tested by EPA, this represents only a 9.6% fuel economy penalty. Compared to the average 1973 Chrysler certification cars at 4500 lb (500 pounds lighter than the test weight of the Questor vehicle) the penalty is 15%. Chrysler claimed, however, "...The fuel economy penalty is extreme (about 30%)." It is the judgment of the report team that Chrysler is overestimating the fuel economy penalty of the Questor system.

It is also not apparent why Chrysler reported "durability problems" as a reason for giving less consideration to the Questor system because they have never reported any durability testing of this type of emission control system.

A partial thermal reactor (PTR) is also considered as a back-up to the standard exhaust manifold of the first choice system. The use of a PTR would shorten the light-off time of the NO_x catalyst in the opinion of the report team, but Chrysler claims they would need improved catalysts which could withstand higher temperatures with this approach.

By switching the air injection point after warm-up from in front of the PTR to behind the PTR, it may be possible, in the judgment of the report team, to realize the benefit of reduced light-off time without experiencing an increase in system temperatures during "stabilized" operation. Chrysler did not report any development of this approach, however.

A potential back-up system, no longer under consideration, consisted of a dual catalyst system with a start catalyst. Start catalysts can trade off durability performance for good light-off characteristics because they can be switched out of the system after warm-up and they are not subjected to the deteriorating effects of the exhaust gas most of the time. Chrysler reported: "...this arrangement was discarded when it was discovered that the reducer catalyst could function as an oxidizer during the warm-up cycle and thus simplify the basic system." No data was reported which would indicate that a NO_x catalyst can do as good a job of warming up the system as a start catalyst designed specifically for that purpose. In the judgment of the report team the start catalyst approach may be superior.

A 3-way-type catalyst system was also investigated. Results were rather discouraging because a conventional carburetor was used on the engine. 3-way approaches require tight control of the air/fuel ratio which is impossible with conventional carburetors. Chrysler did not report whether they knew about these air/fuel ratio requirements before they initiated the 3-way testing.

A maximum fuel economy penalty of 15% has been established as a design constraint. Chrysler reported, however, "... it seems that the 1976 systems are likely to force the total penalty well over the 15% level, using 1971 as a base." No Chrysler data substantiated this claimed problem area.

Packaging is another area given considerable attention. Chrysler apparently desires to make as few chassis modifications as possible.

Chrysler has explored the Texaco stratified charge engine (TCCS) but the level of development effort is rather low. Other alternate approaches, including the turbine engine, have also been explored by Chrysler, but the short period of time remaining before 1976 vehicles must be in production has eliminated "alternate" approaches from consideration.

The cost of the first choice system for 1976 was estimated at \$530, \$430 more than the cost of the emission control system for 1973-74 Chrysler vehicles. The fuel consumption penalty is estimated to be greater than 15% compared to uncontrolled cars. It is difficult for Chrysler to determine a very definite penalty at this time because none of their current systems appear to be capable of meeting the 1976 levels at high mileage. More alterations will be required which may have some effect on fuel economy.

Durability Program - '76

The Chrysler durability program on 1976 prototypes has been quite limited. Of the three systems tested on mileage accumulation, none met the 1976 requirements at low mileage. However, to determine problems of durability, Chrysler initiated mileage accumulation on the General Endurance Cycle. Two dual catalyst concept vehicles and one thermal reactor vehicle were run. Neither of the catalyst-equipped vehicles had exhaust gas recirculation which at least partially accounts for their poor zero-mile oxides of nitrogen emissions. The deterioration of NO_x emissions for the catalyst vehicles was quite high and resulted in termination at low mileage. The thermal reactor vehicle through 50,000 miles of operation consistently exceeded the 1976 levels by a factor of about three on all pollutants. Deterioration did not appear severe; however, many mechanical problems resulted in frequent maintenance.

Catalyst Screening Program - '76

The first portion of Chrysler's catalyst screening program for 1976-type catalysts involves use of the tube furnace. The tube furnace involves aging the catalyst at elevated temperatures. The ability of the catalyst to reduce NO is then assessed. Following these tests, the catalyst is further tested using single-cylinder engine exhaust.

Chrysler feels an important criterion for reduction catalysts is their ability to act as oxidation catalysts during the cold start part of the FTP and such catalysts must therefore be resistant to oxidation in an oxidizing atmosphere. Only precious metal catalysts appear to meet this criterion according to Chrysler. Chrysler did not submit data correlating the oxidizing conditions in the tube furnace with oxidizing conditions occurring during warm-up of a vehicle.

A second important criteria in selection of an NO_x catalyst is minimal ammonia formation. More ammonia forms at lower (richer) air/fuel ratios. Noble metal catalysts containing platinum and palladium give higher reductions of NO at optimum air/fuel ratios (where ammonia formation is minimal) than base metal catalysts. Additives such as ruthenium are needed for these noble metal catalysts to prevent a phenomenon called "carbon monoxide poisoning." This type of "poisoning" Chrysler feels involves preferential absorption of CO on the catalyst surface, which reduces the NO conversion efficiency.

To date, the two best candidates from the Chrysler screening tests are the following catalysts:

1. Johnson-Matthey AEC8A

2. Chrysler Precious Metal Catalyst

Two other candidates seem promising because of their ability to operate at higher temperatures with improved durability.

However, these two other catalysts have lower activity than the two listed above. The runners-up are:

1. Gould GEM 45
2. Chrysler Base Metal Catalysts

These catalysts also require higher operating temperatures for NO removal than the precious metal catalysts listed above. Unfortunately, Chrysler did not supply any compositional information on the Chrysler precious metal or base metal catalysts. Chrysler also did not indicate the criteria on which they found their own catalysts to be superior to those of the catalyst companies.

Chrysler also mentioned that they had a laboratory apparatus to evaluate metallic alloy compounds as NO catalysts. This device was called the ME-CEE (Materials Evaluation - Controlled Exhaust Environment). A catalyst is placed in a ceramic-lined pipe. The ability of this sample to reduce NO with varying amounts of HC and CO was determined. Metallic reduction catalysts are further evaluated using an engine dynamometer set-up. This involves testing a catalyst at various steady state conditions of simulated speeds up to 70 mph.

The effect of acceleration-type transient conditions on the catalysts were considered. Testing is continued on another engine dynamometer for the equivalent of 25,000 miles at simulated speeds up to 100 mph and maximum temperatures of 1800° F. These tests, which were done on metallic alloy-type catalysts only, showed these catalysts to have very acceptable durability. However, Chrysler feels the usefulness of this type of catalyst is seriously limited since they do not become active for NO reductions until temperatures of 1000-1200° F are reached.

Chrysler has tested many NO catalysts from other companies. These companies include: American Oil, Brunswick, Corning, Ethyl, Gould, W. R. Grace, ICI, Kali-Chemie, Johnson-Matthey, Shell, Aeroban, Air Drop Co., Catalyst and Chemicals Inc., Champion, DuPont, Engelhard, Girdler, Gulf Oil, Houdry, Huyck, Mobil, Pechiney, Michigan Seamless Tube Co., Union Oil and UOP.

Progress and Problem Areas - '76

Progress

Chrysler has made progress in the area of system selection, low mileage emission performance and catalyst screening.

In the area of system selection, Chrysler has identified a system for 1976 that has a fewer number of significant problems than other systems they have studied. This system is a typical 1976 system using precious metals for both the NO_x and HC/CO converters. The low mileage emission results reported by Chrysler show some progress, 1976 emission levels having been achieved a few times at low mileage on a back-up system which used metallic NO_x catalysts. Chrysler reported the most extensive amount of catalyst screening test results. It appears that they have made extensive progress in this area, having tested most of the materials considered promising for use as NO_x catalysts.

Problem Areas

Chrysler reported severe durability problems with all types of the NO_x catalysts that they have tested. Both physical destruction and/or loss of efficiency in a very few thousand miles have been experienced to date.

Chrysler also reported major problems in vehicle installation. Some engine/body combinations could not use some emission control systems due to packaging problems.

Another problem is that the 1976 levels have not yet been achieved on their first choice system. Chrysler reported that the metallic NO_x catalyst approach is not their first choice because of the higher light-off temperatures. However, the metallic NO_x catalyst system has achieved the 1976 levels.

The CO measurement problem discussed in the 1975 Problem Areas section also may be a problem with the emission results reported with the 1976 systems.

Conclusions - '76

The report team concludes that Chrysler's chances of certifying for 1976 are questionable. They have been grouped into class 76-2.1, Catalytic System Approach - Average Development Status. The only tests reported below the 1976 levels were not on the first choice system and no vehicles placed on mileage accumulation have been able to maintain 1976 levels for even 4000 miles of operation.

6.1.3 FORD

6.1.3.1 <u>1975 Development Status</u>

<u>Systems to be Used - '75</u>

Ford's first choice system consists of engine modifications (including quick heat intake manifold, solid state ignition, improved carburetion) EGR and noble metal monolithic oxidation catalysts with air injection. To back up the first choice system the use of another catalyst in series and a thermal reactor is being considered. An additional back-up system of thermal reactor without catalysts is being considered for four cylinder vehicles since there are more substrate durability problems on these vehicles and catalysts may not be effective. The Engelhard catalyst seems to be receiving the most attention followed closely by the Matthey-Bishop catalyst. Catalysts supplied by W. R. Grace and Universal Oil Products (UOP) are also receiving consideration.

The first choice EGR and air injection systems have non-proportional or backwards flow characteristics but Ford reported more sophisticated systems are being contemplated:

> "...depending on the problems encountered in achieving the required emissions at acceptable levels of performance, economy and vehicle drive-ability, controls and control circuitry may be added on a selective basis to modify spark timing, control EGR, and possibly to modify secondary air flow as dictated by catalyst feed gas composition and temperatures."

No data was reported by Ford on any 1975 prototypes using proportional EGR systems.

A quick heat intake manifold is included in the first choice system yet no data was reported on cars using quick heat manifolds and catalysts. Data was reported on two vehicles having quick heat manifolds but catalysts were not used on these vehicles. The average of fifteen tests on these two vehicles was 1.32 gpm HC, 8.73 gpm CO and 2.53 gpm NO_x. Hydrocarbon levels were under 1 gpm and carbon monoxide levels were as low as 5.68 gpm on some tests.

The best low mileage data reported on vehicles with "partial" systems was .2 gpm HC, 1.69 gpm CO, and 2.52 gpm NO_x for the first choice system, .22 gpm HC, 1.8 gpm CO and 1.58 gpm NO_x for the twin catalyst back-up system.

Ford considers driveability, performance, cost, packaging, and fuel economy important constraints. They are expecting a 5% loss in fuel economy for their '75 system compared to '73 vehicles. No data was reported, however, to substantiate this penalty. The cost increase over '73 vehicles was estimated at $290, bringing the total cost of emission control (compared to uncontrolled vehicles) to $370.

Ford is intending to use several "modulating devices" on their 1975's. Among those discussed were speed-spark and speed-EGR.

Durability Program - '75

Ford Motor Company's 1975 prototype durability evaluation basically includes three separate fleets of passenger vehicles. Two of these programs, Dearborn and Riverside West, are well underway. The third, Riverside East, is currently well behind schedule and Ford did not report much emission from that program in their status report. Thus, only the first two programs can be discussed here. The Riverside West fleet is a 50,000-mile durability fleet while the Dearborn fleet serves as a 4,000-mile emission data fleet. Thus, the overall goal is essentially one of a "mock certification" program. A total of 38 vehicles are included in the "certification" program; 26 in Riverside West and 12 in Dearborn. While the Dearborn 4,000-mile vehicles have completed their mileage run, only 17 vehicles in the Riverside fleet exceed 36,000 miles with 7 having accumulated 50,000 miles. The bulk of the Riverside program is scheduled for completion by December 15, 1972, and will be totally finished on January 22, 1973. The mileage accumulation rate at Riverside has been very slow, apparently partially due to the fact that not enough test facilities may have been planned for at the start of the program.

To "encompass the full range of Ford Motor Company products", a selection of 5 vehicle/engine types was made for inclusion in the durability program. The following list details those types:

2.0 L	Pinto (not fully represented)
250 CID	Maverick
351 CID	Ford ("Cleveland" engine only)
360 CID	F-100 Truck
460 CID	Lincoln

While these engine/vehicle types do tend to span the Ford line, they do not fully represent all the engine configurations currently marketed by Ford Motor Company.

The prototype system configuration which is included in the Dearborn and Riverside West fleets is broken into three major categories:

Group I - Front catalysts only

Group II - Thermal reactor and front and rear catalysts.

Group III - Front and rear catalysts

Each vehicle in the Riverside West fleet was also equipped with:

Thermactor Air Injection
1973 EGR System
Breakerless Ignition
1973 Carburetor (modified calibration)
1973 Evaporation Control

These vehicles were calibrated at about 2.0 gpm NO_x.

The Dearborn fleet vehicles, on the other hand, were equipped with lean limit carburetion and a 1.50 gpm NO_x level. Significant is the fact that neither fleet was equipped with quick heat manifolds, advanced carburetion, or advanced EGR systems.

While it appears that both fleets followed AMA durability schedules in mileage accumulation, attention should be drawn to much unscheduled and, in many cases, unallowable (from a certification point of view) maintenance. For purposes of deterioration factor calculation no unscheduled maintenance points were used (as per current certification procedures). Since the fleet of vehicles was used primarily for purposes of catalyst evaluation, and because no direct catalyst maintenance was performed, the use of the fleet to develop catalyst deterioration characteristics appears valid.

Of the 17 vehicles with 36,000 miles or more accumulated, 12 demonstrated reasonably low deterioration factors.

CAR	HC DF	CO DF	NO DF
C-1 Maverick	1.58	1.86	1.10
C-2 Maverick	1.34	1.29	less than 1.0
C-1 F-100	1.68	less than 1.0	1.08
C-2 F-100	1.66	less than 1.0	less than 1.0
C-1 Lincoln	1.69	1.62	less than 1.0
C-2 Lincoln	1.25	1.46	1.26
CRC-1 F-100	1.00	less than 1.0	1.03
CC-1 Maverick	1.19	1.05	less than 1.0
CC-2 Maverick	1.25	1.89	1.02
CC-1 F-100	1	less than 1.0	1.09
CC-2 F-100	1.2	less than 1.0	1.23
CC-1 Lincoln	1.00	less than 1.0	less than 1.0

Results on the 351 C engine family have been less encouraging:

CAR	HC DF	CO DF	NO DF
CRC-2 Ford	2.52	2.85	1.12
C-1 Ford	3.98	4.54	less than 1.0
C-2 Ford	2.51	4.18	less than 1.0
CC-2 Ford	2.21	2.49	less than 1.0
CC-1 Ford	2.03	3.61	less than 1.0
CRC-1 Ford	1.72	2.18	less than 1.0

None of the 7 vehicles in the Riverside fleet which have completed 50,000 miles of operation has successfully complied with the Federal regulations for 1975.

If the deterioration factors presented previously are applied to the 4,000-mile data values reported for the Dearborn emission data cars (no adjustment for different NO_x calibration), three vehicles appear to comply with the 1975 emission standards (none of the three types have completed a full 50,000-mile run):

Group II	360 CID F-100 CRC
Group III	360 CID F-100 CC
Group III	460 CID Lincoln

With the possible exception of these 3 vehicles/engine systems, the Ford 1975 durability program has not clearly demonstrated a capability of complying with the Federal requirements. The absence of the more advanced emission control components, especially quick heat intakes on the prototype test cars, however, may cause more pessimistic conclusions to be drawn than are actually warranted.

Catalyst Screening Program - '75

At this time, Ford is still screening a limited number of oxidation catalysts although they realize there is no time for this effort to have a major input for their 1975 cars. Ford has done extensive screening of both base and non-platinum noble metal catalysts searching for a potential replacement for platinum.

To date, only cobalt oxide has been found to be as effective for oxidation but cannot, as yet, be applied to a support.

The unsupported cobalt oxide fuses together too extensively for vehicle use. Platinum-containing catalysts continue to be the most effective oxidation catalysts. Ford is also continuing efforts to develop better monolithic support materials for these platinum-containing catalysts.

New catalysts submitted to Ford undergo a laboratory screening test followed by engine dynamometer tests. Both procedures are described below.

In the laboratory testing apparatus, Ford measures the effectiveness of both fresh and aged catalysts for HC and CO oxidation. The efficiency of a catalyst for converting HC and CO at constant temperature in a simulated exhaust gas is measured. The steady state conversion measurement is then repeated at 75° temperature increments. Ford then calculates a parameter called the activity index from the temperatures (° F) required for 25, 50 and 75% conversion using the formula below:

$$AI = \frac{T_{25\%} + T_{50\%} + T_{75\%}}{300}$$

Typical values range from 1, for a highly effective catalyst, to 10, for an inactive one. As a rule, activity indices are higher for HC than CO conversion. This parameter is a good measurement of fast warm-up which is necessary for good results on the FTP.

The laboratory aging process mentioned above is a thermal aging in the presence of air containing 10% water vapor, about the value found in automotive exhaust. This aging is done at higher temperatures (about 1500° F) for periods of about one week. Aging frequently numerically increases the HC activity index number mentioned earlier more than that for CO, i.e., greater deterioration of HC effectiveness.

In addition to the above laboratory test, promising catalysts are further screened by an engine dynamometer durability test. The exhaust from a 240 CID six-cylinder engine is passed through six catalysts in parallel. The engine is run at 1800 rpm and partial load for 300 hours. Catalyst temperatures are unusually high at 1850° F. Conversions for HC and CO under steady conditions are frequently measured.

Also, a simulated cold start is included to measure catalyst effectiveness during light-off conditions. The temperature at which 50% of the HC is converted can be used to compare catalysts and can be correlated to a large degree with effectiveness over the FTP. However, Ford provided no specific numbers to prove or illustrate this correlation.

Progress and Problem Areas - '75

Progress

Ford has made progress in two areas in the last year, durability testing and system development. Ford's Riverside West durability program is nearing completion, except for the Pintos. The progress attributable to this year-long development durability program has been mainly in the area of experience in durability testing of emission control systems employing catalytic converters.

Ford has also made progress in the development of a quick heat intake manifold, similar in concept to GM's EFE manifold.

Problems

Ford's greatest problems with respect to 1975 emission control systems lie in the lack of durability testing of full 1975-type systems. While the results from Riverside are most extensive that Ford has generated to date on 1975-type systems, the catalysts used on these vehicles have now been superseded by a later version which Engelhard considers to be superior and none of the vehicles was equipped with Ford's own recently developed quick heat manifold. Ford's status report on their 1975 development did not indicate that any vehicles had yet been tested with the quick heat manifold incorporated into an emission control system that included a catalyst.

Ford's Group IV (Riverside East) fleet is intended to be a demonstration of more current technology with more up-to-date catalysts and improved control systems. These vehicles were originally scheduled to be ready to start mileage accumulation by May 31, 1972. However, at the time of the writing of this report, the vehicles in Group IV had just begun the durability testing and Ford did not report any emission data from the Group IV vehicles. Ford did not report that any of the Group IV vehicles were equipped with a quick heat manifold.

The reason given by Ford for this greater than six-month delay in the initiation of the Group IV durability testing is that there were some unexplained low mileage catalyst failures requiring replacement.

Conclusions - '75

The report team concludes that Ford will probably be able to certify for 1975. They have been grouped into class 75-2.1, Catalytic System Approach - Above Average Development Status. Most of the vehicles run to high mileage have demonstrated reasonably low deterioration factors. Many vehicles have extrapolated 50,000-mile emission values close to the 1975 levels despite the fact that they are not equipped with full effort systems. Data supplied by Ford on vehicles equipped with quick heat intake manifolds (but no catalysts) indicates that significant emissions reductions are likely to be realized when the quick heat intakes are installed on catalyst-equipped vehicles.

The data which will be generated on Ford's Group IV fleet will provide a better indication of their potential for certifying than have previous fleets since these vehicles will have more complete systems and later generation catalysts.

6.1.3.2 1976 Development Status

Systems to be Used - '76

The prime 1976 system for Ford is basically the 1975 system with the addition of a NO_x catalyst. This approach is typical of that being taken by all other U. S. manufacturers and most foreign manufacturers. More extensive modifications, however, may be made to the 1975 system for 1976. Ford reported the possibility of using programmed air injection and programmed EGR flow on the 1976 system. Some 1976 prototypes also use low thermal inertia (LTI) exhaust manifolds and modified combustion chambers. The combustion chamber modifications will feature higher compression ratio and increased turbulence.

If the "programmed" EGR control under consideration provides full-time proportional recirculation then higher compression ratios may be possible, in the judgment of the report team, without increasing the octane of unleaded fuel since EGR acts as mechanical octane. Many current engines with EGR systems require low compression ratio because the EGR is not proportional to inlet air flow and under some conditions, particularly high load, there is very little or no recirculation and therefore no mechanical octane effect.

Several different types of NO_x catalysts have been considered by Ford, but work is now concentrated on the noble metal monolithic units. Metallic catalysts are receiving less attention. The best low mileage results reported by Ford, however, were on a vehicle using metallic NO_x catalysts. The average of four tests was .33 gpm HC, 2.27 gpm CO, and .28 gpm NO_x. The best results reported for the noble monolith system were .36 gpm HC, 3.24 gpm CO, and .38 gpm NO_x (average of 5 tests). Based on the data reported it is not apparent why the metallic NO_x catalyst system is not the first choice system.

It is difficult to discuss details of the Ford 1976 system since the Ford program, like that of most manufacturers, is still in the research and development state. Although there was very little data reported in their status report, it appears that Ford is not experiencing significant fuel economy penalties with the 1976 systems they are developing. Estimated cost of the 1976 system has not yet been reported.

No other U. S. manufacturer is closer to production on "alternates" to the conventional pre-mixed charge, spark ignition engine than Ford. The stratified charge (PROCO) engine has been able to achieve the 1976 NO_x level without the use of NO_x catalysts on a 4500 pound vehicle. The PROCO engine uses direct cylinder fuel injection and high EGR rates to achieve this control. The stratified charge combustion itself results in lower NO_x levels due to the fact that a significant portion of the mixture burns in a rich zone where NO_x does not form easily. More importantly, the stratified charge operation increases the EGR tolerance of the engine allowing higher EGR rates than are practical on conventional engines. High HC and CO emissions are a problem with the engine. Oxidation catalyst technology, however, is significantly further developed than reduction catalyst technology. Because of this, an engine such as the PROCO, which requires catalysts for HC and CO but not for NO_x, currently has a better chance of success than an engine which might require catalysts for NO_x but not for HC and CO.

At low mileage, a 4500 lb PROCO-powered Mercury Montego equipped with noble metal oxidation catalysts has achieved .33 gpm HC, 1.08 gpm CO, and .39 gpm NO_x. A small PROCO-powered vehicle (2500 lb Capri) has achieved .11 gpm HC, .27 gpm CO, and .32 gpm NO_x. Both of these vehicles had better fuel economy than current 1975 model vehicles of the same weight.

The PROCO system is not considered by Ford to be a serious 1976 system because of lead time constraints. Earliest possible model year for limited production is estimated by Ford to be 1977.

Another Ford engine concept under development is reported to have similar lead time problems. The "Fast Burn" engine achieves low NO_x levels without catalysts by employing high turbulence to shorten combustion time (hence the term "fast burn") and by using high EGR rates. As with the PROCO engine, high HC and CO levels are the major problem. The engine uses a cupped piston to obtain high turbulence but this piston increases the surface-to-volume ratio and, therefore, causes HC problems. The high EGR rates used adversely affect both the HC and CO emissions. The rapid combustion of the Fast Burn process also tends to lower the exhaust temperature which makes it more difficult for the catalysts to work effectively.

Using oxidation catalysts, Ford has achieved .35 gpm HC, 1.59 gpm CO, and .37 gpm NO_x at low mileage on a 4500 lb Fast Burn powered vehicle.

Questor has reported that Ford has also tested their Reverter system and three consecutive tests run on Questor's vehicle at Ford were all below the 1976 levels. Ford's status report, however, made no mention of the Questor testing or of any development planned for the system.

Durability Program - '76

Ford Motor Company has reported that a limited 1976 durability program has been initiated. This program is not nearly as comprehensively designed as that for their 1975 prototype system. No vehicles have completed 50,000 miles of durability. Basically Ford's primary system approach at this time appears to be a dual bed catalyst with an exhaust gas recirculation system. The purpose of their current testing is to evaluate those catalysts which have performed well through a screening process on an AMA-type durability schedule. Apparently, no attention has been paid at this point to the experimental design with respect to vehicle mix and maintenance. Rather the current effort is a purely developmental one. Several of the vehicles in the program were designed as IIEC (Inter-Industry Emission Control Program) systems with an oxides of nitrogen goal of 1 gram per vehicle mile, more than double the 1976 Federal requirement.

All of the vehicles in the Ford program thus far have demonstrated high deterioration of NO_x control, with the possible exception of the 141 CID PROCO vehicle being run. At 22,000 miles it remains below the 1976 Federal requirements although an oxidizing catalyst change was required at about 13,000 miles.

Ford Motor Company has not reported the successful attainment of 50,000 miles of operation on any 1976-type emission control system.

Catalyst Screening Program - '76

The NO_x catalyst screening program at Ford is similar to that used for HC and CO catalysts. This program involves laboratory screening tests, engine dynamometer durability screening, and low mileage vehicle tests.

The laboratory screening test involves measuring HC, CO and NO removal using an artificial exhaust gas. This removal is measured as a function of temperature for fresh and aged catalysts. The catalyst samples are aged by placing them in an atmosphere containing 10% water vapor and heating the sample at 1145^{o} for a week. The rest of the atmosphere was not specified but it should, in the opinion of the report team, be different from that used for aging the oxidation catalysts (air) since NO_x catalysts in the field would usually experience highest temperatures under reducing rather than oxidizing-type conditions. The activity index is calculated from the net NO_x conversion data accounting for any ammonia production from the following formula:

$$AI = \frac{T_{25\%} + T_{50\%} + T_{75\%}}{300}$$

The values in the numerator are the temperatures (^{o} F) for 25%, 50% and 75% NO_x conversion.

The next stage in the Ford catalyst screening program is engine dynamometer tests. Steady state conditions are used in this test for monolithic units. The HC, CO, and NO_x conversions for various A/F ratios (from 13:1 to 15:1) are determined. The test apparatus is sized to contain PTX3-sized catalysts which does not permit other sizes of catalysts to be used in this test. Since only monolithic units are tested in the apparatus, this shortcoming is smaller than it would be with testing of both monolithic and pelleted catalysts.

A more serious limitation of this test which Ford did point out is that it is not as effective in evaluating base metal catalysts as it is for noble metal catalysts. Apparently, base metal NO_x catalysts do not perform as effectively in steady state tests as in cyclic-type tests characteristic of road operation. For example, a base metal catalyst may have lower steady state conversion efficiency than a noble metal catalyst yet perform equally well on a CVS-type test. Apparently, base metal NO_x catalysts function especially well with variations in A/F ratios that would be seen on cyclic tests. Ford, therefore, verifies the initial screening tests for base metal NO_x catalysts with vehicle testing.

Ford evaluated 25 monolithic catalysts by this procedure and found that only 10 could remove 80% or more NO_x. One of these was a base metal catalyst which had especially high NO_x reductions during richer operations when much ammonia was produced. When the ammonia conversion was subtracted from NO_x conversion, the net efficiency (defined as total NO_x reduction minus NH_3 production) was below 80%. Another general conclusion of this test is that maximum NO_x conversion occurs at 14.1:1 A/F ratio which is about 0.3 units richer than stoichiometric. Ford did not name the 25 units tested but did indicate one of them to be a monel-type catalyst which was not one of the ten best. Aside from this specific program for monolith catalysts, Ford specifically screens both monolithic and pelleted catalysts for NO reduction efficiency on an engine dynamometer. The conditions used are slightly different for monolithic and pelleted catalysts. For monolithic units, the following is done.

MONOLITHIC CATALYST TEST CONDITIONS

Engine Operating Conditions

65 mph, steady state, medium load

1400° F catalyst inlet temperature

800-1200 ppm NO_x, 200,000 hr^{-1} space velocity

Procedure:

1) Vary A/F ratio 13.1:1 to 16.1:1
2) Lower engine load (and space velocity) and repeat 1.
3) Repeat 1 at 1000° F catalyst inlet temperature
4) Add short pulses of secondary air into NO catalyst

PELLETED CATALYST TEST CONDITIONS

Engine Operating Conditions

1) 40 mph steady state road load, 900° F catalyst inlet temperature, 800-1200 ppm NO_x, 35,000 hr^{-1} space velocity
2) 70 mph steady state road load, 1300° F catalyst inlet temperature, 800-1200 ppm NO_x, 70,000 hr^{-1} space velocity

Procedure - not specified

Both inlet and outlet NO_x are measured. The ammonia formation is also measured.

The second major aspect of the catalyst screening program is to measure warm-up activity. The procedures used for monolithic and pelleted catalysts are similar and described below.

CATALYST WARM-UP TEST

Conditions - 40 mph road load, 1.5% CO, 2.5% O_2, 125 ppm HC, 1000 ppm NO_x.

Procedure - pass exhaust gas through catalyst cooled to 100° F - measure NO_x conversion as a function of time.

The third major engine dynamometer test done to screen NO_x catalysts is a thermal cycling-type operation. This procedure is slightly different for monolithic and pelleted catalysts and is as follows:

MONOLITHIC CATALYST THERMAL CYCLING TEST

Part 1 - steady state rich operation - 55 mph, 1.5% CO, 1500° F catalyst inlet temperature, 150 hours

Part 2 - oxidizing - reducing transients same as in part 1 but add air (1% oxygen) for two 15 minute periods each hour

Part 3 - high temperature cycle - 100 hours total

A. Acceleration to 90 mph for warm-up

B. 90 mph steady state, 1700° F catalyst inlet temperature, 43 minutes

C. 15 mph, 1100° F catalyst inlet temperature, 5 minutes

D. Cool to 300° F with air, 10 minutes

Part 4 - AMA durability cycle - time unspecified

Part 5 - higher speed (48 mph) durability cycle

PELLETED CATALYST THERMAL CYCLING TEST

Part 1 - 70 mph, 1.5% CO, less than 0.4% oxygen, 1400° F catalyst bed temperature, 10 minutes

Part 2 - cool to 100° F, 10 minutes

Part 3 - repeat 1 and 2, 120 times

The catalyst attrition is determined for pelleted catalysts as well as the standard NO_x conversion measurements. In addition, Ford has a separate test for pelleted catalysts to measure the effect of variations in the CO/O_2 ratio on the exhaust NO conversion. It is unfortunate that identical thermal cycling tests were not used on the pelleted and monolithic units which would provide a common base for comparison. Ford did not provide any data relating the two methods.

Ford provided no identification of the catalysts they tested as to manufacturer or specific type of catalyst. As a result it is not possible to identify the data developed here with screening tests of the catalyst companies.

Ford has set the following criteria for their pelleted NO_x catalysts from the above tests:

1) Warm-up activity test (fresh)
   50% HC conversion in 100 sec.
   80% CO conversion in 75 sec.

2) Activity test - NO_x conversion
   70% net NO_x conversion between 0.8-2% CO (or 2-8 CO/O_2 ratio) at 1000° F (35,000 hr^{-1} space velocity) and/or 1300° F (70,000 hr^{-1} space velocity)

3) Thermal cycling test
less than 5% attrition

4) Warm-up activity after thermal cycling
45% HC reduction in 100 sec.
70% CO reduction in 75 sec.

5) Activity test - NO_x conversion
60% efficiency under conditions
outlined in (2)

HC and CO activity criteria are probably based on the need for this catalyst to operate as an oxidation catalyst during vehicle warm-up. Ford did not give the criteria of acceptance for monolithic catalysts from the tests described above.

Pellet catalysts that meet the criteria above are then subjected to vehicle tests. The emission level goals for vehicle tests after 100 miles are 1.0 gpm HC, 4.0 gpm CO, and 1.0 gpm NO_x (1975 CVS test procedure). Catalysts meeting these criteria are subject then to vehicle durability tests.

Ford has conducted dynamometer durability tests for catalysts but did not mention how these tests fit in with the ones described earlier. The test takes 300 hours and is composed of the following three modes:

	Mode 1	Mode 2	Mode 3
Speed (rpm)	2200	675	675
A/F ratio	13.5-14.0	13.5-14.0	13.5-14.0
Space velocity (hr^{-1})	20,000	10,000	10,000
Exhaust O_2 (%)	0.2	0.2	0.2
Time (minutes)	42	5	5
Catalyst inlet temp. (^{o} F)	1300	700	650

The HC, CO, and NO_x conversion efficiency are evaluated every 50 hours at steady state conditions of 1000° F catalyst inlet temperature, 60,000 hr^{-1} space velocity, and various A/F ratios (13, 14 and 15:1). Ford did not specify what the criteria for passing these tests were. Frequently throughout the Ford section on catalyst screening they did not describe the criteria for passing nor give any indication on how such criteria could be derived.

Progress and Problem Areas - '76

Progress

Ford has made enough progress during the past year on 1976-type emission control system development to be able to indicate a "prime" or first choice emission control system. The system in its present configuration is a typical 1976 system (dual catalyst, air injection, engine modification, EGR, improved induction system) and the catalysts both have ceramic monolith substrates. The active material for the HC/CO catalyst will be platinum, but the NO_x catalyst may have either a base metal or a precious metal as active material. Ford has progressed enough to be able to rule out the other approaches that they have investigated. They have done this by making some progress in catalyst screening and durability testing. In fact, the 21,000-mile durability run reported by Ford is one of the longest reported to date.

Problem Areas

Ford's largest single problem area with respect to 1976-type system development is the lack of a NO_x catalyst with adequate durability. The durability of the other components of the 1976 system, including the HC/CO catalysts, do not at this time appear to be unsatisfactory.

Conclusions - '76

The report team concludes that Ford's chances of certifying in 1976 are questionable. They have been grouped into class 76-2.1, Catalytic System Approach - Average Development Status. Although the 1976 levels have been achieved at low mileage on at least five different systems (dual catalyst, dual catalyst with metallic NO_x catalyst, PROCO, Fast Burn and Questor), Ford has not demonstrated the required levels at high mileage on any of these systems. The two systems which do not require NO_x catalysts to achieve .4 gpm are not considered feasible because of lead time constraints. The first choice system seems to have more severe deterioration problems than the two systems which employ metallic NO_x catalysts.

6.1.4 GENERAL MOTORS (GM)

6.1.4.1 1975 Development Status

Systems to be Used - '75

Two different systems are receiving primary consideration for GM's 1975 production. Engine modifications including high energy ignition (HEI), modified carburetion, quick heat intake manifolding (called the Early Fuel Evaporation or EFE manifold), EGR, and air injection are common to both systems.

One system, the "underfloor system", utilizes a pellet-type oxidizing catalyst located under the passenger compartment. The other system, the "Manifold Emission Control System" (MECS), uses either pellet or monolithic catalysts housed in a modified exhaust manifold. GM did not report whether or not either of these systems is their first choice system or whether or not both might be used in 1975.

Several of the non-catalytic components being developed by GM are worthy of comment. The GM Early Fuel Evaporation manifold allows significantly leaner carburetor calibration during cold start and warm-up. The exhaust of either four, six or eight cylinders is diverted through crossover passages in the intake manifold during start-up.

The intake charge is vaporized with the assistance of heat transferred from the exhaust gas through a high heat transfer section which divides the intake passages and the exhaust crossover. The following emission levels have been obtained without catalysts:

1975 FTP			
No. of cylinders diverted through intake during cold start	Grams Per Mile		
	HC	CO	NO_x
8	.70	5.2	1.64
6	.68	5.4	1.41
4	.54	6.4	1.38

The NO_x levels reported above indicate that EGR was probably used on the vehicle.

The high energy ignition system allows plug gaps of .060 inches compared to .030 - .035 used with conventional ignitions. This reduces the engine's tendency to misfire with lean or non-uniform mixtures. The high energy system is also more resistant to misfire induced by spark plug fouling. The possibility of catalyst over-temperature problems is significantly reduced. 50,000-mile spark plug life may be possible with this system, when unleaded fuel is used. To determine whether or not this is feasible, GM is currently running several vehicles on durability which are not receiving spark plug changes at 24,000 miles.

Besides working on modifications for their current carburetors, GM has two new carburetors under development. One of the new units, the APACHE (Anti-Polluting Altitude Compensating High Efficiency) carburetor is an offshoot of the current Quadrajet. It features adjustable primary metering which allows tailoring of each carburetor individually.

The other new carburetor is based on a totally different concept. The Integrated Fuel Circuit (IFC) carburetor replaces the conventional idle, cruise, and power circuits with a single metering system. Transition problems between different circuits are eliminated. The IFC carburetor utilizes a diaphragm controlled air valve to maintain a constant depression above the throttle. The constant depression feature should, in the judgment of the report team, facilitate the use of proportional EGR systems.

Three different EGR systems are being considered for 1975. Two provide proportional control. The final selection will, in the opinion of the report team, probably be the result of a driveability/cost trade-off. GM may be able to obtain adequate driveability with the non-proportional system and the proportional system may not be used until 1976.

Almost all of the 1975 system data reported was on the underfloor catalyst system. This system has been under development much longer than the MECS and GM personnel have told members of the report team that the availability of the MECS components is currently not as good as the availability of underfloor components. The best low mileage results reported were on the underfloor systems. One of the better vehicles has achieved .22 gpm HC, .70 gpm CO, and 1.13 gpm NO_x. GM tests show, however, that the MECS system has the potential for lower emissions than the underfloor system because of the superior warm-up characteristics obtained by locating the catalyst in the exhaust manifold.

In their emission control status report submitted in November of 1972, GM did not report test data on rotary engine Vegas with 1975 control systems, although data was reported on rotarys with 1976 control systems.

GM considers cost, packaging, driveability and compatability with 1976 systems important design constraints. Compatability with the 1976 system is giving the MECS system its biggest boost since the quick warm-up characteristics of the manifold converter location will be even more important in 1976. It is the opinion of the report team that cost constraints may have delayed GM's current intensive investigations of noble metal catalysts.

Fuel economy penalties, as claimed by many manufacturers, have not been a problem for GM: "Results to date indicate the fuel economy on these advanced emission control systems is essentially the same as on the 1973 systems on the basis of fleet fuel usage data." GM estimated the retail price increase over uncontrolled vehicles, for the 1975 control system, to be $250-315. Compared to 1973 vehicles we estimate this to be about a $150-215 retail price increase. It should be pointed out, however, that the use of unleaded fuels and high energy ignitions could reduce the maintenance (mufflers and spark plugs) cost of the 1975 vehicle by as much as $100 compared to a 1973 vehicle.

GM's design of the basic engine, carburetion and ignition systems has resulted in no fuel economy penalty and lower untreated (no catalyst) emissions than most other manufacturers using conventional engines.

GM did not provide many details on the "modulating devices" they plan to use in 1975. However, they may run in the reactor (catalyst by-pass) mode during wide open throttle, above 60 mph and above 1500°F catalyst temperature. This type of system may not have significant effects on HC levels, but CO would increase significantly during the by-pass operation. GM's own data indicates there is no direct relationship between catalyst over-temperature problems and vehicle speed. Over-temperature is more related to load and engine misfire. EPA regulations will undoubtedly have an impact on the type of modulating devices used.

Durability Program - '75

The major portion of the General Motors durability program is being conducted at the Milford Proving Grounds. There are four significant objectives behind this effort:

1. To determine overall durability of the proposed prototype emission control systems.
2. To evaluate 5 different catalyst material candidates.
3. To evaluate 3 different converter sizes.
4. To identify problems incidental to an actual certification program.

Currently 39 vehicles have initiated mileage accumulation in this effort with 10 additional units still scheduled for mileage accumulation. Only seven vehicles have been operated 24,000 miles or more. From the records submitted by GM it appears that approximately 200 days are needed for 50,000 miles to be accumulated.

The vehicles selected to be operated in this program represent all of the engine displacements and vehicle weight classes that GM is anticipating to sell in 1975.

The system configurations involved in the program and some emission data are presented in the following tables. Basically two major system concepts are being investigated: The MECS approach and the more conventional underfloor oxidation catalyst approach.

Mileage accumulation is being run according to standard Federal certification procedures. Two different fuels are being used, both at lead levels of .03 grams per gallon. Maintenance cannot be considered as typical of certification practice but after reviewing the maintenance performed, it appears that it should not greatly affect the validity of the program.

CORPORATE EMISSION SYSTEM TEST MATRIX

Systems	Catalyst			Conv. Volume			Fuel	
	Noble	Mixed	Base	260	160	80	Amoco	Chevron
AIR EGR	X	X		X	X		X	X
AIR EGR EFE	X				X		X	X
AIR EGR EFE HEI	X	X		X			X	X
AIR EGR HEI	X	X		X			X	X
AIR EFE HEI		X		X			X	
CCS EGR HEI	X	X		X	X	X	X	
TRIPLE MODE SYSTEM	X			$240\ in.^3$				X

Emission systems are installed in 49 cars representing all displacement and weight classes.

DETERIORATION AND 4000-MILE EMISSIONS

Vehicle Number (catalyst number)	Major System	HC DF	HC 4000	CO DF	CO 4000	NO_x DF	NO_x 4000
#2240 @ 28000 mi. (HN 1646)	Air/EGR	less than 1.0	.41 gpm	less than 1.0	1.77 gpm	less than 1.0	1.61 gpm
#82147 @28000 mi. (HN 1290)	Air/EGR/EFE	less than 1.0	.46	less than 1.0	2.28	2.1	1.80
#2262 @ 24000 mi. (HN 1646)	Air/EGR/EFE	less than 1.0	.40	1.45	1.64	less than 1.0	1.89
#2932 @ 24000 mi. (HN 1646)	CCS/EGR	1.93	.31	3.38	1.45	1.54	1.54
#2931 @ 24000 mi. (HN 1655)	CCS/EGR	1.40	.39	1.64	1.49	1.37	1.46
#2928 @ 24000 mi. (HN 1646)	Air/EGR	less than 1.0	.38	1.83	1.54	less than 1.0	2.48
#2616 @ 24000 mi. (HN 1652)	Air/EGR	less than 1.0	.23	2.21	1.26	less than 1.0	.217

The deterioration factors were calculated by the report team by extrapolating the existing data. The vehicles used were the seven vehicles reported to have completed 24,000 or more miles.

It appears that a number of these first seven vehicles have excellent potential of completing the program successfully. None of these vehicles is equipped with the GM Triple Mode (MECS) System.

Catalyst Screening Program - '75

The General Motors basic catalyst screening program is divided into three major areas: (1) laboratory tests, (2) vehicle emission tests, (3) the AC transient efficiency test.

The initial laboratory tests measure the following physical strength parameters of the catalyst:

Compacted bulk density
Impact attrition
Abrasion resistance
Screen analysis

The compacted bulk density measures, in effect, the density of a pelleted catalyst after it has been compacted by limited mechanical vibration. The GM specification for any catalyst is that its compacted bulk density be less than 45 lb/ft^3 and is related to rapid catalyst warm-up.

The crush strength test is a measure of the resistance of a pelleted catalyst to being crushed in a vice-type machine. A similar test has been developed for monolith units.

The impact attrition test is for pelleted catalysts only and is a measure of weight loss of a catalyst after a 3-4 CFM gas flow has passed through the catalyst for 5 minutes. The catalyst is contained in an experimental glass apparatus designed so that the gas flow causes the pellets to be "fluidized" which leads to attrition. Less than 5% attrition must result for the catalyst to be acceptable.

The abrasion resistance is a somewhat similar test with the catalyst loosely packed in a metal container with wire mesh screen bottom. The sample is shaken vigorously for 30 minutes and must lose less than 0.5% weight to pass the GM criteria. The screen test is a test involving shaking the catalyst pellets through various mesh size screens to determine the size distribution of the pellets.

For monolith units, tests are run on crush strength (mentioned above), thermal shock (ability of the catalyst to withstand temperature changes), thermal expansion and water absorption.

The second major area of laboratory tests involves measuring HC and CO conversion with a bench-type apparatus with simulated exhaust gas. The simulated exhaust gas has the following composition:

CO	1.0%
O_2	2.5%
HC	0.02%
NO	0.1%
N_2	remainder

The temperature at which 50% conversion occurs is measured and must be lower than 600°F and 500°F for HC and CO respectively, to successfully pass this test. In addition to this, the effect of 1600°F, 1700°F, and 1800°F temperatures for 24 hours on light-off temperature is measured. The change must be less than 100°F for both HC and CO. Limited vehicle emission tests are then done to obtain the actual emissions on a 1975 FTP. The goals for these tests are as follows for a fresh catalysts:

0.2 gpm HC
2.0 gpm CO
3.0 gpm NO_x

For an aged catalyst, any levels below those of the 1975-76 standards are satisfactory. These vehicle tests are the second major catalyst screening tests used by GM.

The third major type of catalyst screening test is called the AC transient efficiency test which is an engine dynamometer test. Little detail was given on this test procedure. However, a measure of warmed-up catalyst efficiency is obtained which supposedly correlates with the 50 mph steady state conversion on a vehicle. Also, a prediction is made of the results on the 1975 FTP from a specified dynamometer driving schedule. The engine dynamometer tests involve the measurement of emissions with the following type tests:

1. Simplified limited durability test with a 50 mph average speed.
2. Catalyst stability evaluation with lower speed and temperature conditions realized in urban-type driving which result in sulfur deposition and poisoning.
3. Temperature and time effects.
4. Measurement of lead, phosphorus, and poisoning caused by oil contaminants.
5. Transient efficiency under either oxidizing or reducing conditions.
6. Extended dynamometer durability test consisting of eleven 4-mile laps under varying speed conditions (30-70 mph). This test can be run for the equivalent of 50,000 miles.

Catalysts which successfully complete the screening programs are then installed on vehicles for more extensive tests.

Progress and Problem Areas - '75

Progress

GM has made significant progress in several areas during the past year. The major areas in which significant progress has been made are: (1) possible catalyst choices, (2) durability testing, (3) new system development.

In the area of possible catalyst choices, GM is actively testing precious metal pellet, promoted base metal pellet, and precious metal monolithic catalysts.

The precious metal catalysts use platinum and/or palladium as active materials in various proportions. The promoted base metal catalysts use primarily base metals as active materials, with a small amount of precious metal as a "promoter" to enhance the catalytic activity of the combination of active materials. The precious metal monoliths are similar to those being tested by many other manufacturers.

The reason for the expanded interest and progress in catalysts containing precious metals is the poor durability performance of the base metal catalysts that GM had been concentrating most of their effort on in the past.

The durability testing program that GM is conducting shows the superior performance of the more recent catalyst choices, and also shows the progress that GM has made in the last year in durability testing. Moreover, GM has made significant progress in durability in the last eight months. Since the April 1972 Suspension Hearings when GM reported very little in terms of extended mileage durability results, due to poor catalyst durability performance, GM has initiated a durability fleet test program which is the most comprehensive in the industry. The test program, involving more than

50 vehicles and including most of GM's engine families, appears to be being conducted in an efficient manner. At the time that this report was written the results appear to be encouraging (see the section on durability testing program).

Another area in which GM has made significant progress is in the area of new system development. GM's typical 1975-type emission control system has consisted of, among the other items, a catalytic converter of the "underfloor" type - a wide flat type of container in which the pellet catalyst is placed. However, in the last eight months GM has developed an entirely different catalyst system which is now considered by GM to have at least as much potential as the underfloor-type. This system is the so-called "MECS" system (MECS for Manifold Emission Control System). Since GM made no mention of this system in their April 1972 suspension application, or at the ensuing hearings, it must be assumed that the development of this system has taken place in the last eight months. The rate of progress that appears to have taken place with this system, from essentially an idea to the position of being considered a serious candidate for production for model year 1975, is extremely rapid, and perhaps unprecedented. The underfloor converter concept has been under development for at least 22 months, as a comparison.

Problem Areas

At the time of the writing of this report it appears that GM has two major problem areas with respect to the development of their 1975 emission control systems.

1. The HC control demonstrated to date in GM's durability fleet is not as good as the CO and NO_x control. That is, the HC levels of many of the durability vehicles is much closer to the .41 gpm HC standard than either the CO or NO_x levels are to their standards of 3.4 gpm and 3.1 gpm respectively.

2. GM will shortly have to make major decisions concerning the type of emission control systems to be used in each of their many engine families to ensure that the remaining time for development and production of the chosen systems and components is adequate to meet model year 1975 requirements.

Conclusions '75

The report team concludes that GM will probably be able to certify for 1975. They have been grouped into class 75-2.1, Catalytic System Approach - Above Average Development Status. The data reported on the vehicles undergoing durability testing indicates that system deterioration is low enough that the 1975 levels can be maintained for 50,000 miles. Many of these vehicles are not even full effort systems employing quick heat intake manifolds and proportional EGR. Data available from a quick heat manifold development vehicle indicated that the 1975 levels could be achieved with only 40% cold start catalyst efficiency for both HC and CO. It should be noted that this particular vehicle was also running at one half the 1975 NO_x standard. Many catalysts tested by several different manufacturers (including GM) have retained at least 40% cold start conversion for 50,000 miles.

6.2.4.1 1976 Development Status

Systems to be Used - '76

GM's primary 1976 systems are the basic 1975 systems, underfloor and MECS, with NO_x catalyst added. Carburetion will be richer to produce a reducing atmosphere before the NO_x catalysts. The MECS system will have both the oxidation and reduction catalysts mounted in the exhaust manifold. The underfloor system will also have the NO_x catalyst mounted in the exhaust manifold but the oxidizing converter will be under the passenger compartment as in the '75 system.

Also reported was the development of a 3-way catalyst with oxygen sensor on a fuel injected Opel engine. The oxygen sensor aids in the achievement of a constant air/fuel ratio near stoichiometric. At this air/fuel ratio simultaneous reduction of NO_x and oxidation of HC and CO can be accomplished in a single catalyst.

GM is also working on the Questor Reverter emission control system. This system uses thermal reactors to control HC and CO with a high temperature metallic reduction catalyst for NO_x. A more complete description of the Questor system appears in Section 5 of this report.

Data was also reported on the rotary engined Vega equipped with a manifold dual catalyst system.

The best low mileage results reported on the underfloor system were .17 gpm HC, .99 gpm CO and .19 gpm NO_x. This vehicle used a UOP noble metal oxidation catalyst and a titanium phosphide reduction catalyst.

The best MECS results were .15 gpm HC, 1.9 gpm CO and .34 gpm NO_x. This vehicle used Matthey-Bishop AEC 8A catalysts for oxidation and reduction. GM reported that tests have been run using a metallic NO_x catalyst in the MECS system but no data was provided.

The Opel 3-way catalyst, oxygen sensor, electronic fuel injection system has achieved .22 gpm HC, 2.45 gpm CO and .26 gpm NO_x using a Degussa catalyst.

The best results with the Questor system (full-size vehicle) were .05 gpm HC, 2.65 gpm CO and .27 gpm NO_x.

None of the rotary data reported was below the 1976 levels. No tests were reported with hydrocarbon levels at or under the required .41 gpm.

Of all of these tests the Questor results are the only results obtained with a system that is lead tolerant. Lead contamination is a big problem with the other systems but the Questor system is known to have a high level of lead tolerance. The biggest question with the Questor system is durability. GM has mentioned that some Questor system vehicles may be starting durability shortly. Another important problem with the system may be fuel economy. GM did not mention this area or any development work to improve the fuel economy of vehicles equipped with this type of system.

It might be noted that even though the Questor system has lower emissions than the MECS system and has been under development longer than the the MECS system it has not been put on durability by GM as yet but the MECS system has. GM has, however, done more work on the Questor system than any other manufacturer.

The use of "auxilary devices" on GM's 1976 systems could cause emission levels to be higher than those from uncontrolled vehicles during certain operating conditions. Most of GM's candidate systems for 1976 operate richer than stoichiometric. HC and CO emissions could be quite high if the oxidation catalysts are by-passed. By-passing of the NO_x catalyst is planned for high speed operating modes. Data previously reported by GM indicated the 1976 MECS system could have higher NO_x emissions at 60 mph than uncontrolled cars.

GM estimated that the retail price increase due to the 1976 system would be about $315-430 compared to uncontrolled vehicles. No estimate was made of the change in fuel economy expected. This will depend on which system is used and how well it is refined and developed. If the 3-way catalyst approach is successful then there may be, in the judgment of the report team, no fuel economy penalty at all.

Durability Program - '76

General Motor's 1976 durability program is treated as a direct spin-off of their 1975 program since the corporate philosophy of developing a 1975 system involves designing a system which can be simply integrated into the 1976 system concepts. Thus, the basic approach to a 1976 durability program is as was outlined previously in their 1975 program. Currently the 1976 program has only just been initiated. 39 low mileage experimental vehicles were reported with three vehicle systems accumulating as much as 13,000 miles. A second program is being initiated with the cooperation of the California Division of Highways. A fleet of 25 Chevrolets and 25 Oldsmobiles will be operated by state personnel and tested at specific mileage intervals by the GM California lab. 37 of these vehicles will be 1976 prototypes, the remainder being 1975's. The purpose of this program is to measure system durability in quasi-consumer use.

Of the three vehicles GM has run thus far, all have been equipped with EGR and HC/CO and NO_x converters. All three were 350 CID Chevrolets. In each case the .40 grams per mile 1976 standard was exceeded before 3000 miles was accumulated. Due to these poor conversion characteristics only one of the three systems is still under mileage accumulation.

Due to the preliminary nature of the 1976 program to date no realistic assessment of GM's durability characteristics is feasible currently.

Catalyst Screening Program - '76

The GM catalyst screening program for their 1976-type catalysts is very similar to that described earlier for the 1975 oxidation-type catalysts. This program consists of initial laboratory tests followed by vehicle emission tests and engine dynamometer durability tests.

The initial laboratory test involves the following tests to measure physical characteristics of the catalysts:

Compacted bulk density test
Crush strength test
Impact attrition test
Abrasion resistance test
Screen analysis test

These tests and the criteria for passing them were more fully described in the 1975 section on catalyst screening tests. Following completion of the above tests and measurement of NO reducing ability using a synthetic exhaust gas, the catalyst is subject to the same vehicle and dynamometer durability tests described earlier for oxidation catalysts.

Progress and Problem Areas - '76

Progress

GM has made progress in the past year in the areas of system development and catalyst selection/screening for 1976 systems.

The development of 1976 systems is now concentrated on two system types, the 1975 HC/CO underfloor converter with NO_x converters in the exhaust system ahead of it, and various configurations of the MECS system. Enough progress has been made in the past year on 1976-type emission control systems to warrant limited durability testing of some more promising configurations. Last year GM reported little success in meeting the 1976 levels even at very low mileage.

GM has made progress in the testing of a control system that is different from their more typical systems. GM is working with the Questor Corporation on the development and testing of their Reverter system. Pontiac is the lead division in this effort.

GM is also working on the lambda sensor-type emission control system (3-way catalyst) which shows some promise of achieving 1976 emission standards with good fuel economy (operation as rich as dual catalyst systems is not required). Work on this system, however, was reported only for the Opel.

GM has also made progress in the catalyst selection/screening process for NO_x catalysts for 1976-type systems. Precious metal catalysts have been tested that minimize the ammonia formation problem, and much progress has also been made in the area of metallic NO_x catalyst testing.

Problem Areas

GM's major problem with 1976-type emission control systems is the durability of the NO_x catalyst. Even the most promising system that has achieved the 1976 emission levels at low mileage has exceeded the required levels in a few thousand miles. Beside the problem of not maintaining adequate conversion efficiency, the physical durability of the monolith is also reported by GM to be a serious problem.

Conclusions - '76

The report team concludes that GM's chances of certifying for 1976 are questionable. They have been grouped into class 76-2.1, Catalytic System Approach - Average Development Status. GM has not demonstrated any system which could achieve the 1976 levels at high mileage. Data reported by GM indicated that their two primary systems cannot consistently achieve the 1976 levels even at low mileage. The system which appears to be the most consistent at low mileage (Questor) has not yet been run on durability by GM.

The report team also concludes that GM may have a slight advantage over many manufacturers with respect to 1976 system development, due to their association with Questor.

6.1.5 INTERNATIONAL HARVESTER (IH)

6.1.5.1 1975 Development Status

Systems to be Used

International Harvester's first choice 1975 emission control system consists of engine modifications (including quick heat intake manifold and solid state ignition), EGR and an oxidizing catalyst with air injection. There are no back-up systems as such but IH still has eight or nine different catalysts and four different EGR systems under consideration which could be used in the first choice system. The catalysts under consideration are supplied by five different sources: UOP, Monsanto, W.R. Grace, Engelhard and Matthey-Bishop. Promoted base metal pellets, noble pellets and noble monoliths are all under consideration. Most other manufacturers are not still this indefinite about their catalyst preference.

The four EGR systems consist of the non-proportional 1973 system and three new proportional systems. It was not clear how many of IH's 1975 prototypes are equipped with one of the proportional systems, but it is the judgment of the report team that not very many vehicles are so equipped. IH realizes the deficiencies of the 1973 system: "The current system does not enable optimization of driveability at a given NO_x level, due to its inherent non-proportionality as a function of engine load." IH considers driveability an important constraint, so they may use one of the proportional systems on their 1975 models. They also, however, consider cost an important constraint and this may be why they have been reluctant to decide on a proportional system.

IH will begin phasing in a new series of larger V-8 engines in 1975. Cylinder heads on the new engine will be designed to minimize heat loss, thereby, reducing the time necessary to achieve "light-off" of the catalyst. In 1976 the new series large V-8 will completely replace the current large V-8 and a new series of smaller V-8's will be introduced.

The best low mileage results reported by IH were .21 gpm HC, 2.39 gpm CO, and 2.56 gpm NO_x. Most other manufacturers have done better than this. IH has claimed they are severely handicapped because many of their vehicles must be tested at the 5,500 pound inertia weight. There is a definite disadvantage in having a high test weight, but other manufacturers are doing much better at this same weight. The IH vehicles have a relatively high gross vehicle weight (GVW = vehicle weight + maximum cargo load), but an air pump diverter valve to protect the catalyst from over-temperature when the vehicle is heavily loaded or pulling a trailer can and will be used.

No data was reported on fuel economy. The retail cost estimate for the 1975 system was $309 over the 1973 system.

Durability Program - '75

International Harvester is currently operating three fleets of vehicles under their durability program. While one fleet is utilized for complete system durability evaluation, the other two fleets are designed to evaluate component durability. The Fort Wayne component durability fleet is primarily used for catalyst testing but as other more advanced 1975 systems become available they will be integrated into the vehicles. The Phoenix Proving ground fleet is also used primarily for catalyst evaluation. The third durability fleet which will incorporate completed 1975 systems on six vehicles is currently being built up, but is not yet in operation.

Currently IH has three different engine types in vehicles reported to be under way in their durability program: 345 CID, 392 CID, and 440 CID. All are tested at 5500 pounds inertia. These engines represent two of four families used in 1972. The 440 CID is a new engine line. It appears that IH has not included small displacement engines in their development testing program.

Three different mileage accumulation routes are available for use. In Phoenix the two routes are non-standard with higher average speeds than the route available in Fort Wayne which has been accepted as a suitable certification route. Currently there are vehicles being operated on each of the three road routes. No discussion of maintenance practices being used was made in the IH submittal. Of the four vehicles currently under test only one has accumulated in excess of 20,000 miles and has consistently demonstrated levels of hydrocarbon and carbon monoxide in excess of the 1975 Federal standards along with high carbon monoxide deterioration. Thus, at this time, none of the IH vehicles reported have demonstrated the ability to control emissions below the 1975 levels at high mileage. However, the vehicles under test are not full-system vehicles.

Catalyst Screening Program - '75

International Harvester did not include any information on catalyst screening in the report they submitted to EPA.

Progress and Problem Areas - '75

Progress

IH reported that they have made substantial progress in low mileage emissions. IH reported that they are now able to reach

1975 emission levels, using prototype components, especially assembled and tuned by engineering personnel, at low system mileage.

Problem Areas

IH has not been able to demonstrate adequate durability in any of their emission control systems. Highest mileage to date without exceeding any one of the standards is approximately 4,000 miles.

IH also voiced concern regarding the mass production of unproven components, the lack of firm fuel contaminant regulations, and the problem of converter over-temperature when heavy loads, such as trailer pulling, are experienced.

Conclusions - '75

The report team concludes that it is unlikely that IH will be able to certify for 1975. They have been grouped into class 75-2.3, Catalytic System Approach - Below Average Development Status. IH has not been able to demonstrate the capability of staying below the 1975 levels beyond 4000 miles.

6.1.5.1 1976 Development Status

Systems to be Used - '76

The IH 1976 system is basically the 1975 system with a NO_x catalyst added and air injection and carburetor calibration modified to maintain a reducing atmosphere at the NO_x converter inlet. NO_x catalysts from Matthey-Bishop, Gulf, Solar, Gould, and Engelhard are being considered. Only the Gulf and Matthey-Bishop catalysts have been tested.

IH indicated that proportional EGR systems are being considered for 1975. They were more definite about the possibility of using proportional EGR for 1976, than for 1975, stating, "The 1976

EGR system will require more precise metering relative to engine air flow demand as compared to the 1975 system."

The best low mileage results obtained to date have been .438 gpm HC, 6.63 gpm CO, and 1.20 gpm NO_x. This was using the Matthey-Bishop monolithic NO_x catalyst and a Monsanto pelletized oxidation catalyst in an AC container. All other U.S. manufacturers and most foreign manufacturers have done better than this.

Work on electronic fuel injection (EFI) was also reported. Production design prototypes are to be available in March of 1973. No data was reported on any vehicles using EFI. IH reported that they are "...keeping abreast of development on the Questor system through a signed confidential disclosure agreement with the Questor Corporation." The possibility of installing a Questor system on an IH vehicle was reported.

It is the judgment of the report team that the Questor system combined with EFI might be the easiest way for IH to meet the 1976 levels. This is perhaps an example of an approach they may take since their development approach seems to be that much of the componentry necessary to meet the emission standards must be supplied by vendors rather than the IH engineering organization.

They will have to accelerate their pace of 1976 system development since their program is judged to be well behind a schedule which would be necessary to meet 1976 model year production deadlines.

Durability Program - '76

Currently International Harvester has not initiated any durability program on a 1976-type system. Only one vehicle currently has 1976 hardware installed and it is demonstrating high oxides of nitrogen in a zero mile test.

Catalyst Screening Program - '76

International Harvester did not report on any catalyst screening program for NO_x catalysts. They did indicate that they are working with the following catalyst suppliers:

Matthey-Bishop, Inc.
Gulf
Solar Division, IH
Gould, Inc.
Engelhard

Progress and Problem Areas - '76

Progress

IH reported progress in the design and development of various system components to be used in their 1976 emission control system.

IH is also discussing the possible application of a Questor Reverter emission control system with the Questor Corporation.

Problem Areas

The 1976 development is proceeding slowly due to the fact that much effort is being expended on the 1975 system. Catalytic converter availability is also a problem. The lowest emission result of the three tests reported by IH was HC = .438, CO = 6.63, and NO_x = 1.20. The HC and CO results are over the required 1975-76 levels and the NO_x is three times higher than the required 1976 NO_x level. IH did not report any durability testing results.

Conclusions '76

The report team concludes that it is unlikely that IH will be able to certify for 1976. They have been grouped into class 76-2.2, Catalytic System Approach - Below Average Development Status. IH has not been able to achieve the 1976 levels even at low mileage.

6.2 FOREIGN MANUFACTURERS

6.2.1 ALFA ROMEO

6.2.1.1 1975 Development Status

Systems to be Used - '75

Alfa Romeo markets three different vehicles in the United States. They are developing an emission control system which will be common to each vehicle, since all three vehicles are of similar weights and use a similar engine. The Alfa first choice system will consist of engine modifications, mechanical fuel injection, a base metal pellet oxidizing catalyst and a dual point distributor with provisions for retarding the ignition timing during cold start. Substitution of a noble metal, monolithic oxidation catalyst for the base metal catalyst is being considered as a back-up to the first choice system.

No other manufacturer has reported so many compromises in emission control to retain current levels of driveability, performance and fuel economy. Because Alfa is reluctant to use after-treatment devices which would affect the tuning of their exhaust system, the catalyst has been located relatively far from the exhaust ports. The heat capacity of the exhaust system between the exhaust valve and the catalyst is probably delaying achievement of the "light-off" temperature significantly. Alfa commented on moving the catalyst closer to the cylinder head by saying,"This could be help in warm-up certainly, however, it is almost disasterous in performance loss (15%)." Experiments with thermal reactors were only marginally successful because the "...thermal reactor in parallel with the exhaust manifold was designed in such a way as to not compromise or endanger the engine's performance." Alfa did not report on any plans to close-couple after-treatment devices and then restore performance by enlarging the engine displacement, a possible tradeoff, in the opinion of the report team. Considering the compromises Alfa is making, their emission results at low mileage are better than we would have expected. The first choice system produced .51 gpm HC, 3.25 gpm CO, and 1.99 gpm NO_x. Fuel economy of the '75 system is reported to be the same as the '73 vehicles. Emission control may not be as good when the vehicle is in the hands of the customer as when it is tested according to Federal procedures since Alfa is developing several "modulating devices" to be installed on production vehicles. These modulating devices include catalyst by-pass which will be activated above 4000 rpm and apparently there will be a dashboard switch for enrichment of the mixture at the driver's discretion. Alfa says that the enrichment device is necessary for operation in cold ambients. No development was reported on automatic devices to provide enrichment at cold ambients.

Durability Program - '75

Alfa Romeo's basic durability test program acts as a direct spin-off of successful low mileage demonstrations of a vehicle/system. If promising low mileage data is indicated, the vehicle will be placed on mileage accumulation. The results of one vehicle with slightly more than 15,000 miles has been reported to EPA. Further testing and mileage accumulation is planned.

The single mileage accumulation vehicle that has been run demonstrated poor initial conversion efficiency and exceeded the 1975 hydrocarbon and carbon monoxide standards at low mileage. The following deterioration factors calculated by the report team were based on only 15,000 miles of durability testing.

HC DF	less than 1.0
CO DF	less than 1.0
NO_x DF	1.1

Insufficient durability data is available to more adequately assess Alfa Romeo's durability accomplishments.

Catalyst Screening Programs - '75

Alfa Romeo did not include any information on catalyst testing in the information they submitted to EPA.

Progress and Problem Areas - '75

Progress

Alfa Romeo has made progress in the areas of system optimization and selection and in durability testing.

Enough progress has been made to enable Alfa Romeo to select a first choice and a back-up system. The two systems are typical 1975 systems. The first choice incorporates a pelleted catalyst, the back-up system employs a precious metal monolithic catalyst. Neither system uses EGR. Alfa Romeo has conducted a durability test of their first choice system. The mileage reported was approximately 15,000 miles. Very little emission performance deterioration was experienced.

Problem Areas

Although the limited durability testing done to date has shown little deterioration, the emission levels reported were above the required 1975 levels, especially in HC. Part of the lack of emission control may be due to the placement of the converter. In the opinion of the report team, some emission control may have been sacrificed for this reason. Lead time is also a problem reported by Alfa Romeo.

Conclusions '75

The report team concludes that Alfa Romeo has not yet demonstrated the capability to meet the 1975 standards. They are grouped in class 75-2.3, Catalytic System Approach - Below Average Development Status, because of their poor low mileage emission results, their apparent decisions to sacrifice emission control to maintain performance, and the limited durability testing reported.

6.2.1.2 1976 Development Status

Systems to be Used - '76

The Alfa Romeo 1976 system is basically the 1975 system with the addition of a NO_x catalyst. Both pellet and monolithic converters are being considered. Replacement of the mechanical fuel injection system with a Bosch electronic system is being considered. No data was available from any vehicle or engine dynamometer tests.

Alfa also reported development plans for a 1976 control system for the Alfasud line of vehicles, which are not yet imported into the United States. No data was reported on this system either.

Durability Program - '76

At this time Alfa Romeo has not initiated any durability program on any of their 1976 prototype systems.

Catalyst Screening Program - '76

Alfa Romeo did not include any information on catalyst testing in the data they submitted to EPA on their 1976 systems.

Progress and Problem Areas - '76

Progress

Alfa Romeo has made enough progress in the past year to be able to indicate their choice of emission control system for 1976. It is now planned to be the addition of a NO_x catalyst to the 1975 system.

Problems

Alfa Romeo reported that they have not yet been able to achieve the 1976 emission levels.

Conclusions '76

The report team concludes that Alfa Romeo has not yet demonstrated the capability to meet the 1976 standards. They are grouped in class 76-2.2, Catalytic System Approach - Below Average Development Status due to their 1975 system's poor performance, the fact that 1976 emission levels have not yet been reported (even at low mileage), the magnitude of the task of developing another emission control system for the Alfasud vehicle and the lack of any durability results on 1976 systems.

6.2.2 BMW

6.2.2.1 1975 Development Status

Systems to be Used - '75

BMW has seven 1975 systems still under consideration. Continuing development was reported on the following systems:

1. 2 liter (121 cubic inches) engine, carbureted, engine mods (EM), electric choke, EGR, air injection (AI), rich thermal reactor (RTR).
2. 2 liter engine, carbureted, EM, electric choke, EGR, AI, noble metal monolithic oxidizing catalyst (NMOC), RTR.
3. 2 liter engine, electronic fuel injection (EFI), EM, oxidizing catalyst (OC), EGR.
4. 2 liter engine, carbureted, EM, electric choke, catalyst temperature booster, pellet OC, AI, EGR.
5. 3 liter engine, EFI, EM, EGR, AI, RTR.
6. 3 liter engine, EFI, EM, EGR, RTR, NMOC.
7. 3 liter engine, EFI, EM, EGR, OC.

BMW reported that system number 4, which employs the catalyst temperature booster, has been "less successful" than the other systems because the air injection system cannot supply an adequate quantity of air during cold start operation.

BMW reported ranges of results rather than the specific results of individual tests. Systems 2 and 6 were consistently below the 1975 levels at low mileage. Both of these systems employ rich thermal reactors and oxidation catalysts. System 1, the two liter engine equipped with a rich thermal reactor, was able to achieve CO levels below the 1975 requirements without a catalyst. Hydrocarbon levels ranged from .25 to .5 gpm on this system. All the systems were consistently under the 1975 NO_x requirement.

The use of several "modulating devices" is anticipated by BMW. An engine rpm signal will be used to de-clutch the air pump and restore vacuum spark advance. This will cause a loss of emission control during high speed operation. Emissions may also be higher in urban driving than on the Federal test procedure, depending on how the vehicle is driven.

Other than indicating that the catalyst temperature booster system may be dropped, BMW has not specified which system or systems are "first choice" systems and which are back-up systems. They are waiting longer than most manufacturers to begin concentrating their development on the most promising systems.

BMW also considers the maintenance of good driveability, performance and fuel economy important constraints. BMW may utilize control methods which most manufacturers consider too expensive. BMW's estimate for the retail price of the '75 control system was $1500, the highest of all manufacturers who submitted estimates.

<u>Durability Program - '75</u>

As of the date of BMW's submittal, October 25, 1972, no evaluation of the durability of their proposed 1975 prototype systems had been initiated. The reported reason for the current lack of a program is the unavailability of acceptable catalytic systems. Optimization studies are continuing.

While no durability testing has yet been initiated, BMW plans emission testing at 1,000-mile intervals. This type of testing could significantly impact the length of time it takes to complete a program.

Due to the lack of any durability data, it is not possible to make any assessment of the potential deterioration characteristics of the BMW system approaches.

Catalyst Screening Program - '75

BMW did not include any information on catalyst screening programs in the information they submitted to EPA.

Progress and Problem Areas - '75

Progress

BMW has made progress in the last year in the area of system development and low mileage emission results. BMW has tested several different emission control systems that might be applied to meet the 1975 standards.

Some low mileage emission results have been reported to be below the 1975 levels.

Problem Areas

BMW did not report the results of any durability tests. Catalyst failures at low mileage have prevented extensive mileage accumulation.

Conclusions '75

The report team concludes that BMW has not yet demonstrated the capability to meet the 1975 standards. They have been grouped into class 75-2.2, Catalytic System Approach - Average Development Status, because of their possibly adequate low mileage emission results and their lack of durability data.

BMW may be planning to use an emission control system that is significantly more costly than that planned by most manufacturers. BMW may be developing too many systems at this point in time, instead of concentrating on the most attractive systems as have most other manufacturers.

6.2.2.2 1976 Development Status

Systems to be Used - '76

Two different 1976 systems are under development at BMW. It is not known which is the first choice system. One system uses a three-way catalyst and an oxygen sensor. The output of the oxygen sensor (called a λ-probe by BMW) is used to maintain a constant engine air/fuel ratio (near stoichiometric). At this air/fuel ratio it is possible to simultaneously reduce NO_x and oxidize HC and CO with a single catalyst. This system is being used on both the four and six cylinder engines.

The other system is basically the number one 1975 system described previously with a NO_x catalyst replacing the rich thermal reactor. Development work is apparently limited to the four cylinder engine at this time. A precious metal monolithic NO_x catalyst is used.

No vehicle emission test data was reported on either 1976 system. Based on catalyst screening test data, BMW estimates the low mileage emission levels of the three-way catalyst system will be .2-.3 gpm HC, 2.5-3.5 gpm CO and .3-.5 gpm NO_x. The dual catalyst system estimate is .3-.4 gpm HC, 1.2-2.2 gpm CO and .3-.4 NO_x.

BMW's forecasted cost increase for the 1976 control system was the highest reported by any manufacturer, $1900 more than systems on current vehicles.

Durability Program - ' 76

BMW has not initiated a 1976 durability program as optimization work has not advanced to a degree which would warrant mileage accumulation.

Catalyst Screening Program - '76

BMW did not include any information on a reduction catalyst screening program in the information they submitted to EPA.

Progress and Problem Areas - '76

Progress

BMW has made some progress in system development and low mileage emission results.

Problem Areas

No durability data was reported.

Conclusions '76

The report team concludes that BMW has not yet demonstrated the capability to meet the 1976 standards. They have been grouped in class 76-2.1, Catalytic System Approach - Average Development Status, because of their estimated low mileage results which may be equivalent to what the rest of the industry is demonstrating.

6.2.3 BRITISH LEYLAND

6.2.3.1 1975 Development Status

Systems to be Used - '75

British Leyland Motor Corporation (BLMC) manufactures many different vehicles including MG, Jaguar, Austin, Triumph, and Rover. Unlike the "Big Three" U. S. manufacturers the vehicles manufactured by British Leyland have few similarities. Both the chassis and engines are radically different among individual divisions. This makes the task of developing emission control systems more difficult because a system that is applicable to a Jaguar may be impossible to install on an Austin, for example.

All British Leyland divisions are, however, developing similar systems. Both pelletized and monolithic catalysts are being tested but most of the development is on the noble monolithic Johnson-Matthey and Engelhard catalysts. Some BLMC vehicles (the lightest ones) do not use EGR, others do. Most EGR systems used are the AC-Delco types although some work on a proportional system under development by the S. U. carburetor division was reported. Many other non-proportional EGR systems are also under development.

All BLMC vehicles will use air injection with their catalysts. No development of modulated air injection systems was reported. A variety of engine modifications are used on BLMC vehicles. Most divisions have been able to achieve emission levels about one-half of the 1975 requirements at low mileage. No fuel economy penalty over 1973 vehicles is anticipated. A retail price increase of $330 was forecasted by BLMC.

Durability Program - '75

British Leyland's durability program to date has been guided by the need to identify a durable catalytic system. 17 vehicles were reported to be involved in mileage accumulation testing. None of the vehicles have accumulated 50,000 miles. Only one vehicle at 25,000-plus miles demonstrated continued low emission performance (this vehicle subsequently suffered a failure of the catalyst substrate). Durability testing is being performed through a joint effort including 7 vehicles tested at the Pollution Control Research Laboratory. In addition, each division of British Leyland--Austin-Morris, Triumph, Jaguar, and Rover--is conducting its own durability program. Currently it does not appear to the report team that British Leyland will be able to successfully complete any 50,000-mile program by January 1973, the date they have identified as the deadline for selection of a catalyst supplier.

Currently no Rovers or Jaguars have initiated mileage accumulation. The bulk of the work to date has been done using Austin-Morris Marinas as test vehicles. Plans call for the inclusion of other product lines and the Marina is projected to have the greatest 1975 sales volume. Thus, it appears that British Leyland has designed their durability program to eventually cover their anticipated 1975-type model sales.

The vehicle configuration used in the durability testing to date have included the most advanced hardware available to British Leyland - both catalytic reactors and EGR systems. However, the need for better carburetion, choke, and ignition systems have been identified as problems. Thus, the vehicle systems not directly catalyst related cannot be judged as typical of 1975 systems.

To accelerate mileage accumulation rates a route with an average speed of 40 mph has been used. This average speed is higher than that used for certification purposes. It was reported that emission testing is conducted after tune-ups which implies more frequent than allowed maintenance on these fleets. Much of the durability mileage has employed essentially lead sterile fuel and thus doubt is cast on the magnitude of the catalytic deterioration demonstrated to date.

None of the vehicles has successfully completed 50,000 miles of operation. One car operated 25,000 miles remaining below the 1975 Federal levels. Deterioration of the emission performance on this vehicle, a Marina with an Engelhard spiral wound PTX, was slight. However, the catalyst substrate had failed and eroded by 28,000 miles and the vehicle test was discontinued.

British Leyland's greatest hurdle apparent from their reported durability program is that of mechanical catalyst failure. The frequency of these failures at best has left their current program of marginal usefulness in selecting a catalyst supplier, in the opinion of the report team.

Catalyst Screening Program - '75

British Leyland has no specific catalyst screening practices. However, they do measure warm-up performance of catalyst samples in a laboratory warm-up rig using an engine dynamometer. Both the time needed for light-off and the HC and CO effectiveness for catalysts when fresh and during durability tests are measured with this apparatus.

Progress and Problem Areas - '75

Progress

BLMC has made progress in system development and some lesser amount of progress in durability testing. The basic 1975 prime system configuration for most of the vehicle/engine combinations of BLMC appear to have been chosen, at least conceptually. Most of the systems are typical 1975 systems. Some of the lighter weight vehicles may not use EGR.

One vehicle was reported to have reached 25,000 miles of durability testing.

Problem Areas

BLMC has experienced severe catalyst durability problems. The substrate has failed in nearly every test. Even the vehicle that completed 25,000 miles, and was under the 1975 levels at that time, had a catalyst substrate failure shortly thereafter.

BLMC also expressed concern about the lead content in the proposed EPA rule, indicating that they feel it may be too high.

BLMC had experienced two problems which were not reported as major problems by other manufacturers. One problem resulted in cylinder head replacement being a common occurrence, and the other problem is the apparent difficulty in the development of an automatic choke.

Conclusions '75

The report team concludes that British Leyland has not yet demonstrated the capability to meet the 1975 standards. They are classed in group 75-2.3, Catalytic System Approach - Below Average Development Status because of their continuing severe substrate durability problems, their system's apparent problems with lead contamination even at low lead levels, their slowness in the introduction of engine modifications like hardened valve seats, their cylinder head cracking problems and their apparent gap in the development of as common a device as an automatic choke.

The number of different engine family combinations and the number of apparently independent emission control development programs within BLMC may be diffusing their efforts somewhat.

6.2.3.2 1976 Development Status

Systems to be Used - '76

The British Leyland system for 1976 is essentially the same as the 1975 system with the addition of a NO_x catalyst. BLMC indicated that the 3-way catalyst plus oxygen sensor is being investigated but no data was reported.

Only one model in the BLMC line has been able to achieve the 1976 levels at low mileage. This was accomplished on an Austin vehicle using two International Chemical Company catalysts, one for NO_x and one for HC and CO. The best results were .20 gpm HC, 1.89 gpm CO, and .26 gpm NO_x. EGR was not used and BLMC only plans to use EGR if its use is absolutely necessary. Almost all of BLMC's EGR development has been on non-proportional systems, therefore, they must associate some fuel economy and driveability problems with the use of EGR.

Durability Program - 76

No durability vehicles with 1976 prototype systems were reported on mileage accumulation by BLMC in their status report.

Catalyst Screening Program - '76

British Leyland included very little on NO_x catalyst screening programs other than to say they were similar to the tests they use for oxidation catalysts. For oxidation catalysts, warm-up performance in a laboratory apparatus and engine dynamometer are measured. The time required for light-off and NO conversion for both fresh and aged catalysts would be measured.

Progress and Problem Areas - '76

Progress

BLMC has progressed to the point where the 1976 emission levels have been achieved at low mileage. BLMC has also apparently decided that the typical (dual catalyst) system is their prime 1976 system at this time.

Problem Areas

BLMC reported that the deterioration in emission control system performance was even more severe than the deterioration of 1975 system performance. No vehicle has met 1976 levels for any extended mileage.

Conclusions '76

The report team concludes that British Leyland has not yet demonstrated the capability to meet the 1976 standards. They are grouped in class 76-2.1, Catalytic System Approach - Average Development Status because of their ability to meet the 1976 levels at low mileage, their 1975 development status, and their orally reported durability results of more than 10,000 miles below the 1976 levels.

6.2.4 DAIMLER-BENZ (MERCEDES)

6.2.4.1 1975 Development Status

Systems to be Used - '75

The Daimler-Benz first choice system for their gasoline vehicles consists of engine modifications, EGR, noble metal monolithic oxidation catalyst and air injection. Some models use electronic fuel injection while others use carburetion. Neither the fuel injection nor the carburetion system were reported to be significantly different than current systems.

A back-up system utilizing a "start catalyst" is reported to be under development but no data was provided on this system. A start catalyst can be a catalyst that "lights off" at a low temperature but is not practical for continuous use because of durability problems or hot efficiency problems. The start catalyst can be switched out of the system as soon as the main catalyst is warmed up and ready to take over. The start catalyst system has its merits from an engineering viewpoint but the added cost and complexity compared to a single catalyst system discourages many manufacturers from working on it, in the opinion of the report team.

Low mileage emission levels on Mercedes vehicles using electronic fuel injection have been as low as .08 gpm HC, .75 gpm CO, and .79 gpm NO_x. These levels are lower than those achieved by most other manufacturers. No details were provided on the exact configurations tested and no comments were made on any of the tests reported.

Daimler-Benz did not specify any information about specific design constraints but they did seem to be concerned about fuel economy and performance. An 8% power loss was claimed for the 1975 systems and a 20% fuel economy penalty, compared to 1972 vehicles was reported. Compared to uncontrolled vehicles, Daimler-Benz reported that the fuel economy penalty is 40%. EPA data on the tests of hundreds of uncontrolled and controlled vehicles, however, shows very little change in fuel economy from uncontrolled to 1972. Daimler-Benz did not present data to substantiate any of the claimed fuel economy problems.

Daimler-Benz is planning to by-pass the catalyst during high engine speed, high vehicle speed and high temperature operation. No other information on modulating devices was provided.

Daimler-Benz also uses Diesel engines in some of their vehicles. They are the only manufacturer who currently sells a Diesel-powered passenger car in this country. Combustion in the Diesel engine is significantly different than in conventional gasoline engines because of the unthrottled, heterogeneous mixture operation. Combustion is initiated by the heat of compression in the Diesel engine, rather than by a spark plug. Unlike the gasoline engine, the fuel in the Diesel is not homogeniously mixed with the air, rather it is in the form of tiny droplets. As the heat of compression vaporizes these droplets a combustible mixture is formed and burning is initiated. It is not necessary to throttle the Diesel engine because the burning of the droplet, like the burning of a match, depends on the local, not total, air supply. A gasoline engine cannot operate without throttling because its homogenous mixture would be too lean to burn at lighter engine loads.

Carbon monoxide emissions from the Diesel are very low because of the overall lean operation. CO formed during the droplet burning is easily oxidized into CO_2 during the expansion stroke because of the presence of high temperatures and excess oxygen.

Hydrocarbon emissions can be very low in a properly designed Diesel engine if the fuel spray is kept away from the boundaries of the combustion volume to avoid quenching on the "cold" surfaces of the cylinder walls and pistons.

Oxides of nitrogen emissions from Diesels can also be quite low if the fuel spray pattern and droplet sizes are controlled to reduce the availability of oxygen and nitrogen during the initial phase of the combustion.

A 1972 Mercedes Diesel, tested repeatedly at low mileage by EPA, met the requirements for 1975 easily. This testing included the use of the modified test procedure which is proposed for Diesel vehicles. Mercedes has developed an inexpensive modification for the injection system which reduces the hydrocarbon levels even further. With the modified injection system the Mercedes Diesel car emits levels of HC, CO, and NO_x approximately one-half those required for 1975.

An additional attraction of the Diesel passenger car is its inherently good fuel economy. While being tested at 3500 pounds inertia weight the fuel economy of the Mercedes Diesel was measured to be 24 miles per gallon during urban driving. No other 3500 pound or heavier vehicle ever tested by EPA has achieved urban fuel economy close to this level, the average 1973 vehicle being 14.0 miles per gallon in the 3500 pound class.

Durability Program - '75

Daimler-Benz reported that three vehicles had been placed on mileage accumulation. The highest mileage indicated was 9,000 miles and all three vehicles exceeded the 1975 Federal requirements relatively early in the mileage accumulation programs. Low mileage emission data was reported on three different engines: the 4-cylinder, 134 cubic-inch; 6-cylinder, 167.5 cubic-inch; and the 8-cylinder, 276 cubic-inch. Due to the total lack of program detail supplied by Daimler-Benz, it is impossible to assess the adequacy of the Daimler-Benz durability experimentation.

Catalyst Screening Program - '75

Mercedes supplied no information on catalyst screening activities for their 1975 systems in their October 1972, submittal to EPA. They did, however, refer back to the information they submitted at the April 1972, hearings. The only non-vehicle catalyst tests mentioned by Mercedes are engine dynamometer tests done to simulate mild, medium severe, and severe driving conditions. These test results are used to evaluate various catalysts.

Progress and Problem Areas - '75

Progress

Daimler-Benz has added a possible back-up system to their 1975 first choice system. Testing on both systems is continuing, although data was only presented from the first choice system at low mileage. Not enough information was presented by Daimler-Benz to indicate whether or not any progress has been made on the durability performance of 1975-type emission control systems.

Problem Areas

Daimler-Benz reported problems of rapid deterioration of emission performance of their first choice system. The back-up system employing a "start" catalyst may alleviate this problem. Part of the problems that Daimler-Benz is encountering may be due to the fact that their vehicle tests show that the NO_x level that they are trying to meet is approximately 1.5 gpm, not the Federal standard of 3.1 gpm.

Conclusions '75

The report team concludes that Daimler-Benz has not yet demonstrated the capability to meet the 1975 standards with their gasoline engine emission control systems. Daimler-Benz will, in the judgment of the report team, be able to meet the 1975 standards with their Diesel-engined vehicles.

Daimler-Benz is, therefore, grouped into two classes, 75-1, Non-Catalytic Approach and 75-2.2, Catalytic System Approach - Average Development Status. Their inclusion in class 75-2.2 is somewhat arbitrary since Daimler-Benz submitted little useful information upon which to assess the status of their development program.

6.2.4.2 1976 Development Status

Systems to be Used - '76

The Daimler-Benz 1976 system is basically the 1975 system with the addition of a NO_x reduction catalyst. No mention was made of use of the start catalyst which is being considered as a back-up for 1975. NO_x catalysts from Kali-Chemie, and Heraeus are being considered.

The best low mileage data on the 1976 system was obtained on a carbureted MB 250 model: .12 gpm HC, 1.10 gpm CO, and .15 gpm NO_x. Best results for the fuel injected V-8 MB280 were reported to be .36 gpm HC, 1.98 gpm CO, and .36 gpm NO_x.

A variety of auxiliary devices on their 1976 vehicles will include: speed-EGR, rpm-EGR, rpm-air injection, and water temperature-air injection.

Daimler-Benz is predicting essentially the same fuel economy for the 1976 system as the 1975 system. Normally, a dual catalyst system uses richer carburetion than a single catalyst system. Significant fuel economy penalties are usually expected. Daimler-Benz did not report any reasons for the essentially equivalent fuel economy of the 1976 system and the 1975 system.

The biggest inconsistency in the Daimler-Benz 1976 status report concerned the question of durability. Mileage accumulation apparently has not yet been attempted and D-B reported:

"Starting a durability run on a higher (higher than low mileage targets of .15, 1.5, .20) basis of emission values would result in exceeding the standards shortly after the beginning."

They also reported:

"...we have not yet had made available to us any reduction catalyst with an acceptable rate of deterioration."

It is not clear to the report team how Daimler-Benz can be sure none of the catalysts supplied to them have acceptable deterioration when they have not yet run them on durability.

Development of a 1976 control system for the Diesel-powered vehicle was not reported. During a presentation made to the National Academy of Sciences Committee on Mobile Source Pollution Control Programs on August 30, 1972, Daimler-Benz reported that the "best" they can do in laboratory is .8-.9 gpm NO_x with the modified Diesel. On March 30, 1972, however, a modified Diesel was measured at .25 gpm HC, 2.28 gpm CO and .37 NO_x by Daimler-Benz. Not one test reported to EPA last spring was over .7 gpm NO_x when EGR was used. Daimler-Benz's attitude toward the Diesel is curious, in the opinion of the report team. They have achieved impressive emission levels in their own testing but seem reluctant to follow the results up with more extensive durability testing.

Durability Program - '76

Daimler-Benz has not initiated durability testing of their 1976 prototype concepts. No schedule was submitted to indicate when such testing might be initiated.

Catalyst Screening Program - '76

Daimler-Benz presented limited information on their NO_x catalyst screening programs. The following general screening tests are conducted:

Test	Objective of Tests
bench scale	initial catalyst activity
laboratory	determine light-off temperature
bench scale test	mech. durability and chem. activity
CVS test	exhaust emission

Mercedes gave no additional details on these tests. However, the charts in the back of the Mercedes submittal indicate they measure HC, CO, and NO_x emissions from all catalysts they receive versus air/fuel ratio. It is not known if laboratory apparatus or an engine dynamometer is used for these tests.

The following catalysts have been received and tested by Daimler-Benz:

Degussa	OM722	OM506	OM721
Engelhard	PTX3/121	3119	
	PTX3/121	3118	
	PTX4/121	2978	
	PTX4/121	3008	
	PTX4/121	3112	
	PTX423S/121	2771	
	PTX423S/121	2916	
	PTX423S/121	2965	
	PTX423S/121	2979	
	PTX423S/121	3122	
	PTX523S/121	2903	

W. R. Grace	502F	501F
Heraeus	721	97
	722	04
	721	96
	722	03
	721	9312
Kali Chemie	4035	
	3368	
	4023	
	4035-6	
	4035S3	
	4023/Febral 80	
	3368/Febral 80	
Johnson-Matthey	EC1/4	
	EC3A/12	
	EC8A	
	EW3A/4 m.b.	
	EW3A/4	
	EW8A/4 m.b.	
Sud-Chemie	A4	
Champion	Monel	

Progress and Problem Areas - '76

Progress

Daimler-Benz has made progress in system selection and low mileage emission results. The first choice system for 1976 has been chosen. It is a typical dual catalyst system. The low mileage emission test results reported indicate that Daimler-Benz has been able to achieve the 1976 levels, at low mileage.

Problem Areas

No durability testing was reported because of the inability of Daimler-Benz to achieve their own low mileage goals. Deterioration of NO_x control is a severe problem. Daimler-Benz reported that in order to meet lead time schedules for 1976, contracts with suppliers would have to be signed in mid-November 1972. No such agreement was reported in their status report.

Conclusions '76

The report team concludes that Daimler-Benz has not yet demonstrated the capability to meet the 1976 standards with their gasoline engine. In the judgment of the report team, the Diesel engine development reported by Daimler-Benz has much more potential to meet the 1976 standards, based on their achievement of the 1976 levels at low mileage and oral claims by Daimler-Benz that the Diesel has very little emission control deterioration with mileage.

Daimler-Benz is grouped into class 76-1, Non-Catalytic Approach and 76-2.1, Catalytic System Approach - Average Development Status. The reason for their grouping in 76-2.1 is the same as the reason for grouping them in class 75-2.2.

6.2.5 FUJI HEAVY INDUSTRIES LTD. (SUBARU)

6.2.5.1 1975 Development Status

Systems to be Used - '75

The Subaru first choice system will consist of engine mods (including electric choke), rich thermal reactor, oxidizing catalyst, air injection, and EGR. Catalysts will be supplied by either Degussa (pellets), Engelhard (noble monolith), or Johnson-Matthey (noble monolith). The Degussa pellets seem to be receiving the most attention at this time. Two back-up systems under consideration could be used only if the emission performance of the first choice system is good enough to allow the deletion of either the thermal reactor or the catalyst. Subaru has not been able to achieve adequate CO control with the thermal reactor, no catalyst approach. They feel that the use of a catalyst without a thermal reactor will not provide enough HC and CO control as the catalyst efficiency deteriorates at higher mileages. At low mileage the catalyst, no thermal reactor system was achieving .24 gpm HC, .9 gpm CO, and .88 gpm NO_x, while the catalyst plus thermal reactor is achieving .16 gpm HC, 1.4 gpm CO, and .64 gpm NO_x. While these levels do not look significantly different it should be noted that the catalyst only results were generated with a 2250 test weight and the catalyst plus thermal reactor results were with a 2750 test weight. Subaru did not report tests using a 2750 test weight with catalyst only.

It is not clear to the report team why Subaru is using an EGR system since NO_x levels are typically under 1.0 gpm with a system that provides a maximum of 6% EGR at light loads and almost none at higher loads where NO_x emissions are high. NO_x emissions may be under the proposed California level of 1.5 gpm without any recirculation. The heaviest Subaru vehicles fore-casted for 1975 production will be tested at 2750 inertia weight.

Vehicles in this weight class can often achieve low NO_x levels without EGR because of the lower power requirements required to drive the cycle compared to heavier cars. One of the 2250 test weight vehicles under test has been consistently under the 1976 NO_x requirement of .4 gpm without a reduction catalyst.

Subaru does not seem to be working under many constraints which could affect their ability to meet the 1975 requirements. To retain performance they have decided to increase the displacement of their engine by 17%. To facilitate system packaging they have gone to a dry sump lubrication system to allow placement of the thermal reactor under the engine in an area normally occupied by the oil pan. A tunnel has been added to the floor of the vehicle to provide space for the catalytic converter. A fuel economy penalty with the rich thermal reactor is anticipated but is being accepted until improvements can be made which will not compromise emission performance. Subaru has consistently chosen to accept major cost, performance, and passenger accommodation penalties rather than compromise emission performance. Few manufacturers appear to be willing to take this approach, in the opinion of the report team.

Subaru plans to use a catalyst by-pass valve "...in case of an emergency such as overheating of a Hang-On device due to misfire,..." if it is allowed by EPA. No other "modulating devices" are planned. Subaru reported that "...irrespective of ambient conditions, engine revolution and load, each device works exactly in the same manner as in the 1975 Federal Test Procedures." The emissions of Subaru vehicles should be as low on the road as during the Federal Test Procedure, in the judgment of the report team.

The retail cost of the 1975 control system was estimated to be $370. Should catalyst changes be required, Subaru estimates the replacement cost (including labor) of a noble metal monolith will be $37. Replacement cost of a pellet catalyst was estimated to be $16. These were the lowest replacement cost estimates provided by any manufacturer.

<u>Durability Program - '75</u>

Subaru had not, at the time of their submittal, initiated durability testing of their first choice system: thermal reactor, oxidizing catalyst, exhaust gas recycle and engine modification. Durability mileage has, however, been initiated on five vehicles to determine the deterioration associated with major system components. Subaru's planning calls for the initiation of first choice system durability testing in October 1972. Six vehicles have been built up for this purpose.

Of the five vehicles which have undergone at least some mileage accumulation, three were equipped with EGR/oxidizing catalysts and two with EGR/thermal reactors. All testing is being done with the 83 cubic inch displacement engine with vehicle inertia weights of either 2250 pounds or 2750 pounds. It is assumed by the report team that these test vehicle configurations are representative of the contemplated Subaru 1975 vehicles. Subaru did not supply any details on the test fuel type or maintenance procedures used during their program. Of the five cars started in the program, one was terminated due to engine trouble, two others due to high emission degradation.

Currently one thermal reactor vehicle and one catalyst vehicle are continuing in the program with reported mileage under 15,000 miles.

Catalyst Screening Program - '75

Fuji reported three different types of screening tests which are used to evaluate pelletized catalysts:

1. Catalysts are tested to determine the temperatures required to attain 10, 50, and 90% conversion efficiencies. The criteria for acceptance of a catalyst are that it achieve these efficiencies (10, 50 and 90% at 250, 325 and 500°C respectively for HC and 175, 250 and 275°C for CO.

2. A heating and vibration test determines attrition. The details of the test were not reported. To be acceptable a catalyst must have less than 5% weight loss after 300 hours.

3. Test to determine the effect of lead have also been run. No details of the procedure or criteria for acceptability were reported. The only conclusions reported were that "...lead contamination of catalyst (sic) is a serious problem."

No procedure for evaluating monolithic catalysts were reported.

Progress and Problem Areas - '75

Progress

Subaru has progressed to the point where a first choice 1975 system has been identified. This system includes both a thermal reactor and a catalyst. Low mileage test results on this system are below the 1975 levels.

Problem Areas

Because of the nature of their vehicle, Subaru has been forced to make major changes to the engine and body to accommodate the 1975 emission control system. The major engine changes are: 1) changing to a dry sump lubrication system and 2) changing the exhaust port location. Both engine changes have been made to accommodate the thermal reactor. The body also is planned to be modified extensively, with a tunnel in the floor to accommodate the catalyst. Subaru now has a flat floor because of the front wheel drive of their vehicles.

No extensive durability data has yet been generated on the first choice system.

Conclusions '75

The report team concludes that Subaru has not yet demonstrated the capability to meet the 1975 standards. They are grouped in class 75-2.2, Catalytic System Approach - Average Development status because of their good low mileage results and their lack of extensive durability data.

6.2.5.2 1976 Development Status

Systems to be Used '76

Subaru has not yet selected a first choice 1976 system. Two systems are being developed; a dual catalyst, EGR, and partial thermal reactor system, and an EGR and full thermal reactor system. Best low mileage results with the two systems were .15 gpm HC, .76 gpm CO and .34 gpm NO_x for the catalytic system, and .13 gpm HC, 4.3 gpm CO, and .41 gpm NO_x for the non-catalytic system. Both systems are in the early stages of development.

Durability Program '76

No durability testing has as yet been initiated by Subaru on 1976 emission control systems.

Catalyst Screening Program '76

Subaru's catalyst screening program for 1976 is the same as the program described for 1975.

Progress and Problem Areas '76

Progress

Subaru has made some progress, achieving 1976 levels at low mileage on a catalytic system.

Problem Areas

Subaru reported many problems for 1976, the major ones being catalyst durability and efficiency; and the size, fuel economy penalty and durability of the thermal reactor system.

Subaru reported that they have essentially paused in their 1976 development to reassess the whole program.

Conclusions '76

The report team concludes that Subaru has not yet demonstrated the capability to meet the 1976 standards. They are grouped in class 76-2.1, Catalytic System Approach - Average Development Status, because of their good low mileage results and lack of adequate durability.

6.2.6 HONDA

6.2.6.1 1975 Development Status

Systems to be Used - '75

The Honda approach for 1975 is the most unique in the industry. The Compound Vortex Controlled Combustion (CVCC) engine burns a heterogeneous air/fuel mixture. The CVCC concept is similar in some respects to the more well-known stratified charge engines of Ford (PROCO) and Texaco (TCCS). While the Ford and Texaco engines use direct cylinder fuel injection to obtain charge stratification, the Honda CVCC engine obtains stratification with the use of a prechamber and a carbureted mixture.

Two separate intake valves are used on each cylinder of the CVCC engine. One valve is located in the prechamber and the other in the main chamber. During the intake stroke a rich mixture is drawn into the prechamber and a lean mixture is drawn into the main chamber. Combustion is initiated by a spark plug located in the prechamber. The heat of combustion causes the burning gases to expand into the main chamber where they ignite the lean mixture. Combustion of the air/fuel mixture is completed in the main chamber, resulting in low emissions of CO, HC, and NO_x.

CO control is achieved because the engine is operated at a very lean air/fuel ratio overall (A/F$>$ 20). Conventional engines cannot be operated this lean because of the difficulty in igniting mixtures leaner than about 18:1 A/F. Ignition is easily achieved in the CVCC engine by locating the spark plug in the fuel rich prechamber.

Hydrocarbon control is achieved because of the condition in the main chamber and the operating parameters of the engine. The temperature, oxygen concentration and gas dynamic flow characteristics in the main chamber all favor hydrocarbon oxidation. The timing of the valve events in this three valve engine is also important.

NO_x formation is a function of air (N_2 + O_2) availability and temperature. A significant portion of the combustion in the CVCC engine occurs in the rich region of the prechamber where the air availability is kept low because of the mixture richness. By the time the combustion is occurring in the main chamber, where there is high air availability, the temperature has dropped because of expansion.

Vehicle test data reported by Honda indicates that overall vehicle performance has not been compromised by using the CVCC engine. To avoid a loss in power output the displacement of the CVCC engine has been made larger than the conventional engine currently used by Honda. With the new two-liter (120 cubic inches) displacement the Honda CVCC car will accelerate through a quarter mile in 17.8 seconds, faster than some large American cars with V-8 engines. Top speed is reported to be 93 mph and urban-suburban fuel economy is 24.2 mpg. Since the emission control does not depend on after-treatment devices or an EGR system, it is not anticipated that Honda will employ any "modulating devices" which compromise emission performance to achieve improved driveability and fuel economy during operation atypical of the Federal emission test procedures. Honda CVCC vehicles should be as clean on the road as during the Federal test, in the opinion of the report team.

Emission data reported by Honda was remarkably consistent. The wide variations in test results reported by other manufacturers have not been experienced by Honda. The variability problems of others are caused to a degree by their particular emission control systems, rather than by inherent deficiencies in the Federal test procedure. One of the lowest sets of emission values ever measured from a CVCC powered vehicle was obtained in EPA's own Ann Arbor laboratory. A Honda vehicle with 50,000 miles on it was tested at .19 gpm HC, 1.73 gpm CO, and .65 gpm NO_x. Fuel economy on the Federal driving cycle was 20 mpg. This is about 20% lower than the average of the 2000 pound 1973 models, however, it should be noted that the power-to-weight ratio of the Honda car was higher than the average 2000 pound 1973 car. At equivalent power-to-weight ratios the fuel economy should be similar to conventional uncontrolled engines, in the judgment of the report team.

Honda has experimented with catalytic control methods in the past, but they have decided to abandon the catalyst work in favor of focusing more effort on refining the CVCC engine for production. There are no back-up systems under development any longer.

Honda has also studied the possibility of adapting the CVCC process to larger engine and vehicles. A 1972 Chevrolet Vega (2500 pound inertia weight) was purchased by Honda, thoroughly evaluated, and then adapted to CVCC operation. Horsepower after the modification was 1.0 horsepower higher, vehicle top speed was the same (94 mph) and fuel economy was improved by 8%. Exahust emissions were measured at .26 gpm HC, 2.62 gpm CO, and 1.16 gpm NO_x. Computer simulation by Honda of a 350 CID-4500 pound vehicle predicted HC and CO levels just under the 1975 requirement and about 1.5 gpm NO_x.

This work was done to prove the adaptability of the process to other engines.

The estimated cost increase reported by Honda for the 1975 engine is one of the lowest reported at $100 - 150.

Durability Program - '75

Honda Motor Company has basically had a two-phase durability test program. Phase I involved the durability evaluation of various catalytic approaches. Due to recurring failures of these approaches (highest reported mileage about 30,000 miles), Phase I catalytic testing has been abandoned as a plausible approach. Phase II testing involves extensive evaluation of the Honda CVCC engine system. At this time many low mileage vehicles have been tested with this system. Four vehicles have completed or are close to completing a 50,000-mile durability program. Two mileage accumulation techniques have currently been employed on the four durability vehicles. One car was operated for 50,000 miles on a chassis dynamometer following the AMA schedule. The other three vehicles were operated on the proving ground Suzuka circuit.

The engine currently being tested with the CVCC concept is a 1,948 cubic centimeter, four-cylinder engine. It is assumed that this is the only configuration which will be available in Honda vehicles. Enough statistical confidence is attached to the fleet low mileage testing to indicate Honda's capability of complying at low mileage with Federal specifications.

During the mileage accumulation, Honda has reported minor mechanical problems but has assured in their submittal that these problems have been remedied. Also, certain modifications were performed on three of the four durability vehicles at high mileage. These modifications were minor and did not significantly affect the emission characteristics. The following table reports the actual 4000-mile emission data and the calculated deterioration factor for each vehicle that has completed high mileage accumulation. This factor has been calculated only using emission data up to the occurrence of the modifications mentioned previously.

Car Number and Mileage	Emission Data and Deterioration Factor					
	HC 4000	HC DF	CO 4000	CO DF	NO_x 4000	NO_x DF
#1006 50,000 miles	0.20	1.16	2.30	1.07	0.96	1.03
#2033 20,000 miles	0.21	1.15	2.74	1.08	0.95	1.04
#2034 44,000 miles	0.25	1.06	2.50	1.01	0.89	1
#2035 32,000 miles	0.21	1.12	2.38	1.12	0.95	1.00

Car #2034 was tested in the EPA laboratory subsequent to minor modifications and completion of 50,000 miles of operation. The following table indicates a comparison between the reported Honda 50,000-mile data point and the average of data measured by EPA.

Car #2034 50,000-mile Data

	Honda	EPA
HC	0.22 gpm	0.24 gpm
CO	2.25 gpm	1.75 gpm
NO_x	0.70 gpm	0.65 gpm

Catalyst Screening Program - '75

Honda does not have an active catalyst screening program for 1975 because they do not plan to use a catalyst.

Progress and Problem Areas - '75

Progress

Honda has made the most significant progress of any automobile manufacturer in the past year. Last year Honda was working on typical 1975 systems using various combinations of after-treatment devices such as catalysts and thermal reactors. Because of the poor durability performance of the after-treatment devices that Honda was working with, they decided to abandon that approach and to try to clean up the basic engine emissions using their CVCC engine.

Honda has been successful in reducing the engine emissions to levels below the requirements for 1975 for 50,000 miles. Research and development work on this system for 1975 has been essentially completed and the work is now concentrated on the production aspects of the engine. No production problems are foreseen by Honda.

Problem Areas

The following is a quote from Honda:

> "In the course of the durability test, we have faced several minor troubles, which are simple mechanical malfunctions of some components of certain additional devices. And, steps have already been taken to rectify them. Such troubles, common in any development processes, do not basically affect the emission control capability."
>
> "We see no difficulty, therefore, in assuring the durability and reliability of the CVCC engine system."

Conclusions '75

Honda will be able to meet the 1975 standards. Honda may also be able to have 100% of their production be below the 1975 standards. EPA evaluation of the data from Honda indicates that the average emissions of the 25 stage-3 vehicles plus three standard deviations times the highest DF reported for each of the pollutants results in predicted emissions for Honda which are still below the 1975 levels.

Compared to all other manufacturers surveyed, in the judgment of the report team, Honda has developed the best 1975 system. No other manufacturer has achieved this combination of low emissions, good vehicle performance, and fuel economy. Honda has also been the boldest and most innovative. No other manufacturer is developing an alternative to the premixed charge gasoline engine for 1975 production. Most have relied heavily on their suppliers for emission control systems and hardware.

6.2.6.2. 1976 Development Status

Systems to be Used - '76

The Honda 1976 system will be essentially a recalibrated 1975 CVCC engine. No after-treatment devices such as NO_x or oxidation catalysts will be used. An EGR development program is underway but Honda was reluctant to release test data from that program because the results are too preliminary. Without EGR or catalysts Honda has achieved .25 gpm HC, 2.5 gpm CO, and .43 gpm NO_x. This was an average of three consecutive tests. No other manufacturer has reported results this encouraging without EGR.

Durability Program - '76

Honda has not yet initiated mileage accumulation of any CVCC equipped vehicles which have been calibrated or modified to comply with the 1976 Federal oxides of nitrogen requirement.

Catalyst Screening Program - '76

Honda does not plan to use catalysts for 1976.

Progress and Problem Areas - '76

Progress

Honda has decided to concentrate on meeting the 1976 standards in much the same way in which they have already done with the 1975 system, i.e., work on the basic engine and not use after-treatment devices. Work is just beginning on an intensive basis, now that research and development work on the 1975 system has been completed.

Since the basic 1975 system already gives NO_x emissions under 1.0 gpm NO_x, the .4 gpm NO_x level is not too far away. Very preliminary tests have yielded NO_x emissions of .43 gpm NO_x with HC and CO under the 1975 levels.

Problem Areas

Honda has yet to demonstrate NO_x control consistently below .4 gpm NO_x and has not yet demonstrated the required durability.

Conclusions - '76

Honda will probably be able to meet the 1976 standards, in the judgment of the report team. There is very little data from Honda on their 1976 development,since it is just beginning, but even the first preliminary results reported are encouraging, especially since EGR was not used. Honda has been grouped into class 76-1, Non-Catalytic Approach.

6.2.7 MITSUBISHI

6.2.7.1 1975 Development Status

Systems to be Used - '75

Mitsubishi manufactures the Colt vehicle which is marketed by Chrysler in the U. S. The 1975 system under development for this vehicle consists of engine modifications (including altitude compensated carburetion), thermal reactor, and oxidation catalyst with air injection. A solid state ignition with provisions for spark retard during cold starts may also be included. Because the Colt vehicle requires only a 2500 pound test weight, EGR is not required to achieve the 1975 Federal requirements for NO_x. A variety of catalysts have been tested. Some of the best low mileage results were with the use of a UOP noble metal pellet type catalyst, .10 gpm HC, .79 gpm CO, and 2.42 gpm NO_x. Other catalysts tested include Engelhard, Mobil, Air-Products, Kali-Chemie, Mitsubishi, Osaka, Tokyo Roki, and Johnson-Matthey. The several types of manifold oxidation systems under consideration range from a standard exhaust manifold with air injection to a large volume, baffled thermal reactor. In between these extremes is a medium volume, cored-reactor similar to the Chrysler partial thermal reactors. No data was provided on any vehicles run with one of these manifold oxidation systems without catalysts so it is difficult to comment on the system's effectiveness.

The most outstanding feature of the Mitsubishi 1975 system is the air injection modulation system. An air control valve which senses both intake manifold vacuum and exhaust back pressure is used to provide air injection proportional to engine load. Data exist which show there is an optimum air injection rate for each engine loading condition. Lighter loads require less air injection than heavier loads for optimum emission control. Most manufacturers' systems, however, provide more air injection at lighter loads than at heavier loads. This is exactly the opposite of the air injection characteristics required for best emission control. Toyo Kogyo was the only other manufacturer, besides Mitsubishi, to report some type of air modulation system under development.

No mention was made of "auxiliary devices" which might impair the system's emission control during some operating modes. A catalyst by-pass valve which would be activated above 1470°F catalyst temperature is being developed. Mitsubishi reported: "The use of the by-pass valve, in the converter system, is entirely dependent on the approval of EPA." It should also be noted that the air modulation system reduces the air injection to the catalyst at high loads to prevent high temperatures. A graph of the air injection rate as a function of load and engine speed seemed to indicate to the report team that the air flow may be completely cut off at higher power levels. This may not be as desirable, in our opinion, as just reducing the rate somewhat. The graph seems to indicate that air would still be injected during moderately hard accelerations and expressway cruise. Wide open throttle operation, however, could result in very high emissions.

The Mitsubishi basic approach is one of the best, in concept, of all manufacturers using conventional engines.

Mitsubishi's cost estimate for the 1975 system was $245-376. Fuel economy is estimated by Mitsubishi to be 10-22% worse than current vehicles.

Durability Program - '75

After successful completion of catalyst screening evaluations, Mitsubishi normally subjects candidate catalytic systems to a 50,000-mile durability evaluation. The purpose of this testing is to measure actual vehicle/system deterioration. As of this writing 25 test vehicles are involved in this mileage accumulation program.

For its test purposes Mitsubishi utilizes 1972 and 1973 Dodge Colts. Two engines are used, 98 and 104 CID. These vehicles represent Mitsubishi's current U. S. market.

The durability testing thus far has basically been a catalytic converter evaluation procedure. Most of the vehicles have been equipped with prototype catalytic converters only. Of particular significance is the fact that none of the durability systems have yet included the manifold reactor with the modulated air injection.

Mileage accumulation is achieved through the use of an AMA equivalent procedure. Fuel used has been lead sterile rather than a trace lead containing fuel.

Only one vehicle (#111) has been reported with over 36,000 miles accumulated. This car has completed its 50,000-mile program with converter 4023k. Deterioration factors are:

HC	DF	less than 1.0
CO	DF	less than 1.0
NO_x	DF	less than 1.0

Carbon monoxide levels at the 4,000-mile point and at 50,000 miles exceeded 3.4 grams per vehicle mile. Hydrocarbon and oxides of nitrogen remained below the 1975 Federal requirements for 50,000 miles.

Use of one vehicle only does not allow confidence in production decision making, in the opinion of the report team.

Catalyst Screening Program - '75

Mitsubishi has a very simple, effective, and quick screening program involving laboratory tests followed by engine dynamometer tests. The laboratory tests involve measuring HC and CO conversion efficiencies at different temperatures. The resulting comparison of temperature versus conversion will show promising candidates which will then be checked for durability. Durability testing is also a laboratory-type procedure and involves exposing small quantities of catalyst to engine exhaust. This system is constructed with 34 parallel tubes to examine 34 different catalysts. The effectiveness of the catalyst for HC and CO conversion is measured after 100, 200, and 1,000 hours.

Following this test, successful candidates are tested in a full converter system on an engine dynamometer for 10 hours. The purpose of this brief test is to confirm the emission numbers obtained previously. The catalyst is then subjected to a 50,000-mile vehicle durability test.

Progress and Problem Areas - '75

Progress

Mitsubishi has made enough progress in the last year to enable them to select a "best choice" system, and begin to test a fleet of vehicles with this system on them. The test fleet was at approximately 8,000 miles at the time of this writing, with all 7 vehicles reported under the 1975 levels at that time.

Mitsubishi is also one of the two manufacturers to have progressed to the use of modulated air injection.

Problem Areas

The durability results on other 1975-type systems reported by Mitsubishi have not been successful in maintaining the emissions below the 1975 levels. Mitsubishi also expressed concern at the .05 gpg maximum lead level proposed by EPA. They will run their durability vehicles on .03 gpm from now on, but they anticipate that the results may not be as good as the lead sterile results they achieved earlier.

Conclusions '75

The report team concludes that Mitsubishi has not yet demonstrated the capability to meet the 1975 standards. They have been grouped in class 75-2.2, Catalytic System Approach - Average Development Status. While their system concept is judged good and some emission levels are also good, the lack of extensive durability results at .03 gpg lead on the most advanced system does not permit a more optimistic evaluation.

6.2.7.2 1976 Development Status

Systems to be Used - '76

The Mitsubishi 1976 system is basically the 1975 system with the addition of a NO_x catalyst, EGR and a "start catalyst" located before the NO_x catalyst. The EGR system will have "proportional" flow characteristics. Mitsubishi is one of the few manufacturers to report any development on start catalysts. The function of the start catalyst in this system is to provide HC and CO control before the main catalyst is warmed up and to help the NO_x catalyst warm up faster. It would be desirable, in the opinion of the report team, to switch the start catalyst out of the system after the main catalysts are warmed up to isolate it from the deleterious effects which could be caused by lead and high temperature. This is not done, however, on the Mitsubishi system. The start catalyst is left on stream but air is not injected into it after the rest of the system is warmed up. The start catalyst may have little effect on emissions when air is no longer injected into it.

The best low mileage results reported on this system were obtained with an American Oil base metal pellet NO_x catalyst, a Kali-Chemie noble pellet oxidation catalyst, and an Engelhard PTX-5 noble monolithic start catalyst. The results were .07 gpm HC, 1.33 gpm CO, and .26 gpm NO_x. Only 6% EGR rate was used. Other NO_x catalysts investigated include those of Johnson-Matthey, Kali-Chemie and Mitsubishi. Mitsubishi reported that the rich carburetor calibration causes a 15-25% fuel economy penalty for these systems. The cost estimate for the 1976 system was $430-700.

Apparently the only "auxiliary devices" being considered by Mitsubishi are those which are necessary to prevent catalyst over-temperature situations. Data from Mitsubishi and many other manufacturers indicates that the exhaust emissions without air injection can be as high from the 1976 vehicles as from uncontrolled cars.

Mitsubishi's '76 approach is among the best of those manufacturers using reduction catalysts. The use of both a start catalyst and modulated air injection is unique in the industry.

Durability Program - '76

Mitsubishi has conducted very limited durability testing of promising reducing catalyst systems. Their testing procedures are identical to those followed during their 1975 durability testing. Lead sterile fuels were employed until October of 1972 at which time gasoline with .03 grams per gallon of lead was introduced. The vehicles employed to date have been equipped with only a reducing catalyst, thus hydrocarbon and carbon monoxide levels consistently exceed the 1976 requirements. Both vehicles reported at the time of their submittal were operated to 36,000 miles before the testing was terminated. Throughout this testing the vehicle demonstrated NO_x levels exceeding the 1976 levels. A second car was run to 22,000 miles before termination. At low mileage this vehicle demonstrated 1976 NO_x levels. At approximately 20,000 miles this vehicle exceeded the NO_x requirements and had shown high deterioration.

Catalyst Screen Program - '76

Mitsubishi has a very direct and quick catalyst screening program for reduction catalysts before starting actual vehicle tests. This program involves initial laboratory tests followed by engine dynamometer tests.

The first part of the laboratory test involves passing portions of exhaust gas from a test engine over small samples of catalyst (either monolith or pelleted) kept in a furnace. The NO conversion as a function of temperature (from 390-1100°F) is then recorded. A durability test is then run which is similar to that used for the oxidation catalysts. This system involves passing engine exhaust through an apparatus containing 34 small tubes in parallel, each containing small amounts of catalyst sample. The NO conversion effectiveness is then measured at 100, 200, and 1,000 hours.

Catalysts which perform satisfactorily on this durability test are then tested in a full-size catalyst converter on an engine dynamometer. A simulated 1975 CVS FTP is used for this test.

A limited 10-hour durability test is run on this dynamometer which should uncover any obvious discrepancies between the laboratory apparatus performance and what would happen on a vehicle. After this test, the catalyst is tested on a vehicle for a 50,000-mile durability test. Some of the results of these screening tests are considered promising by the report team. Mitsubishi clearly noted both the catalyst they tested and the 1975 CVS emission results.

Progress and Problem Areas - '76

Progress

Mitsubishi has progressed to the point where two systems are under serious consideration for use in 1976. One system is a typical 1976 dual catalyst system, the other system is a three catalyst system, with the third catalyst being a "start" type oxidation catalyst for use during the cold start. The three catalyst system has achieved 1976 levels at low mileage.

Problem Areas

Mitsubishi reported problems in the area of NO_x catalysts, (efficiency and durability) vehicle installation (limited room), and in their opinion, probably poor reliability in the field. No durability results have as yet been generated on the three catalyst system.

Conclusions '76

The report team concludes that Mitsubishi has not yet demonstrated the capability to meet the 1976 standards. While their start catalyst system approach is considered good, lack of acceptable durability results prevents a more optimistic classification for them than 76-2.1, Catalytic System Approach - Average Development Status.

6.2.8 NISSAN (DATSUN)

6.2.8.1 1975 Development Status

Systems to be Used - '75

The Nissan first choice system for 1975 consists of engine modifications, EGR and a noble metal monolithic oxidation catalyst with air injection. The engine modifications include altitude compensated carburetion with a quick choke, a quick heat intake manifold and a solid state ignition system with provisions for retarding timing during cold starts. Most of Nissan's development work has been with Engelhard catalysts and in light of the recent public announcement of a Nissan-Engelhard agreement it appears to the report team that Nissan will use the Engelhard catalysts in production.

The addition of a thermal reactor to the first choice system is being considered as a possible back-up system. None of their latest fleet (Phase IV) of prototypes, however, are equipped with thermal reactors.

One of the best low mileage tests reported for the most advanced prototype was .19 gpm HC, .43 gpm CO, and .99 gpm NO_x. Earlier prototypes using the thermal reactor plus catalyst back-up system were tested as low as .30 gpm NO_x without NO_x catalysts. These earlier prototypes were generally somewhat higher than the standards on HC and CO emissions, but the vehicles did not include modifications such as quick chokes, cold start retard or quick heat manifolds.

Nissan considers fuel economy, performance, cost, and compatibility with 1976 systems important constraints. The lack of compatibility with 1976 systems was given as one of the reasons for diminished interest in the thermal reactor plus catalyst approach. 10% is considered by Nissan the maximum fuel economy penalty acceptable. Current 1975 prototypes meet that constraint. To maintain vehicle performance, Nissan is planning to increase engine displacements on some models. Retail cost of the 1975 system was estimated by Nissan at $350-450.

Nissan is currently behind schedule on their 1975 program because much of their earlier work was based on the assumption that fuel with a lead content of .01 grams per gallon would be acceptable for certification testing. Because Nissan was seeing low DF's with .01 gpg fuel, they did not intensify the development of systems with sufficiently low zero mile emissions until they finally accepted the fact that they had to run higher lead levels. Testing of fuel with .03-.05 gpg lead did not begin until the middle of 1972.

It was not clear whether Nissan is intending to use auxiliary emission control devices on their 1975 vehicles to make it easier for them to satisfy their design constraints. A system intended for use in 1975 vehicles, however, apparently may defeat some of the emission control systems during certain operating modes, in the opinion of the report team.

Nissan reported:

> "This system aims to optimize exhaust emissions and driveability under every driving condition by using ambient temperature sensor, water temperature sensor, engine speed sensor, vehicle speed sensor, acceleration switch, etc., and controlling air/fuel ratio, spark timing, EGR flow rate, secondary air flow rate, fuel cut-off, etc." (Emphasis added)

The exhaust emissions during non-LA4-type driving patterns and high and low ambients were not reported by Nissan. No development work was reported on any alternatives to the conventional spark ignition engine.

Durability Program - '75

Nissan has employed a four phase program as a durability evaluation tool. Subsequent to successful completion of screening and bench testing Nissan has introduced successful components into a durability program. The following is a brief description of each of the four phases of the program.

Phase I - The objective of this test is to evaluate each component, at the initial stage of development, that has appeared promising in initial screening evaluation. This fleet included 7 durability vehicles.

Phase 2 - The objective of this test was to evaluate primary design concepts (B and AB described later) with improvements designed to avoid EGR and other problems encountered in Phase 1. This fleet included 6 durability vehicles.

Phase 3 - The objective of this test was to evaluate Nissan's first choice system (B) using a fuel with a more realistic trace lead content. The durability fleet consisted of 5 vehicles.

Phase 4 - The objective of this test which has just been initiated is to evaluate the first choice system modified to minimize the drastic lead effects apparent in Phase 3. This fleet contains 9 durability vehicles.

Phases 1, 2, and 3 have been terminated while Phase 4 has only recently been initiated. If Nissan accumulated mileage at a normal rate, this final phase should be completed during the spring of 1973. The following indicates the durability fleet representation employed by Nissan for each phase:

Phase 1 - Datsun 510	1600 cc.
Phase 2 - Datsun 510 & 610	1600 and 2000 cc.
Phase 3 - Datsun 610	2000 cc.
Phase 4 - Datsun 610	2000 cc.

It does not appear, therefore, that any of the fleets to date have fully represented Nissan's current United States production since an engine currently marked by Nissan, a 2400 cc six-cylinder, is not represented.

Phase 1 and 2 contained vehicles with prototype concepts AB and B while Phase 3 and 4 utilize concept B only. The following describes these concepts:

AB	B
Engine Modifications	Engine Modifications
Air Injection	Air Injection
Exhaust Gas Recycle	Exhaust Gas Recycle
Thermal Reactor	Oxidizing Catalysts (noble monolith)
Oxidizing Catalyst (noble monolith)	

All of the durability test vehicles in all phases had full system concepts installed.

Mileage accumulation was performed according to the AMA procedure. Phase 1 and 2 vehicles were fueled on gasoline with a lead content of less than .01 grams per gallon.

Phase 3 and 4 vehicles used fuel of .03 to .05 grams per gallon. Maintenance performed during mileage accumulation was not in accordance with Federal procedures, but satisfactory with respect to a developmental fleet.

Phase 1 vehicles had high initial emission levels and relatively high deterioration. None of these vehicles appeared to comply with the 1975 Federal requirements. In Phase 2 one of the six vehicles had emission levels lower than as required for 1975 through 50,000 miles of operation. At 25,000 miles the average of all 6 vehicles was lower than the required levels indicating potential compliance with a catalyst change. However, this fleet was operated on lead sterile fuel. Phase 3 vehicles all demonstrated high deterioration in hydrocarbon or carbon monoxide levels attributed by Nissan to the higher fuel lead content. None of these vehicles remained below the standards for 25,000 miles of operation. The fleet operation was terminated at low mileage due to this high deterioration. Thus no projection of the continued rate of deterioration, if any, is possible. Phase 4 designed to avoid the severe lead effects experienced in Phase 3 has just been initiated. All of the vehicles are currently at low mileage.

Catalyst Screening Program - '75

Nissan has done limited catalyst screening work using an engine dynamometer and a modified AMA route driving pattern. Actually, Nissan has not screened a large number of oxidation catalysts according to the information they submitted to EPA. Instead, they have examined only the Engelhard PTX unit (model was not specified) and Johnson-Matthey AEC3A. After mileage was accumulated on the engine dynamometer, the catalysts are transferred to a vehicle for a 1975 CVS test.

Progress and Problem Areas - '75

Progress

Nissan has made progress in the past year in gaining durability experience with 1975-type control systems. At least 4 different fleets of vehicles have been or are being tested with different types of control systems. The Phase IV fleet appears to incorporate Nissan's first choice 1975 emission control system.

Nissan has also been reported to have signed an agreement with Engelhard to supply catalysts for their future requirements.

Problem Areas

Nissan's biggest problem appears to be the lead content of the gasoline. Most of their durability testing on the Phase 1 and Phase 2 fleets was done on fuel containing less than .01 gpg lead. Phase 3, run on .03 gpg to .05 gpg fuel was not very successful. Phase 4 is an attempt to overcome the problem that Nissan attributed to the lead level. Not enough data has been generated yet to determine whether or not they will be successful.

In attempting to meet both Federal HC and CO standards and the assumed California 1.5 gpm NO_x level, Nissan may be creating more of a problem with the control of HC and CO to within the Federal levels than is necessary.

Conclusions '75

The report team concludes that Nissan has not yet demonstrated the capability to meet the 1975 standards. They are grouped into class 75-2.2, Catalytic System Approach - Average Development Status, because of their problems with the lead level in their durability testing, although their low mileage results have been adequate.

It is the judgment of the report team that Nissan could achieve better emission control if their development was not aimed at meeting the 1975 Federal HC and CO and the 1975 California NO_x requirements.

6.2.8.2 1976 Development Status

Systems to be Used - '76

The Nissan 1976 system is basically the 1975 system with the addition of a NO_x catalyst. Johnson-Matthey and International Chemicals NO_x catalysts seem to be receiving the most consideration. The best low mileage results have been .27 gpm HC, 1.57 gpm CO, and .13 gpm NO_x. No car has yet been able to reach 4000 miles with sufficient NO_x conversion efficiency to stay below .40 gpm. In spite of the fact that they formerly achieved NO_x levels below .4 gpm with their old Phase 1 1975 system at high mileage, Nissan has not reported any development work on an EGR plus oxidation catalyst approach for 1976. The old Phase 1 vehicle did not even use proportional EGR. It is not apparent to the report team why Nissan is not investigating the advanced EGR approach. The Phase 1 1975 system which achieved the 1976 NO_x levels utilized a thermal reactor. Nissan's first choice '76 system has only a 3% fuel economy penalty compared to their '75 system. The Nissan vehicles are light enough that there may be potential for achieving adequate NO_x control without NO_x catalysts and to still maintain fuel economy and driveability, in the opinion of the report team. No development work on advanced engine modifications, modulated air injection systems or proportional EGR systems which might achieve this result was reported. One of Nissan's constraints for 1976 is apparently to rely heavily on the catalyst approach.

Durability Program - '76

Nissan is approaching the evaluation of candidate 1976 prototypes systems in a fashion similar to their 1975 program. Subsequent to promising screening evaluations, systems are installed on vehicles for mileage accumulation. At the present time 3 vehicles have been used to evaluate 5 different reducing catalyst approaches.

For test purposes Datsun 610 vehicles with 2000 cc. engines are being used. These cars are equipped with concept package C including: engine modifications, exhaust gas recycle, air injection, oxidizing catalyst and reducing catalyst. The test procedures being followed are identical to those used in Nissan's '75-type fleet with fuel lead levels of .03 - .05 grams per gallon.

Four of the five reducing catalysts evaluated to date have significantly deteriorated prior to 10,000 miles of operation. The fifth system is at zero miles.

The program is not advanced to the point where any kind of assessment can be made as to the potential for successful completion of the durability testing.

Catalyst Screening Program - '76

Nissan included little specific information on their catalyst screening program. They did list the two major goals of their screening tests which are given below:

1) Determine NO_x conversion efficiency over wide ranges of inlet CO concentrations.

2) Determine if there is a sufficiently wide temperature difference between the temperature of 80% reduction of NO_x and the maximum allowable temperature for catalyst durability.

Progress and Problem Areas

Progress

Nissan has chosen the typical dual catalyst approach for 1976. Some test results at low mileage have been below the 1976 levels.

Problem Areas

All of the durability tests have been stopped due to high NO_x deterioration. Nissan has not yet been able to find a suitable NO_x catalyst.

Conclusions '76

The report team concludes that Nissan has not yet demonstrated the capability to meet the 1976 standards. They are grouped in class 76-2.1, Catalytic System Approach - Average Development Status, because of their adequate low mileage results and lack of acceptable catalyst durability.

The report team also concludes that Nissan's dual catalytic system is not markedly superior to the non-NO_x catalytic approaches that Nissan has demonstrated that also meet 1976 emission levels at low mileage.

6.2.9 RENAULT

6.2.9.1 1975 Development Status

Systems to be Used

Renault is developing two different 1975 control systems. Both will use engine mods, air injection, a noble metal monolithic oxidation catalyst and EGR. One system will use carburetion (altitude compensated) and the other will use electronic fuel injection (L-Jetronic). Carburetors will employ quick chokes. They will be used on the R12 and R15 model vehicles. The fuel injected engine will be used in the R17 model. The EGR systems to be used will apparently be purchased rather than manufactured by Renault. Solid state ignitions may be used with one or both systems. All Renault vehicles will be tested at the 2750 pound class.

The best low mileage results reported were .008 gpm HC, 1.009 gpm CO and 1.456 gpm NO_x. It was not clear from the Renault report whether this vehicle used fuel injection or carburetion. Results obtained on one of the R12 vehicles (carbureted) were .17 gpm HC, .92 gpm CO and 2.36 gpm NO_x. EGR was not used on this test. Other tests were reported with NO_x levels as low as 1.20 gpm without EGR, HC and CO emissions were still under the 1975 levels at .33 gpm HC and 1.53 gpm CO. Renault did not report the manufacturer's name for each catalyst they are testing. One of them, however, is the Engelhard noble monolith.

Only modest fuel economy and performance penalties were reported. The fuel economy loss was estimated at 3%. The retail cost increase over '73 vehicles was estimated at $215-350.

No data was reported which would allow the emissions before the catalyst to be determined. Since some results with catalysts were above 10 gpm CO and 2 gpm HC it appears to the report team that Renault is relying heavily on the catalyst rather than lowering the basic emissions of their engines.

Durability Program - '75

The Renault submittal was not explicit as to purpose or procedures used in their 1975 prototype durability. From the data supplied it appears that durability testing of candidate oxidizing catalysts was initiated in November 1971, and has continued. A total of eight mileage accumulation runs were made and reported on two catalyst types, code-named Ren 15 and Ren 17. Testing was performed only on carbureted engines while Renault did identify fuel injection as a possible 1975 approach. For test purposes one Renault 16 and three Renault 12 vehicles were utilized. All but one of the eight test runs reported indicated high hydrocarbon and carbon monoxide at relatively low mileage. Vehicle 316 equipped with a Ren 17 converter was reported to be at 19,383 miles on October 12, 1972. At that time the vehicle was below the 1975 levels and hydrocarbon and carbon monoxide deterioration appeared minor. It appears that this vehicle is continuing to operate under mileage accumulation.

Catalyst Screening Program - '75

The oxidation catalyst screening program for Renault is divided into two major parts, laboratory tests and engine bench tests. The following laboratory tests are performed.

- Measurement of attrition
- Surface area measurement
- Density and porosity measurement
- HC and CO oxidation activity

The attrition measurement test is divided into two parts. The first part consists of submitting the catalyst to a vertical shaking motion for five hours. The second part of the test involves horizontal shaking motions (200 cycles/minute). The small particles are then strained from the larger ones and the weight loss is noted.

The specific surface area is determined by the standard BET method involving measuring gas absorption on the surface at a specified pressure. The density and porosity are then determined. The catalytic activity is determined by measuring HC and CO removal from a synthetic laboratory gas mixture under constant temperature conditions. The efficiency of the catalyst as a function of temperature for 10%, 50% and 90% conversion are noted.

Promising candidates are then tested on an engine bench test. No further details were given on the engine bench tests. Renault listed only nine oxidation catalysts and two catalysts for oxidation or reduction that have been tested to date. Renault identified these catalysts only by number and did not indicate who supplied them.

Progress and Problem Areas - '75

Progress

Renault has made progress in achieving lower low mileage emission results. Renault has picked a first choice system, a typical 1975 system employing a platinum monolithic catalyst. Some durability testing has been performed.

Problem Areas

Some of Renault's earlier durability testing was conducted with fuel with 27 ppm of lead. The more recent tests use 10 ppm lead content fuel, close to .03 gpg.

Renault reported problems in the area of mechanical durability of the catalyst. Renault anticipates the need to replace the catalyst at 25,000 miles.

Conclusions '75

The report team concludes that Renault has not yet demonstrated the capability to meet the 1975 standards. They are grouped in class 75-2.2 Catalytic System Approach - Average Development Status because of their good low mileage results and limited durability.

6.2.9.2 1976 Development Status

System to be Used - '76

Three different systems are under consideration by Renault for 1976. A dual catalyst system, which is basically the 1975 system with a reduction catalyst added, is being considered for both the R-12/15 models and the fuel injected R17 model.

A single bed, three-way catalyst is being considered for the fuel injected R17 model. This system employs an oxygen sensor which is used to maintain a nearly stoichiometric air/fuel mixture. At this air/fuel ratio it is possible to simultaneously reduce NO_x and oxidize HC and CO in one catalyst.

A thermal reactor-reduction catalyst system was also reported to be under development. Almost no information was supplied on this system. It appears to be similar to the Questor system in some respects, including the use of an NO_x catalyst and the lack of an oxidation catalyst.

No data was reported on either the 3-way catalyst system or the thermal reactor-NO_x catalyst system. The best low mileage results reported on the dual catalyst system were, .31 gpm HC, 2.10 gpm CO and .32 gpm NO_x.

Under the 1976 section of their submittal Renault reported:

> "The addition of a supplementary catalyst introduces an additional increase in fuel consumption of approximately 3%, but the definitive overall result has not been established because optimization of the system has not been completed."

They also reported that the dual catalyst system would be run at λ = .8-.9 (12.5:1 Air/fuel ratio). Considerably more than a 3% loss would normally be expected by the report team at this air/fuel ratio.

Durability Program - '76

Renault has reported that the results of screening tests to date have not warranted the initiation of any durability testing.

Catalyst Screening Program - '76

The reduction catalyst screening program for Renault is similar to the screening tests done on oxidation catalysts. Both laboratory and engine bench tests are performed.

The laboratory tests make the following general measurements described previously.

Attrition
Surface area
Density and porosity
NO reduction activity

These catalyst are further tested by an engine bench test which was not described. Renault indicated that only five reduction catalyst have been tested to date.

Progress and Problem Areas - '76

Progress

Renault is presently considering two possible systems for 1976; the dual catalyst and the 3-way catalyst "λ -sensor" system.

Low mileage results on the dual catalyst system are below the 1976 levels.

Problem Areas

Very little durability testing has been completed, due to catalyst problems.

Conclusions '76

The report team concludes that Renault has not yet demonstrated the capability to meet the 1976 standards. They are grouped in class 76-2.1 Catalytic System Approach - Average Development Status because of their low mileage results and their limited durability. They were not grouped in class 76-2.2 because of the reported work on the oxygen sensor, three-way catalyst system, considered by the report team to be a promising approach.

6.2.10 SAAB

6.2.10.1 1975 Development Status

Systems to be Used - '75

The Saab first choice system consists of engine mods, pellet oxidation catalyst and air injection. Both carburetion and electronic fuel injection will be used in 1975. Carbureted engines will utilize EGR, injected engines will not. Even on the carbureted engine EGR is not required to meet 1975 NO_x levels since the Saab vehicle, even though a full five passenger sedan, weighs only 2500 pounds. EGR development is probably being done to meet the proposed California NO_x standard of 1.5 gpm, in the opinion of the report team.

Pellet catalysts from three suppliers: Monsanto; Kali Chemie; UOP; are being investigated. Both promoted base metal and noble metal pellets are being considered. Noble metal monoliths from Engelhard and Johnson-Matthey are receiving some consideration as possible back-up catalysts but Saab has had many substrate durability problems in the past. Substrate durability problems are aggravated on Saab vehicles since all Saab engines are four cylinder. Attempts to isolate the catalyst from the vibration of the engine were not reported.

Saab considers the maintenance of good fuel economy, driveability, and performance important constraints. Thermal reactor systems were investigated and 1975 levels were achieved but this work has been abandoned, "...it was decided that this work should be discontinued mainly because of increased fuel consumption characteristics as well as incompatability of the thermal reactor with probable 1976 emission control systems." The fuel economy penalty of the first choice system was estimated to be 10% compared to 1972 vehicles. Saab reported that cost and sheet metal changes required for a particular system also receive much consideration. Total retail cost of the first choice system was estimated by Saab to be $166 over the 1973 system.

Data reported by Saab indicates that the emissions of the basic engine before catalyst treatment may not have received adequate consideration. No data was reported for vehicles without catalysts but even with catalysts hydrocarbon emissions were as high as 2.29 gpm and CO emissions were often higher than 15 gpm and as high as 43.9 gpm, in one case. Other manufacturers have developed engine modifications which result in HC levels below 1 gpm and CO levels below 10 gpm without catalysts. Saab, like many other manufacturers, may be relying heavily on the catalyst approach.

Despite relatively high "feed gas" levels Saab has been as low as .09 gpm HC, .47 gpm CO, and 1.18 gpm NO_x at low mileage. With EGR emissions have been as low as .08 HC, .61 CO, and .84 NO_x at low mileage.

Saab did not report the intended use of any "modulating devices" for 1975 other than a system which would dump air pump discharge if the catalyst temperature became too high.

Durability Program - '75

Saab's durability program is predominantly a catalyst evaluation experiment. Seven vehicles are being subjected to mileage accumulation equipped with different catalyst candidates. While two of the seven vehicles are being tested with monolith types, Saab's primary system for 1975 consists of pellet catalysts with air injection. Catalysts for test are chosen on the basis of those which have shown the highest success in preliminary screening. All of the test vehicles being operated are Saab 99's with either 2.0 liter or 1.85 liter engines. Emphasis is placed on manual transmission vehicles. The single greatest problem associated with Saab's current testing procedures appears to be their practice of replenishing catalytic material. It was reported that three of the six bead-type catalyst systems received this type of treatment. On Saab's single high mileage prototype material was added 11 times in 35,000 miles. It cannot be anticipated that this type of maintenance would be allowed during certification procedures. Lead sterile fuel has been used to evaluate what has proven to be Saab's most successful durability vehicle and thus causes further reservation as to the vehicle's true deterioration characteristics.

Looking at the reported data, Saab only has two vehicles at high enough mileage to be fairly commented upon. Vehicle #385, equipped with a Monsanto type 404 catalyst, demonstrated high hydrocarbon and carbon monoxide levels frequently during its 33,500 miles of operation thus far. The vehicle's catalyst was topped off 13 times and the fuel used was lead sterile. Vehicle #341 has been run 41,500 miles on lead sterile fuel. The catalyst material is identical to that previously mentioned. A total of 11 catalyst refill operations were performed. While carbon monoxide levels have exceeded the standard several times, this vehicle appears, in the judgment of the report team, to have an excellent chance of completing 50,000 miles successfully.

Saab identified two areas of consideration which they feel will determine the feasibility of compliance with the 1975 requirements-one catalyst change at 20-24 thousand miles and the use of lead sterile fuel. From the data presented; however, it would appear to the report team that catalyst attrition may represent another major problem for Saab.

Catalyst Screening Program - '75

Saab measures six basic points of parameters in their catalyst screening test which are listed below:

1) HC and CO conversion versus oxygen concentration

2) HC and CO conversion versus A/F ratio

3) Warm-up test - temperature versus HC and CO conversion with air injection (2% oxygen in resultant mixture)

4) Warm-up test - temperature versus HC and CO conversion without air injection

5) Warm-up test - time versus HC and CO conversions with air injection (2% air in resultant mixture)

6) Warm-up test - time versus HC and CO conversion without air injection

These tests are run on an engine dynamometer set-up. An optimum air/fuel ratio was determined before running each test sample. A total of 19 catalyst samples from 8 different manufacturer's have been tested, most of which are listed below:

Degussa	OM 506
Degussa	506E
Degussa	OM506ET
Engelhard	PTX323S
Engelhard	PTX4
W.R. Grace	Davex 45V
W.R. Grace	Davex 136
W.R. Grace	Daves 140
Johnson Matthey	AEC3
Johnson Matthey	AEC8
Johnson Matthey	AEC8a
Kali Chemie	KC4035K
Kali Chemie	KC4035K-S3
Monsanto	ECA401

Monsanto	ECA404
Monsanto	404
Monsanto	406
UOP	PZ-1-216-MZ

Progress and Problem Areas - 1975 Systems

Progress

Saab has chosen their first choice system and has accumulated some durability testing with it. The results to date indicate that, on the basis of the Saab testing, they believe that the durability requirements can be met for 20,000 to 25,000 miles provided that the container is big enough to allow for the attrition with their beaded catalyst.

Problem Areas

Saab has experienced severe problems with monolithic catalysts and has abandoned their use for the time being. Saab reported that they are very concerned with the permitted lead level in the fuel, and are not optimistic about the results that they will obtain using what Saab calls "EPA fuel" of .04 gpg lead content.

Conclusions - '75

The report team concludes that Saab has not yet demonstrated the capability to comply with the 1975 standards. They are grouped in class 75-2.2 Catalytic System Approach-Average Development Status. The nature of the catalyst attrition problem experienced by Saab and the fact that sterile fuel was used for durability testing do not permit a more optimistic assessment at this point in time, although Saab's results have been generally good.

6.2.10.2 1976 Development Status

Systems to be Used - '76

Two different approaches for 1976 are under consideration by Saab. One approach uses dual catalysts and is basically the 1975 system with the addition of a NO_x catalyst. The other approach is the 3-way catalyst with an oxygen sensor. This second approach requires the use of the Bosch L-Jetronic fuel injection system.

The best low mileage results on the dual catalyst system reported were .21 gpm HC, 1.82 gpm CO, and .33 gpm NO_x. Best results on the 3-way catalyst system were .23 gpm HC, 9.07 gpm CO, and .36 gpm NO_x. All other manufacturers reporting results on 3-way catalysts systems have reported better emission results than Saab reported.

Saab did not provide information on fuel economy, performance or driveability on either of these systems. Saab has formerly (1971) reported emission results below the 1976 requirements without the use of NO_x catalysts. Over one year ago they had achieved .14 gpm HC, 2.65 gpm CO, and .29 gpm NO_x. It is not clear to the report team why Saab has not followed-up the development of this system which used EGR for NO_x control. The Saab vehicles are light enough that there is potential for achieving .4 gpm NO_x without the use of a reduction catalyst, but for some reason Saab does not like to use EGR. In their status report to EPA they stated:

> "The extent of EGR, if any, will be subject to and dictated by the state of the art of the catalytic NO_x-control at the time of the preparations of that model year production. We will clearly not use any unnecessary EGR rate, over what would be required to bring the system performance down to the engineering goal for NO_x."

No data was reported that indicated any significant problems associated with the use of EGR nor was any information reported on the development of proportional EGR systems which might achieve low NO_x emissions, low CO and HC emissions and acceptable fuel economy simultaneously. The reason for the lack of this type of EGR development work is not known.

The Saab retail price increase for the 1976 emission control systems are the lowest of all manufacturers reporting. The dual catalyst system was estimated at $255 higher than the 1973 system. The 3-way catalyst system was estimated to be only $115 higher than a 1973 system.

Durability Program - '76

Saab is continuing to develop a 1976 system approach. At this point the development has not progressed to the point where mileage accumulation has been initiated.

Catalyst Screening Program - '76

Saab is continuing to develop a 1976 system approach. At for 1976 catalysts are similar to those used for 1975 oxidation catalysts. This includes tests run on an engine dynamometer to determine NO reduction as a function of air/fuel ratio and warm-up capability of the NO_x catalyst.

Progress and Problem Areas - '76

Progress

Saab has progressed in their 1976 development to the point at which two systems are under serious consideration for 1976. The systems are the λ sensor 3-way catalyst system and the more typical dual catalyst system. Saab has been able to achieve 1976 levels at low mileage with the dual catalyst system.

Problem Areas

Saab has not yet been able to decide on the catalyst type for either of the two systems. Saab has been experiencing problems with both the monolith and the pellet type of catalyst. Saab has not generated any durability data on 1976 systems, so the actual durability problems with their 1976 system is not known. Saab has also been unable to achieve their own low mileage in-house emission goals for 1976.

Conclusions - '76

The report team concludes that Saab has not yet demonstrated the capability to meet the 1976 standards. They are grouped in class 76-2.1 Catalytic System Approach-Average Development Status because of their low mileage results and lack of durability data.

6.2.11 TOYO KOGYO (MAZDA)

6.2.11.1 1975 Development Status

Systems to be Used - '75

Toyo Kogyo is the only manufacturer who currently sells a rotary engine powered vehicle in this country. The emissions and production cost characteristics of the rotary engine have been the subject of much speculation in recent years. The emission levels of an uncontrolled rotary engine are different than those of the conventional reciprocating engine. Rotary HC levels tend to be much higher (more than double) than those of the reciprocating engine while NO_x levels are somewhat lower. CO levels are essentially the same. While Toyo Kogyo is developing emission control systems for both the rotary and the reciprocating engine for 1975, the rotary development is more complete.

The 1975 control system for the rotary is almost identical to that used on current rotary-powered Mazdas. It consists of engine modifications, rich thermal reactor and air injection. EGR is not required since the rotary has very low NO_x levels, especially when run rich, and the Mazda vehicles are light weight. One of the most significant differences between the current Mazdas and the 1975 prototypes is the air injection modulation system. Toyo Kogyo and Mitsubishi are the only ones who have reported that they have developed an air injection modulation system for 1975. Modulated air injection is especially desirable with a rich thermal reactor system because it allows the engine to be calibrated leaner, thereby minimizing fuel consumption penalties, without sacrificing emission control.

Toyo Kogyo worked with the following self-imposed constraints while developing their 1975 control system for the rotary:

1. Maximum fuel economy penalty, 10%
2. No safety hazard
3. $100 maximum cost increase
4. Driveability same as 1973 (excellent)
5. System must be packageable in 1973 chassis
6. Same maintenance requirement as 1973
7. Same performance as 1973.

All of these constraints have been met. The fuel economy penalty is 6% and the low mileage emissions are as low as .22 gpm HC, 2.08 gpm CO, and .77 gpm NO_x on some cars.

Two different systems are under consideration for the 1975 reciprocating engines. One system consists of engine modifications, rich thermal reactor and modulated air injection. The other system uses a noble metal monolithic oxidation catalyst instead of the thermal reactor. Engelhard and Johnson-Matthey catalysts are receiving the most consideration. Air injection is apparently not modulated with the catalyst system. It appears that the air injection with the thermal reactor system is sometimes partially diverted into the intake system to lean the mixture.

Toyo Kogyo's self-imposed design constraints for the reciprocating engine are similar to those for the rotary except that they are willing to accept a 10% performance drop on the reciprocating engine and one rank lower driveability. They are also willing to accept a larger ($300) cost increase.

These constraints are all being met with the rich thermal reactor system but Toyo Kogyo is not yet certain that the maintenance constraint can be met with the catalyst system. At low mileage the thermal reactor system has achieved .13 gpm HC, 2.31 gpm CO, and 1.19 gpm NO_x and the catalyst system has been measured at .15 gpm HC, 1.5 gpm CO, and 2.35 gpm NO_x.

Toyo Kogyo has reported their intentions to use "auxiliary devices" on the 1975 models which would divert air pump discharge from the thermal reactor or catalyst when the engine speed exceeded 4000 rpm or the vehicle speed exceed 60 mph. Toyo Kogyo's own data shows that this will result in significant increases in HC and CO emission levels. Toyo Kogyo has stated that the reason for the air pump diversion is to control the thermal reactor temperature. It is not apparent to the report team why the single variable of engine speed is the most proper parameter to sense in order to control the air pump discharge. There may be operating conditions when the engine speed would be above 4000 rpm but the thermal reactor would not be in danger of overheating. Under such conditions, emission control is needlessly sacrificed, in our opinion.

Durability Program - '75

Currently Toyo Kogyo is utilizing a durability program to assess the suitability for 1975 production of three different engine/emission control system concepts. Included in this program is the rotary engine/thermal reactor, conventional engine/thermal reactor, and conventional engine/catalyst approach. The rotary engine program was initiated in April 1972 and the first of four vehicles are scheduled to be finished with the program by January of 1973. The conventional engine programs have only recently been initiated and there is not sufficient information available to assess this part of Toyo Kogyo's program.

Basically, two vehicle/engine types are being employed for the rotary engine durability program: a 35.0 x 2 CID engine in a 3,000 pound inertia vehicle. Both automatic and manual transmissions are represented. The conventional engines that are being prepared for, or just begun on, a mileage accumulation program include 97 and 110 cubic-inch displacement engines with both automatic and manual transmissions. Thus, all three of Toyo Kogyo's current engine families are represented.

While the details of the conventional engine systems initiating testing were not reported, the rotary system tests do include full 1975 components.

Mileage accumulation on the rotary engine vehicles has been run according to standard AMA procedures. Toyo Kogyo reports that maintenance on the rotaries thus far is normal "..with the exception of non-substantial defects" which were attributed to inadequate design or fabrication. The single rotary vehicle, MCC III No. 1, which has completed 50,000 miles of operation demonstrated the following deterioration factors:

HC	DF	1.14
CO	DF	less than 1.0
NO_x	DF	1.05

Low mileage emission data reported for that vehicle was:

HC 0.34 grams per mile
CO 2.45 grams per mile
NO_x 0.90 grams per mile.

It appears, at this time, that barring unforeseen incidents involving the remaining three rotary durability vehicles, that Toyo Kogyo has successfully demonstrated 50,000-mile durability with their rotary engine.

The vehicle MCC III No. 1 has been tested in the EPA Laboratory after over 50,000 miles had been accumulated. The emission levels measured were below the 1975 standards, thus verifying the reported good emission control performance reported by Toyo Kogyo.

Catalyst Screening Program - '75

Toyo Kogyo has the following general catalyst screening and dynamometer tests:

- Initial screening
- Low mileage test
- Warm-up
- High temperature aging test
- 50,000-mile durability (constant speed)
- 50,000-mile durability (cyclic test)

The first test uses synthetic exhaust gas while the other tests use an engine dynamometer to provide the exhaust for the catalyst.

The initial screening test involves measuring HC and CO conversion at fixed temperatures of about 570°, 750°, and 930° F. The catalyst is then aged with exhaust from an engine at constant speed. After the equivalent of 2,500 and 5,000 miles, the activity is measured again at these temperatures. The criteria set for passing these tests are given below.

Initial Screening Test

Percent HC Conversion	Temperature °F		
Catalyst Condition	570°	750°	930°
fresh	60%	65%	75%
2,500 miles	55%	65%	75%
5,000 miles	50%	60%	70%
Percent CO Conversion			
Catalyst Condition			
fresh	60%	82%	92%
2,500 miles	55%	65%	75%
5,000 miles	50%	60%	70%

In addition to these levels, there should be less than 3% attrition and no cracks in the catalyst.

The next major tests used by Toyo Kogyo involve low mileage emission tests on an engine dynamometer. Light-off temperatures are measured. The criteria for light-off temperature is that it be below 400°F. Also, 90% CO conversion should be attained in 90 seconds.

The next major test involves high temperature aging which measures CVS emissions after 10 hours at about 1800°F. Also, shrinkage and cracking of the catalyst are noted.

Following these tests, engine dynamometer durability tests are run to 50,000 miles at a 50 mph steady state condition. Catalyst temperatures range from 1100°-1350°F. Deterioration of CO effectiveness should be less than 10% using the CVS. Toyo Kogyo uses a second dynamometer durability test for catalyst screening which involves a cruise condition, transient driving, and cool down. The desired specification is that for 50,000 miles the CO activity deteriorates less than 10% using the CVS.

To date, several catalyst candidates show little deterioration for 50,000 miles only if the temperature is kept below 1100°F. These catalysts deteriorate rapidly at temperatures over 1200°F.

Progress and Problem Areas - '75

Progress

Toyo Kogyo has made significant progress on their rotary vehicles in the period of time since the suspension hearings in April 1972. At that time they had met their low mileage goals and had just started durability testing. The test fleet consists of four vehicles. One vehicle has now completed the 50,000-mile test, with satisfactory results. The other vehicles are at intermediate points in the mileage accumulation, also continuing satisfactorily. The results to date show no problem whatsoever in the durability of the thermal reactors. Toyo Kogyo continues to have a "very bright outlook" with respect to meeting the 1975 standards. Durability testing is also continuing on the reciprocating engine.

Problem Areas

Toyo Kogyo has not yet been able to demonstrate that they can meet the 1975 standards with their reciprocating engine, although the results are below the 1975 levels at 6,000 miles.

Conclusions - '75

Toyo Kogyo will be able to meet the 1975 standards with their rotary engine plus thermal reactor emission control system. Toyo Kogyo has been grouped in class 75-1 Non-Catalytic Approach because of the performance of their rotary engine system.

6.2.11.2 1976 Development Status

Systems to be Used - '76

There are two 1976 control systems under development for the rotary engines. The first is basically the 1975 system with the addition of EGR. The second system could be considered a backup system as it will probably only be used if the first approach fails to produce the required NO_x levels with acceptable performance, driveability and fuel consumption. The second system adds a NO_x catalyst and an oxidation catalyst to the first choice system. Toyo Kogyo is hoping for success with the first system as it would be much lower in cost and would not have the durability problems associated with catalyst devices.

Three different 1976 systems for the reciprocating engine are under consideration. The first uses a thermal reactor and EGR. The second uses a thermal reactor, EGR, a NO_x catalyst and an oxidation catalyst. The third uses a NO_x catalyst, and oxidation catalyst and EGR.

Tests results, at low mileage, on the first choice system for the rotary engine are averaging .35 gpm HC, 2.17 gpm CO and .49 gpm NO_x. These levels are at what Toyo Kogyo considers an acceptable fuel economy, driveability and performance penalty. At .49 gpm NO_x the fuel economy loss was 12% compared to 1973. Driveability was degraded about 15%, lowering it into the "fair" category. The 0-60 mph acceleration time was increased by .7 seconds but the vehicle's top speed (111 mph) was not affected. Data was reported, in graphical form, which indicates that .29 gpm NO_x can be achieved with the first choice system but Toyo Kogyo considers the driveability unacceptable at that NO_x level. A program to improve the EGR mixing is now underway to improve EGR tolerance. The increase in retail cost of the '76 system over the '75 system should be modest, in the judgment of the report team, since EGR is the only additional component.

Very little information was supplied on the backup system for the 1976 rotary-powered vehicle. The results of one test using the thermal reactor, dual catalyst and EGR approach: .1 gpm HC, .8 gpm CO and .35 gpm NO_x. A problem with this system, besides the added cost and complexity, is the 40% increase in NO_x which is being measured across the oxidation catalyst. Since this is a catalytic system the emissions can be expected to increase significantly with mileage accumulation. Toyo Kogyo plans to work hardest on the first choice (no catalysts) system until they repeatedly achieve below .4 gpm NO_x as it is a much more desirable system, in their opinion.

The first system for the reciprocating engine (thermal reactor plus EGR) is similar to the first choice system for the rotary but the results are not as low. The lowest NO_x level "practically achievable" is .7 - .8 gpm. Toyo Kogyo reported "the potentiality of the EGR system would be limited accordingly." It was indicated that NO_x levels as low as .1 - .2 grams can be achieved by combining the thermal reactor system with a NO_x catalyst and an oxidation catalyst but it was reported that, "...the bed temperature of the catalysts become (sic) extremely high, causing problems with respect to durability, and these systems, therefore, would not be suitable for practical use." Low mileage emission levels of .25 gpm HC, 2.8 gpm CO and .27 gpm NO_x were reported on the thermal reactor plus dual catalyst approach using a Kali-Chemie NO_x catalyst and an Engelhard oxidation catalyst.

The dual catalyst plus EGR system (no thermal reactor) was reported as low as .14 gpm HC, 2.7 gpm CO and .14 gpm NO_x using Johnson-Matthey catalysts AEC-3A and AEC-8A for NO_x and HC-CO respectively. This system employed a "quick warmup system" which was not on the thermal reactor plus dual catalyst car.

Although not mentioned in their text, a graph in the status reported indicates that the 1975-type single catalyst system maybe a possible way of achieving 1976 NO_x levels on the reciprocating engine, since NO_x levels of approximately .65 gpm were achieved. The bed temperature, however, of the oxidation catalyst was over 800°C at that NO_x level. Maximum bed temperatures are over 100° lower with the dual catalyst system and durability might be better, with the dual catalyst system.

No data was reported on the driveability, cost, fuel consumption and performance penalities associated with the first choice system since the program is in its infancy. Actually all of the information on 1976 systems is rather preliminary as Toyo Kogyo reported:

> "...with respect to both the rotary engine and the reciprocating piston engine, almost all of Toyo Kogyo's research and development efforts is (sic) now being concentrated in the achievement of the 1975 emission standards and we do not at the present have the reserve capacity to perform all of the research projects considered to be worthwhile in developing the 1976 system. In our opinion, we would not be able to exert our efforts for these projects in full scale until we have made a definite decision regarding the development of our 1975 system."

There may be a problem with certain "auxiliary" devices under consideration. As mentioned in the 1975 Development Status Section, an air pump diverter is under consideration. Toyo Kogyo also reported:

> "With regard to both the rotary engine and the conventional engine for 1976 model, the EGR may hereafter be controlled by ambient temperatures depending on the test results on the relation between the ambient temperature and driveability when EGR is adopted."

Durability Program - '76

Since Toyo Kogyo has not yet achieved their desired low mileage oxides of nitrogen level no mileage accumulation has been initiated. Plans call for this program to begin early in 1973.

Catalyst Screening Program - '76

Toyo Kogyo has the following general catalyst screening and dynamometer tests for reducing catalysts:

Initial screening

Low mileage test

Warm-up test

High temperature aging test

50,000-mile durability (constant speed)

50,000-mile durability (cycle test)

All of the tests use an engine dynamometer except the first test which involves synthetic exhaust gas.

The initial screening test involves measuring NO conversion from a synthetic exhaust gas (1000 ppm NO, 1% H_2, 1% O_2) at fixed temperatures of about 570°, 750°, and 930°F. After the equivalent of 2,500 and 5,000 miles, the activity is measured again at these temperatures. The criteria set for passing these tests are shown below.

Percent NO Conversion

Catalyst Condition	570°F	750°F	930°F
fresh	70%	75%	85%
2,500 miles	55%	60%	70%
5,000 miles	50%	55%	60%

The test results for four NO_x catalysts, presumably the better candidates, were given in the data submitted and, when the ammonia correction is applied, are well below the set criteria. A typical value is about 50% net NO_x conversion even with a fresh catalyst. Neither the suppliers nor composition of the four catalysts was indicated. Toyo Kogyo mentioned that they tested several noble metal monolith NO_x catalysts, but no more details were provided.

Progress and Problem Areas - '76

Progress

Toyo Kogyo has identified two possible 1976 systems for their rotary engine: one, the 1975 system with EGR, and the other, a more typical 1976 dual catalyst system. The dual catalyst system has achieved emission levels below the 1976 levels at low mileage. Some NO_x values were reported for the 1975 system plus EGR that were below the 1976 NO_x levels, but since HC and CO data from those tests were not reported, it is unclear whether or not the 1975 system plus EGR has attained the 1976 HC, CO, and NO_x levels. Toyo Kogyo reported that the NO_x levels attainable without deterioration in driveability are .5 to .6 gpm.

Problem Areas

Toyo Kogyo has been unable to put forth a full effort on 1976 systems, due to the fact that a very large fraction of their capability has been used to develop the 1975 system. Work on the 1976 system at a high level of effort is just beginning.

Problem areas that remain to be solved with the 1975 system EGR are: achieving results below .4 gpm NO_x with no sacrifice in the HC and CO control at acceptable driveability and demonstrating the durability of the system.

The problems with the dual catalyst system, both rotary and reciprocating,are much the same that other manufacturers are facing, primarily rapid deterioration of the NO_x catalyst.

Conclusions '76

The report team concludes that Toyo Kogyo has not yet demonstrated the capability to meet the 1976 standards.

The report team also concludes that the potential for success of the Toyo Kogyo rotary engine development is better than the potential of the reciprocating engine. Since the 1976 development was reported to be just beginning, little data was available. Toyo Kogyo is grouped in class 76-1 Non-Catalyst Approach because of the potential of the rotary engine.

6.2.12 TOYOTA

6.2.12.1 1975 Development Status

Systems to be Used - '75

Toyota's first choice system consists of engine modifications, EGR, noble metal oxidation catalyst and air injection. To back up the first choice system a rich thermal reactor system and a rich thermal reactor plus catalyst system are being considered. No data was reported on the backup systems.

In the judgement of the report team, the Toyota first choice system is less sophisticated than systems being developed by some other manufacturers. Development work to significantly lower the basic engine's emissions was not reported, proportional EGR system development was not discussed and catalysts are not close-coupled to the engine. Toyota reported serious problems with performance, driveability, fuel economy, and maintenance. The best low mileage values achieved were .15 gpm HC, 1.40 gpm CO, and 1.3 gpm NO_x. A 15% fuel economy penalty and a retail cost increase of $230 were reported by Toyota for the first choice system.

All development reported by Toyota to date has been on only one of the engine families.

Durability Program - '75

Toyota Motor Company utilizes a vehicle mileage accumulation program to evaluate systems which have, in preliminary laboratory screening, demonstrated potential for successful application to 1975 prototype systems. Currently, their durability program includes mileage accumulation on six vehicles with eight additional vehicles scheduled in a further phase of the program. Toyota reports that their durability program is several months behind schedule.

All of the vehicles utilized in the program, thus far, have been 96.9 cubic-inch displacement Carinas at a 2,500 pound inertia setting. The usage of this engine system represents only one engine family of five being marketed in the United States in 1973. This program is, therefore, not representative of Toyota's current vehicle mix.

The basic system concept which has been employed on the Toyota durability fleet consists of engine modifications, air injection, exhaust gas recycle and oxidation catalysts. NO_x settings tend to be less than 1.5 gpm.

The single greatest area of concern when analyzing the Toyota testing procedure is maintenance. In addition to questionable unscheduled maintenance events, Toyota has reported that "careful maintenance" has been performed at every 4,000-mile point.

Three vehicles (Phase I) have completed in excess of 36,000 miles. All three vehicles demonstrated reasonable success at low mileage points in complying with the 1975 goals. Deterioration, however, was excessive with respect to hydrocarbon and carbon monoxide.

Phase II vehicles currently have reached the 16,000-mile mark. Even at this fairly low mileage point deterioration appears severe.

Catalyst Screening Program - '75

Toyota has a very effective screening program which can be performed in a short time period. They do an initial laboratory screening test, a thermal stability durability-type test, and an engine dynamometer test. Following these tests, vehicle durability tests are run on successful candidates.

The initial laboratory screening test consists of passing an artificial exhaust gas over a small catalyst sample and measuring HC and CO conversion efficiency at a specific temperature. The thermal stability test is in two stages. The first stage involves measuring catalyst activity, as above. After the catalyst has been in an oven at 1470°F. In the second stage the catalyst is kept in the oven at 1470°F for 100 hours but engine exhaust gas is also added.

Promising catalysts from these tests are then run on an engine dynamometer in a thermal cycling-type test. Two catalysts in parallel can be tested simultaneously. Engine exhaust from the engine running at constant speed goes through one catalyst while room air is pulled through the other. Every 10 minutes the engine exhaust is put through the other catalyst while air pulled through the first catalyst cools it. These tests determine the effect of thermal cycling on catalyst performance and durability. To date, platinum-and palladium-containing catalysts seem to be most effective for higher activity at lower temperatures. However, Toyota reported that noble metal catalysts are not as durable at higher temperatures (over 1400°F) as base metal catalysts.

Progress and Problem Areas - '75

Progress

Toyota has decided to use a precious metal monolithic catalyst for 1975, and has recently signed an agreement with Engelhard to supply the needed components. Toyota has been able to achieve the 1975 emission levels at low mileage.

It has been reported in the press that Toyota has signed a license agreement with Honda regarding the CVCC engine.

Problem Areas

Toyota reported problems in several areas including fuel economy, safety, cost, driveability, packaging, maintenance performance and durability.

There may not be enough lead time remaining to adapt the CVCC process to all of Toyota's engines for 1975 should their own in-house development prove unsuccessful.

Conclusions - '75

The report team concludes that Toyota has not yet demonstrated the capability to meet the 1975 standards. They are grouped in class 75-2.2, Catalytic System Approach-Average Development Status because of their adequate low mileage results and lack of successful durability.

The report team also concludes that many of the problems are exacerbated by Toyota's desire to meet Federal HC and CO standards and the assumed California NO_x level of 1.5 gpm, rather than the Federal NO_x standard of 3.1 gpm.

6.2.12.2 1976 Development Status

Systems to be Used - '76

The Toyota 1976 approach is essentially to use the two 1975 systems with NO_x catalysts added. No work was reported on advanced engine modifications or proportional EGR systems to lower the basic emissions of the engine. Toyota is relying primarily on the catalyst approach, in the opinion of the report team. While other manufacturers, with heavier vehicles, have obtained NO_x levels below the 1976 requirements without reduction catalysts, Toyota reported that they did not believe they could certify at a NO_x level of even 1.0 grams per mile with NO_x catalysts. The best low mileage results reported were .24 gpm HC, 1.40 gpm CO, and .34 gpm NO_x. It was not reported whether or not this vehicle used a thermal reactor.

Since they have reportedly signed an agreement with Honda to license the CVCC process, Toyota may be planning to develop a CVCC powered vehicle for 1976 production. No development work on the CVCC engine was reported, however.

Durability Program - '76

The background and rationale behind Toyota's 1976 prototype durability program is identical to their 1975 program. Three vehicles are equipped with engine modifications, air injection, exhaust gas recycle, reactive exhaust manifold, oxidation catalyst and reducing catalyst. The schedule of mileage accumulation has been pushed back by six to eight months due to persistent failures of both 1975 and 1976 system approaches.

The 1976 prototype vehicles were exposed to the same rigorous maintenance at 4000-mile intervals as was reported for the 1975 fleet. In addition, reduction catalyst changes were performed on two of the three vehicles, the third was terminated at 20,000 miles due to high NO_x deterioration. All three systems are demonstrating high hydrocarbons and carbon monoxide deterioration as indicated in the 1975 report. In addition, unacceptably high oxides of nitrogen deterioration have been indicated on all three vehicles.

Catalyst Screening Program - '76

The Toyota catalyst screening program involves 1) laboratory bench test with a simulated exhaust gas, 2) thermal durability tests, and 3) engine dynamometer tests.

The synthetic exhaust gas used in the first test has the following composition:

CO	1%
HC	0.05%
NO	0.1%
O_2	0.3%
N_2	remainder

Ammonia formation is measured with both this gas and a similar gas with 1% hydrogen added. Catalysts with Palladium (Pd), Platinum (Pt) and Palladium-Ruthenium (Pd-Ru) active materials were tested and found to have high amounts of ammonia formation. However, the amount of ammonia formatiion is strongly dependent on the gas composition. No tests were done in the laboratory bench apparatus to investigate the ammonia formation as a function of gas composition. Toyota also measures ammonia formation as a function of A/F ratio in engine dynamometer tests.

The thermal stability tests are run by exposing the catalyst to air at 1470° for 15 hours and measuring its efficiency afterwards in terms of HC conversion. By contrast, 100 hours aging at 1470° is done on the oxidation catalyst. A more realistic test for thermal stability of NO catalysts in the opinion of the report team would be the exposure to exhaust gas at 1470° and then measuring HC, CO, and NO conversion efficiency. This condition is more realistic for actual catalyst aging exposes the catalyst to less oxygen and measures conversion efficiency for NO, the parameter of interest.

The final catalyst screening process is an engine dynamometer test. The steady state NO conversion efficiency is determined as a function of air/fuel ratio. The following general pelleted type catalysts have been tested for NO removal: Pd-Ru (90%), Pt-Ru (88%), unspecified base metal (45%), chromium base metal (95%), chromium-cobalt base metal (92%). The first three catalysts were tested at 840° temperature. Similar tests were done on a monolithic NO catalyst of unspecified composition and NO conversion efficiencies of about 60-85% were found.

Progress and Problem Areas - '76

Progress

Toyota has progressed to the point where two systems are under serious consideration for 1976. The first choice system is a typical 1976 dual catalyst. The second back-up system consists of the first choice system plus a thermal reactor. A few of Toyota's low mileage results have been below the 1976 levels. Toyota probably has as much experience as anybody in the industry in durability testing of 1976 emission control systems. The reported agreement with Honda may allow the consideration of the CVCC engine for 1976.

Problem Areas

None of Toyota's durability testing has been encouraging to date. Rapid loss of efficiency in the NO_x catalyst is the most severe emission control problem. Toyota claims that even with catalyst replacement there would be very little possibility of satisfying a NO_x standard of 1.0 gpm.

Toyota also reported problems with fuel economy, safety, cost, driveability, and performance.

Conclusions - '76

The report team concludes that Toyota has not yet demonstrated the capability to meet the 1976 standards. They are grouped in class 76-2.1 Catalytic System Approach-Average Development Status because of their durability problems.

6.2.13 VOLKSWAGEN (VW)

6.2.13.1 1975 Development Status

Systems to be Used - '75

VW is the only manufacturer reporting that a NO_x catalyst is under consideration for 1975 production. They are also the only manufacturer reporting that a three-way catalyst is under consideration for 1975 production. Altogether four systems are being considered:

1. Electronic fuel injection (EFI), thermal reactor (TR), NO_x catalyst (RC), oxidation catalyst (OC), air injection (AI), EGR?
2. Carburetion, TR, RC, OC, AI, EGR?
3. Carburetion, RC, OC, AI, EGR?
4. Advanced EFI, 3-way catalyst, EGR?

Systems 2 and 4 are reported to be receiving the most attention. VW reported that they are developing a carburetor similar to the IFC carburetor reported by GM which operates on the constant depression principle. It is not clear to the report team whether VW expects to have the carburetor in production by 1975.

Different EFI units are used on systems 1 and 4. System 1 uses the conventional D-Jetronic unit which meters fuel as a function of manifold vacuum and engine speed. System 4 uses the new L-Jetronic system which meters fuel as a function of inlet air velocity.

It was not clear if any of the four VW systems would use EGR. It is possible that VW has a proportional EGR system (since it is admitted above the throttle) but the flow characteristics of the EGR were not reported.

Only one set of data was reported by VW and the type of system under test was not identified. The low mileage emissions reported were .35 gpm HC, 2.99 gpm CO, and .41 gpm NO_x.

VW considers performance and fuel economy important design constraints. System 4, using the 3-way catalyst has the greatest potential of retaining good fuel economy in the opinion of the report team because a rich mixture is not required.

It was difficult to determine whether or not VW plans to use "modulating devices" which would adversely affect emission control during non-LA4 operation, since the section of their report discussing such devices was in German.

Durability Program - '75

Volkswagon's durability investigations of 1975 prototype systems have been very limited. Their program was disastrously impacted by the premature selection and stockpiling of a catalytic monolithic substrate which lacked mechanical integrity. Thus, no high mileage durability data of catalytically controlled prototypes is available. Tests of only one durability vehicle was reported. At 3400 miles this vehicle exceeded the 1975 carbon monoxide level.

It is not possible to reliably assess the prospects of the Volkswagon durability testing programs at this time.

Catalyst Screening Program - '75

VW referred to their submission to EPA during the April 1972 hearings for information on their catalyst screening program. This submittal contained only limited information on these tests. VW has an initial screening test involving measurement of HC and CO conversion on fresh and aged catalysts. VW also measures the resistance of the catalyst to both thermal shock and mechanical vibration and light-off temperature.

After these laboratory tests are completed, the catalyst is run on an engine dynamometer test and then, if it is promising, on a vehicle. VW provided no additional details.

Progress and Problem Areas - '75

Progress

VW has made some progress in system selection for 1975. They apparently have narrowed down the field to two choices, a typical dual catalyst system and a λ sensor system.

Problem Areas

VW did not report any durability results on 1975-type emission control systems. If, in fact, they have not run any durability they are behind most other manufacturers in gaining actual test experience from durability vehicle testing. VW also mentioned problems with respect to fuel economy, power loss, and driveability.

Since VW has always maintained that their development is a 1975-76 development, they have not reported 1975 results separately. Since, in our opinion, VW will not use a NO_x catalyst for 1975, it is not known if any durability problems will crop up if they introduce a system for 1975 which is essentially a 1976 system without the NO_x catalyst and with different system calibrations. VW did not report any test results on such a system.

Conclusions - '75

The report team concludes that VW has not yet demonstrated the capability to meet the 1975 standards. They are grouped in class 75-2.2 Catalytic System Approach - Average Development Status rather arbitrarily, since VW provided little information and data about their development programs.

The report team also concludes that VW will not use a NO_x catalyst for 1975 since in our opinion it is not necessary for VW to use a NO_x catalyst to meet the 1975 Federal NO_x standard.

6.2.13.2 1976 Development Status

Systems to be Used - '76

Refer to the 1975 Development Status section 6.2.13.1 for a description of the VW systems. VW reported on 1976-type control systems with either a reducing catalyst or a 3-way catalyst for both 1975 and 1976.

Durability Program - '76

VW's durability program is discussed under 1975 Durability Program.

Catalyst Screening Program - '76

VW did not include any details in their submission on catalyst screening programs for 1976 NO_x catalysts. The IIEC work on NO_x catalysts being done by American Oil Co. was mentioned as being a part of their NO_x catalyst program.

Progress and Problem Areas - '76

Progress

VW has made progress in system selection for 1976. They will probably use either a dual catalyst system or a λ sensor system.

Problem Areas

VW reported only one durability test on an unspecified 1976 system for an accumulated mileage of less than 3200 miles. It is not known if this is the same system on which VW reported durability data last year (1971) up to 24,000 miles.

Such limited durability testing, especially considering that the vehicle was over the 1976 NO_x standards to begin with, puts VW behind most manufacturers in this area. The problem areas mentioned by VW are the same for the 1976 system as for the 1976 system, namely, fuel economy, power loss, and driveability.

<u>Conclusions - '76</u>

The report team concludes that VW has not yet demonstrated the capability to meet the 1976 standards. They are arbitrarily grouped in class 76-2.1 Catalytic System Approach Average Development Status, since limited data was reported.

6.2.14 VOLVO

6.2.14.1 1975 Development Status

Systems to be Used - '75

Volvo's first choice system consists of engine modifications, electronic fuel injection, EGR, noble metal monolithic oxidation catalyst and air injection. Back-up systems are identical to the first choice systems except for the substitution of different catalysts for the Engelhard or Johnson-Matthey catalysts which will be used in the first choice system. The first back-up system would use either Kali-Chemie, UOP, or Grace noble monoliths while the second back-up system would use either base or noble metal pellets.

A new "KA" fuel injection system will be introduced on the four-cylinder engines by 1975. The "Jetronic" system currently used on 1973 model Volvos will still be used on the six-cylinder engines. The KA system is another Bosch system similar to the Jetronic but it controls fuel delivery as a function of inlet air velocity rather than intake manifold vacuum measurement. This could be a desirable feature on an engine using EGR, in the opinion of the report team, since the EGR flow rate influences manifold vacuum. Current Volvo EGR systems have a "backwards" calibration (higher than desirable flow at light loads, lower than desirable at heavier loads where NO_x control is more important) but proportional systems are under development. Apparently the catalyst-equipped test vehicles reported did not use the proportional system. Levels of 1.6 gpm HC, 10.6 gpm CO and 1.6 gpm NO_x have been achieved without catalysts or air injection using the proportional EGR.

The Volvo air injection system like that of all other manufacturers, except Toyo Kogyo and Mitsubishi,is a "backwards" system which supplies more air than is desirable at lighter engine loads. Volvo's own data indicates that there is an optimum air injection rate for each load. Emission control has been compromised, in the judgment of the report team, by using air injection systems that are not modulated.

Low mileage results on Volvo's first choice system have been as low as .16 gpm HC, 1.2 gpm CO, and 1.36 gpm NO_x. Very low results have also been obtained with a rich thermal reactor system which is no longer under consideration. A vehicle equipped with a rich, turbulent thermal reactor achieved .05 gpm HC, 1.43 gpm CO, and 1.30 gpm NO_x, but Volvo abandoned the work on this system because "...cracking, breaking, and distortion of the insulation and reactor core parts was a continuous problem which prevented any meaningful durability testing," and "...investigations showed that thermal reactors could not be successfully combined into any emission system to pass 1976 limits." This last statement indicates that one of Volvo's design constraints is that a 1975 system must be adaptable to a 1976 system configuration.

Volvo also considers the avoidance of power loss an important constraint. They also report that the shortage of lead time has been an important constraint. "...difficulties were caused by the lack of timely information on test procedures, the fuel specification to be available in 1975, on the allowable or required maintenance on emissions systems, and whether the averaging of production test results was to be permitted or not."

Locating after-treatment devices on their vehicle with a minimum of frame and sheet metal changes has also been difficult.

Volvo estimated the fuel economy penalty associated with their 1975 system will be 10% compared to '73 or 20% compared to uncontrolled vehicles. The cost of the '75 system was estimated at $140 (manufacturers cost, not retail price).

Durability Program - '75

Volvo's durability program is designed to determine the deterioration associated with their basic prototype system designs for 1975 model year vehicles. Of most significance in the program is the demonstration of catalyst deterioration characteristics. Thus far, Volvo reports that 11 different vehicles have been run, at least to low mileage, in their durability program. Seven other vehicles are currently under preparation for introduction into the durability program.

The test cars in the Volvo durability fleet have been selected to be as mechanically representative of the cars planned for sale in 1975 as possible.

Basically, the systems under evaluation consist of exhaust gas recirculation and oxidizing catalysts. However, not all of the vehicles in the program currently are equipped with EGR.

Volvo is employing three distinct mileage accumulation procedures: the standard Federal,high speed durability, and taxi service durability. The addition of two non-standard procedures for mileage accumulation is to quantify deterioration different from that associated with the Federal procedure but possible in consumer use.

Maintenance performed on the vehicles was designed so as to maximize the development data to be obtained, rather than in strict conformity with Federal procedures. Cars in the program have been updated to maintain the best representative systems on the vehicles. Changes in EGR design will be incorporated on all of the durability vehicles subsequent to completion of optimization study.

Three vehicles to date have in excess of 24,000 miles accumulated:

OB 46234/1 - high deterioration in HC, CO, and NO_x
OB 46232/2 - high deterioration in CO
OB 44085/1 - high deterioration in CO
converter failure at 29,980 miles

Catalyst Screening Program - '75

The catalyst screening program at Volvo includes both laboratory and engine dynamometer testing.

The laboratory test uses a synthetic exhaust gas composed of exhaust from a small Honda engine to which oxygen and CO are added to simulate automotive engine exhaust. This gas is passed over a heated catalyst and HC and CO conversions are measured. Also, the following parameters are being investigated:

Optimum bed dimensions
Space velocity
Conversion temperature
Amount of oxygen needed

In addition to these basic tests, attrition and thermal shrinkage are also measured. For thermal shrinkage tests, the catalyst is heated for 24 hours at each of the following temperatures: 1600°, 1700°, and 1800° F. Volume change is then measured.

The engine dynamometer tests involve measuring HC and CO conversions with various catalyst candidates. The following measurements are also taken:

1. Gas temperature before and after the converter
2. Catalyst temperature
3. Pressure drop across catalyst while varying rpm rpm (1800-3000), A/F ratio (13.5-15.5), and air injection rate

Also, a simulated cold start is done using different rates of air injection. A limited durability test of 50 hours at steady state conditions (3000 rpm) is also carried out.

Progress and Problem Areas - '75

Progress

Volvo has made some progress in system selection, catalyst and durability testing. The system to be used by Volvo is a typical 1975 system (except for electronic fuel injection). The platinum monolithic catalyst in the Volvo system will be sourced from Engelhard. It has been reported that a contract has been signed between Volvo and Engelhard for approximately 100,000 units for the 1975-77 time period. Volvo has accumulated more durability experience with their systems, some having more than 28,000 miles on them.

Problem Areas

Although some vehicles are still running after more than 28,000 miles, other vehicles that Volvo has tried have failed at much earlier mileages. Volvo also reported much greater catalyst deterioration with fuel containing .046 gpg lead compared to their earlier tests with fuel of a lower lead content (.01 gpg). Volvo did not report any testing at a lead level more typical of the average lead level expected for 1975 (.03 gpg).

Volvo also reported problems in getting catalysts from the catalyst manufacturers on a timely basis.

Conclusions - '75

The report team concludes that Volvo has not yet demonstrated the capability to comply with the 1975 standards. They are grouped in class 75-2.2, Catalytic System Approach - Average Development Status, because of their continuing durability problems.

6.2.14.2 1976 Development Status

Systems to be Used - '76

The Volvo 1976 first choice system is basically the 1975 system with the addition of a NO_x catalyst. Both pelleted and monolithic catalysts from several different manufacturers are being investigated. Unlike the 1975 EGR system, the 1976 system will be proportional. The "KA" fuel injection system which senses inlet air velocity rather than manifold vacuum, will be used on both the four- and six-cylinder engines in 1976. For 1975 the "KA" system is scheduled only for the four-cylinder models.

The best low mileage results achieved on the dual catalyst system were .26 gpm HC, 1.68 gpm CO, and .28 NO_x. This particular vehicle used Johnson-Matthey catalysts for both reduction and oxidation.

Volvo is also working on a 3-way catalyst system with an exhaust oxygen sensor to feed back information to the fuel injection system which will allow a stoichiometric mixture to be maintained.

At low mileage impressive results have been obtained: .08 gpm HC, 1.94 gpm CO, and .13 gpm NO_x. Again the catalyst was a Johnson-Matthey. Volvo reported many problems with this system including high catalyst temperatures, poor driveability, and oxygen probe durability problems.

Volvo claims that their biggest constraint for the 1976 model is the lack of adequate time to complete the system development. Volvo indicated that a catalyst temperature warning device will be used on the 1976 model. The use of "auxiliary devices" was not reported.

The EGR system, however, may not be a full-time system as it apparently is designed to provide high EGR rates only for a short period of time at higher loads. A schematic of the system provided by Volvo revealed a vacuum chamber connected to the intake manifold through a tiny orifice. When the load is increased, as in accelerating the vehicle away from rest, a vacuum is maintained in the chamber long enough to hold the EGR valve open during the acceleration. When the engine is kept highly loaded for a long enough period of time the vacuum in the chamber will be reduced to the point where it closes the EGR valve because the higher pressure air from the intake manifold will bleed into the vacuum chamber through the orifice.

Durability Program - '76

Volvo has reported that no vehicle durability testing has yet been initiated due to the very early state of development of 1976 prototype systems.

Catalyst Screening Programs - '76

The catalyst screening program at Volvo includes tests on an engine dynamometer to determine optimum performance characteristics for dual catalyst systems as well as conversion of HC, CO, and NO_x. The secondary air flow into the catalyst in these tests is about 15% of engine air consumption. A number of NO catalysts are seen to have a 90% efficiency when they are new and used under steady state conditions. The difference in the NO conversion after stage 1 and 2 is probably the amount of ammonia formed in stage 1 that is reoxidized to NO after stage 2. The large discrepancy of effective NO conversion for the Kali-Chemie

4035K pellets with two different oxidation catalysts was not explained. These two widely different numbers (about 50% and 85%) show that it is important in NO_x catalyst screening programs to measure ammonia formation directly. Volvo did not indicate that they made this important measurement in their catalyst screening program.

Progress and Problem Areas - '76

Progress

Volvo has made some progress in 1976 system development and durability testing. Volvo may introduce two new engines in 1976; the 5040 and the ZM. It is not clear whether these new engines will entirely replace the current B20 and B30 engines.

Volvo's 1976 system will most likely be a dual catalyst system, but the λ sensor system is also being developed. Some tests by Volvo have been below the 1976 levels. A few tests reached the 1976 NO_x level without use of a NO_x catalyst.

Problem Areas

Although some tests have been below the 1976 levels, serious durability problems remain for Volvo. Rapid NO_x catalyst deterioration, increased HC and CO levels and packaging are a few of the more major problems. The tests with just EGR resulted in burning out the oxidation catalyst. Lead poisoning, fuel economy, and over-temperature problems were also mentioned.

Conclusions - '76

The report team concludes that Volvo has not yet demonstrated the capability to meet the 1976 standards. They are grouped in class 76-2.1, Catalytic System Approach - Average Development Status, because of their adequate low mileage results and durability problems.

6.2.15 PEUGEOT

The status report from Peugeot was received just as this report was in the final stages of production. Necessarily, the discussion of Peugeot's development status is somewhat more limited than that of the other manufacturers. The late arrival of their response is the reason that the placement of Peugeot is out of alphabetical order.

6.2.15.1 1975 Development Status

Systems to be Used '75

Two systems are under consideration for 1975. Both are typical 1975-type systems. The "first class" system uses a precious metal monolith catalyst. The "second class" system uses a precious metal pellet catalyst. Aspects of the Peugeot system that are significantly different in detail from the typical 1975-type system are the type of air pump and the location of the catalyst. Peugeot plans to use an air pump of the Rootes type as opposed to the Saginaw-type pump being considered by most other manufacturers. Peugeot also contemplates positioning the catalyst more than 108 inches away from the exhaust ports, a distance significantly longer than that planned by most manufacturers. The wheelbase of the Peugeot 504 model is 108 inches, as a comparison.

Low mileage emission results are typically .1 to .3 gpm HC, below 1.0 gpm CO and below 1.0 gpm NO_x. Peugeot is achieving the low NO_x results in an attempt to meet California '75 NO_x. Tests without EGR are typically less than about 2 gpm NO_x.

Peugeot reported that without EGR the vehicle top speed is reduced by about 5 mph and the fuel consumption is increased between 9 and 25 percent depending on the speed. The comparison was made to European specification vehicles. The estimated first cost of the '75 first choice system was estimated by Peugeot to be about $270, the second choice system about $250.

Durability Program '75

Peugeot is currently conducting endurance tests on their 1975 system. Some vehicle tests appear to be durability tests, others appear to be system optimization tests. Peugeot reported durability results from 6 vehicles. Three vehicles are reported to be still running at 18,800, 11,300 and 4,000 miles respectively. No EGR is used on these 3 vehicles. The most significant vehicle, M.1876, at 18,774.3 miles had .19 gpm HC, .74 gpm CO and .83 gpm NO_x. The support for the catalyst on this vehicle was cracked at 11,100 miles. Many catalyst failures were reported by Peugeot. The vehicle with the most accumulated mileage, M.2899, had a melted catalyst due to an ignition problem at 21,416 miles. No vehicle was reported to have progressed farther.

Catalyst Screening Program '75

Peugeot's catalyst screening program involves four stages. Catalysts are laboratory tested for chemical and mechanical properties, then if successful, pass on to an engine dynamometer test, a CVS test and finally durability testing. The manufacturers of the catalysts tested by Peugeot were not identified by Peugeot.

Progress and Problem Areas '75

Progress

Peugeot has progressed to the point where a prime '75 system has been identified and some durability testing is underway.

Problem Areas

Catalyst durability is a major problem for Peugeot. No vehicle has yet been reported to have run even 25,000 miles without failure. Peugeot also reported problems in the area of over-temperature protection systems and lead contamination.

Conclusions '75

The report team concludes that Peugeot has not yet demonstrated the capability to meet the 1975 standards. They are grouped in class 75-2.2, Catalyst System Approach - Average Development Status, because of their good low mileage results and inadequate durability.

6.2.15.2 1976 Development Status

Systems to be Used '76

Peugeot plans to use a dual catalyst system for 1976. Use of a thermal reactor in addition to the two catalysts is still under consideration. The lambda-sensor, three-way catalyst is also under consideration. Peugeot may use the new engine under joint development by Peugeot,Renault and Volvo for 1976. Using a NO_x catalyst, but without EGR, a NO_x level of .36 gpm was reported. The engine type and HC and CO emissions were not specified. The first cost of the 1976 system was estimated by Peugeot to be approximately $400 over 1973 as a base, or approximately $125 more than the 1975 system.

Durability Program '76

Due to the early stage of development, no '76 durability program is yet underway at Peugeot.

Catalyst Screening Program '76

Peugeot's catalyst screening program for NO_x catalysts is essentially the same as the 1975 catalyst screening procedure. NO conversion efficiency of NO_x catalysts is also measured in addition to the HC and CO conversion.

Progress and Problem Areas '76

Progress

Peugeot has made enough progress to enable them to consider using a typical dual catalyst system for 1976.

Problem Areas

Catalyst mechanical durability and efficiency are expected to be serious problems by Peugeot. Other problems are yet to be encountered, since the '76 development program is in the early stages. With respect to NO_x catalyst efficiency, Peugeot stated:

> "It should be noted that the efficiency of the reduction catalysts which we tested, wanes as time passes."

Conclusions '76

The report team concludes that Peugeot has not yet demonstrated the capability to meet the 1976 standards. They are grouped into class 76-2.1, Catalyst System Approach - Average Development Status, rather arbitrarily since little detail on the 1976 development program was presented.

SECTION 7

APPENDIX

Reproduced below is a sample of the letter that was sent to the manufacturers on September 8, 1972. Copies of the letter were sent to American Motors, Chrysler, Ford, General Motors, International Harvester, Daimler-Benz, Volkswagen, and the Automobile Importers of America. Responses were received from 20 automobile manufacturers. Also reproduced below is a sample of the outline identifying and discussing the type of information requested.

Dear Sir:

As part of its continuing overview of the industry's efforts, and in order to implement sections 202(b)(4) and 202(b)(5) of the Clean Air Act, the Environmental Protection Agency needs current information on efforts by automobile manufacturers to meet the 1975 and 1976 light duty motor vehicle emission standards. Accordingly, pursuant to section 307(a)(1) of the Clean Air Act, you are requested to provide us with information regarding your development status and progress toward meeting these standards.

The information requested, which is described in the enclosed outline, is divided into five main areas: (a) organizational structure of your company's emission control program; (b) information describing emission control systems design, (c) information describing experimental testing and development programs, (d) emissions data, and (3) cost data.

The information provided by your company regarding 1975 system development should follow this outline, but may be limited to a discussion of changes made in design, testing protocol, or organizational structure, and to new test data and other information which has not been previously reported to EPA. Other information may be incorporated by reference to the earlier documents including responses to our request of September 1971, or to material submitted at the April 1972 public hearings on the suspension request for the 1975 standards.

The information regarding 1976 systems development should follow the enclosed outline and should represent a complete discussion of your 1976 system development program. Trade secret information submitted by you will be kept confidential by the Administrator to the extent and under the conditions set forth in the enclosed outline.

Two copies of your response to the request for emission control system information should be received at the following address by October 13, 1972, for the model year 1975 system development activities, and by November 1, 1972, for the model year 1976 system development activities.

Responses should be addressed to:

Director, Division of Emission Control Technology
Attention: Technology Assessment
Environmental Protection Agency
Motor Vehicle Emission Laboratory
Ann Arbor, Michigan 48104
U.S.A.

Any questions concerning the data requested should also be addressed to the above office, which has primary responsibility within EPA for acquiring and analyzing data on the status of technology for automotive emission control. Also, staff from that Division may need to contact you for additional information or explanations, and such request should be deemed by you as an integral part of the data gathering effort initiated by this letter.

Your cooperation in ensuring that the Environmental Protection Agency receives clear, detailed, and understandable information describing the efforts of your company in the design, development, and testing of 1975 and 1976 emission control systems will contribute materially to the decision-making process related to the implementation of Title II of the Clean Air Act.

Sincerely yours,

Original Signed by:

Eric O. Stork

(for) Robert L. Sansom
Assistant Administrator
for Air and Water Programs

Enclosure

OUTLINE FOR EMISSION CONTROL STATUS REPORT

The following outline should be followed in submitting the requested information. Any information not identified in the outline or the discussion of the outline that you feel is necessary for an accurate description of the emission control technical effort of your company may also be included.

I. Light Duty Emission Control Organization

   A. Discussion of organization

   B. Description of the critical path for system development

   C. Organization chart

II. Emission Control Systems

   A. Identification and description of the systems

   B. Discussion of system optimization

   C. Description of system operation

III. Development and Testing Program

   A. Description of test program and organization

   B. Test program basis and rationale

   C. Test vehicle description

   D. Test program status

IV. Experimental Data

   A. Vehicle Data

   B. Non-vehicle data

V. Cost Information

A. First cost

B. Operating cost

VI. Confidentiality of Trade Secret Information

DISCUSSION OF OUTLINE

I. Light Duty Emission Control Organization

A. Discussion of organization

This is a discussion of how your company's effort in light duty emission control is organized. What functions are carried out by what groups in the research, design, development and testing of emission control systems? Identify their separate areas of responsibility. Special attention should be given to the description of the functions of the group responsible for interfacing with catalyst manufacturers. Also identify if any functions are performed outside your company, such as testing, consulting or component development.

B. Description of the critical path for system development

This should include a description of the evolution of a system from concept to production. The path that the system takes should be described for a hypothetical system, following it through from concept to production, and a specific description should be provided of the path for each separate system identified in II below. Included in the discussion of the systems should be the identification of key decision points in the evolution of the system, identification of the person(s) responsible for such decisions, and for the systems described in II below the actual history with calendar dates of the decisions in the evolution of the systems described.

C. Organization chart

This is a chart of the organization described and discussed in A and B above. It should be presented in enough detail to identify personnel down to the first supervisory level.

II. Emission Control Systems

A. Identification and description of the systems

This should include both a generic and specific description of each system (first choice and all backup systems) under consideration for the model year under discussion. If any feature of the emission control system differs between model lines it should be treated as a different system. An example might be the emission control system for a 2000 lb vehicle as contrasted to the emission control system for a 5000 lb vehicle. An example of a generic 1975 emission control system is engine modifications, EGR, air injection and an oxidation catalyst. The detailed description should include enough information about the system to distinguish it from other systems in the same generic category. The description should be accompanied by engineering drawings and pictures when appropriate to more fully identify and describe the system or subsystem. At least the following topics should be discussed and fully identified.

1. Engine type - reciprocating 4-stroke, rotary, etc.
2. Engine modifications - compression ratio, combustion chamber shape, valve timing, bore/stroke ratio, spark plug location.
3. Intake system - detailed description of carburetor(s) fuel injection system, choke and choke control, intake manifold and intake port.
4. Exhaust port description

5. Ignition system

6. EGR system - flow rate, type of control, take-off location, introduction location, type of cooling (if cooled).

7. Air injection - type of pump, supplier, flow rate vs. engine speed, modulation and switching control, location of air injection nozzles.

8. Thermal reactor - type (lean/rich), configuration, materials, internal flow geometry.

9. Catalysts - type (reducing/oxidizing), active material (general class or specific, if known) loading and weight of catalyst material, substrate structure type (monolith/pellet), substrate composition, location, shape and size, geometry, manufacturer and manufacturer's identification number, nominal space velocity and space velocity range.

B. Discussion of system optimization

1. This should include a discussion of the design constraints within which each system was optimized in emissions. Examples of such constraints are, fuel economy, safety, cost, driveability, packaging, maintenance, and performance. Quantitative values should be identified for all of the constraints for which your company has determined such quantitative values. Others should be discussed in the manner in which they were set down for the design engineer.

2. This should provide a discussion of all designs that were not successful in surviving the optimization studies that your company performed, giving the criteria by which they failed.

3. Of the systems that are under consideration for the model year being discussed identify and explain any tradeoffs that have been made within the emission control system. Quantify any examples by including design calculations or engineering reports. An example might be catalyst location, where one emission control related tradeoff could be the tradeoff between a location close to the exhaust port for fast light-off versus a more remote location that might have less of an over-temperature problem.

C. Description of system operation

1. The sequence of operations of the entire emission control system during the 1975 Federal Test Procedure should be discussed in detail, with special attention given to those parameters which vary during the cycle, for example, spark timing, the choke position, air injection (if modulated or switched) and EGR flow rate.

2. The way in which the system operates under the following other conditions should be discussed; the emissions under such conditions should be quantified in IV-A below.

   a. Operation in low (less than 60 degrees F) or high (greater than 86 degrees F) temperature ambient conditions.

b. Operation under conditions of speed and/or load which do not occur during the 1975 Federal Test Procedure.

III. Development and Testing Program

A. Description of test programs

1. This should include a general description of the type of laboratory or bench scale testing carried out on emission control subsystems or components.

2. This should include a description of any catalyst screening tests and the basis for selecting/rejecting catalysts.

3. This should include a discussion of any tests made for optimization purposes described in II-B above, a general description of the variables that were changed, the range over which they were varied, and the inferences drawn from the system optimization tests.

B. Test program basis and rationale

1. This should include general discussion of the use of vehicles for component testing and trade-off studies, especially as it affects system optimization. Distinction should be made between vehicles used for component testing versus complete system tests.

2. This should include a complete description of all vehicle emission test programs for the model year under discussion, including the number and

type of vehicles, the reasons for choosing the vehicle mix, the mileage accumulation schedule for each vehicle and the number of emission tests at each mileage point.

C. Test vehicle description

This should include an identification of the vehicle nameplate, test weight, transmission type, axle ratio and an identification of the emission control system as outlined in II-A.

D. Test program status

This should include a discussion of the current status of each emission durability vehicle and a comparison of its status with respect to the original planning. Significant problem areas, if they exist, should be identified.

IV. Experimental Data

A. Vehicle Data

1. Include 1975 FTP data on all durability fleet vehicles described in III-B above.

2. Include a description of the reasons for any vehicle not completing the full scheduled durability mileage.

3. Include a complete discussion of vehicle fuel economy during the testing. If fuel economy is not measured on the same mileage accumulation schedule as the durability schedule, a complete description of the fuel economy test and data from current model year and uncontrolled vehicles

of the same weight for comparison purposes should be supplied. Also, include discussion of the driveability and performance of the test vehicles, again with quantitative data and with quantitative comparisons to current model year vehicles.

B. Non-vehicle data.

1. This should include the results from any catalyst screening tests, with a description of test methodology, and must include the test results from the catalysts that were selected for the durability vehicles.

2. Include any other non-vehicle data considered important such as engine dynamometer studies on the effect of fuel contaminants on catalyst durability.

V. Cost Information

A. First Cost

1. The cost breakdown should be in the same form as that used by the National Academy of Sciences Committee on Motor Vehicle Emissions in Appendix H of their January 1, 1972, semi-annual report to the EPA. This should also be specific as to what fraction of the various product lines will require specific devices.

B. Operating Costs

This should include expected extra costs to the customer over the vehicle lifetime (assume 50,000 miles) due to:

1. Fuel and lubricant cost, specifying the miles per gallon fuel economy assumed for each engine family.

2. Maintenance cost other than catalyst replacement. Such estimate should break out parts and labor cost separately providing the ratios of parts cost for OEM versus replacement cost. The estimate should also indicate the expected level of required maintenance on each major emission control component which results in such costs.

3. Catalyst replacement cost, if planned. This estimate should separate labor and material costs. Material costs should break out catalyst and container costs.

VI. Confidentiality of Trade Secret Information

A. Information submitted in response to the request which accompanies this outline will be deemed to have been obtained pursuant to section 307 (a) (1) of the Clean Air Act.

B. This means that only information which "would divulge trade secrets or secret processes" will be kept in confidence. (Even this information will not be kept confidential in two situations: (1) when the information is emission data, or (2) if and when the information becomes "relevant" to a pending suspension proceeding. See paragraph D.) In order to assure that such information will be kept confidential prior to any suspension proceeding, you must identify with particularity the data you regard as likely to "divulge trade secrets or secret processes" if disclosed, and you must present information to substantiate such claims. Such claims and supporting information must be submitted at the time of submission of the requested information or such claims will be deemed to be waived.

C. If the Administrator determines that a satisfactory showing has not been made that the information would disclose trade secrets or secret processes, you will be notified by certified mail. No sooner than 30 days following the mailing of such notice, any information with respect to which trade secret status has not been established will be placed in a public docket. Any information as to which the Administrator determines that a satisfactory showing has been made will be held confidential in the period prior to commencement of any suspension proceeding.

D. As in the case of the previous suspension proceeding, if any trade secret information becomes pertinent to the issues raised in a new proceeding on an application for suspension, it may be disclosed by the Administrator. In order to retain confidential treatment of such information, you must show to the satisfaction of the Administrator that non-disclosure of such information is justified by "exceptional considerations", as that phrase was defined in the course of the previous suspension proceeding. The showing that must be made is that the information is of such slight probative value in resolving the issue being considered by comparison to the harm likely to result from disclosure that public release of the information is not justified. If the Administrator determines that a satisfactory showing has not been made, you will be notified by certified mail. No sooner than 10 days following the mailing of such notice and telephone notice to a representative of your General Counsel's office, such information will be placed in a public docket. Any information as to which the Administrator determines that a satisfactory showing has been made will be held confidential and will not be considered by the Administrator in deciding whether to grant or deny a pending application for suspension.