TRADEOFFS
ASSOCIATED WITH POSSIBLE AUTO EMISSION STANDARDS

A Report to the Administrator
Environmental Protection Agency

Prepared by

Emission Control Technology Division
Mobile Source Pollution Control Program

February 1975

TRADEOFFS
ASSOCIATED WITH POSSIBLE AUTO EMISSION STANDARDS

A Report to the Administrator
Environmental Protection Agency

Prepared by

Emission Control Technology Division
Mobile Source Pollution Control Program

February 1975

CONTENTS

SECTION 1

INTRODUCTION

1.1 Purpose of the Report

This report has been prepared to provide the Administrator with our best judgement of what the impacts are likely to be of possible suspension decisions and recommendations to the Congress he might make. The impacts considered by the report team are strictly those which are the direct results of changes in emission control technology. These impacts include:

1. Vehicle cost changes

2. Vehicle fuel economy changes

3. Unregulated pollutant level changes

Indirect impacts that changes in emission control technology might cause were not dealt with. Impacts such as:

1. Changes in vehicle miles traveled (VMT)

2. Changes in ambient air quality

3. Changes in market demand

were considered beyond the scope of this report and may be better analyzed by others in the Agency.

1.2 Methodology

For each of the possible decisions and recommendations which the report team considered to be of greatest interest to the Administrator, the expected direct impacts were determined as a function of time. Five Scenarios are depicted which are the estimated results of five different decisions and recommendations the Administrator might make:

1. Suspend 1977 standards, set interim standards and recommend a freeze at 1.5 HC, 15 CO, implement a crash program that results in the elimination of catalysts from 1977 models.

2. Suspend 1977 standards, set interim standards and recommend a freeze at .9 HC, 9.0 CO.

3. Suspend 1977 standards, set interim standards of .9 HC, 9 CO, 2.0 NOx, recommend .41 HC, 3.4 CO, 2.0 NOx for 1978 through 1980.

4. Deny, recommend 2.0 NOx through 1980.

5. Deny, recommend lowest possible NOx through 1980.

For scenarios 1 and 2, the impact of 2.0 NOx versus 3.1 NOx was considered so insignificant compared to the impact of the other scenarios that specific differences between these two NOx levels were not depicted. The estimated impacts for scenarios 1 and 2 would be nearly the same for either NOx level. However, some quantification of the expected differences in impact of 2.0 versus 3.1 NOx is given in section 3.1 of this report.

For each scenario the report team estimated the type of emission control systems that would be used to meet the standards, the customer first cost of these control systems , the fuel economy of a typical car using those control systems and the sulfate emission levels the typical car would produce. All of these factors are shown for model years 1974 through 1980 for each of the five scenarios.

The impact of sulfate emission standards, or some other program to reduce vehicular sulfate levels, is considered for each scenario in addition to a "no sulfate control" case. Projections of tailpipe sulfate levels for scenarios 2 through 5 are made for three different assumptions:

1. No program to reduce the sulfur level of unleaded gasoline, no vehicular sulfate control, lead phase-down.

2. A blending and allocation program to reduce the sulfur level of unleaded gasoline, modified lead phase-down regulations, no vehicular sulfate control.

3. A moderate blending and allocation program to keep the sulfur level of unleaded gasoline at one half of pool levels, modified lead phase-down regulations, and a moderate vehicular sulfate control program implemented.

The control system usage projections are based on industry estimates of the type of systems they are planning to use for various emission levels and the judgement of the report team.

Cost estimates are based on Section 4 of <u>Automobile Emission Control The Technical Status and Outlook as of December 1974 (1).</u>* The cost

---

* Numbers in parentheses designate references at end of report.

estimates from that report were based on industry projections and the findings of the National Academy of Sciences and are expressed as the cost difference over uncontrolled vehicles.

Sulfate emission estimates are based on experimental work performed by the EPA Ann Arbor laboratory and Exxon Research and Engineering and studies of sulfur in gasoline performed by the M.W. Kellogg Co. (3) (4).

Fuel economy estimates are based on industry data on prototype cars, and analysis of EPA certification data for model years 1974 and 1975 (2). All fuel economy estimates are shown relative to the typical 1974 car. CHANGES IN FUEL ECONOMY FOR THE VARIOUS SCENARIOS ARE THE CHANGES DUE ONLY TO THE IMPACT OF EMISSION CONTROL HARDWARE ON ENGINE EFFICIENCY. The possible impacts of model mix shifts, weight reduction programs, aerodynamic drag changes and other such factors are not considered. These factors which were not considered could have more impact on vehicle fuel economy than the changes in emission control systems.

Previous analysis has clearly shown that the fuel economy level of nominally identical cars meeting the same emission standard can be significantly different. This situation occurs because different manufacturers place different levels of interest in fuel economy. Fuel economy can be traded-off against first cost and driveability. Rather than attempt to deal with this problem of differences in corporate philosophy with respect to fuel economy, the report team assumed that during the time period from 1977 through 1980 sufficient pressure (public or regulatory) would be on the industry to cause all manufacturers to place a greater emphasis on fuel economy than has been the case in the past, even at some trade-off in first cost. This assumption is somewhat hazardous because the variance in fuel economy that currently results from differences in corporate philosophy is another factor that has more impact on vehicle fuel economy than changes in emission control systems and emission standards.

In summary, the report team can project the changes in vehicle fuel economy related to engine efficiency changes with some confidence under the assumptions we have made. Since, however, the impact of future emission standard scenarios on fuel economy is small compared to other factors, the probability of accurately projecting the absolute value of the fuel economy of future model year cars based only on the level of future emission standards is small.

SECTION 2

SUMMARY AND CONCLUSIONS

2.1 Summary

Figures 2.1 and 2.2 summarize the report teams' projections for the first four scenarios of Section 1. It can be observed from Figure 1 that the first cost difference between the various scenarios ranges from a maximum of $160 in the 1977 model year to $180 in 1980. Table 1 shows the control system usage on which the cost estimates are based.

The difference in fuel economy between various scenarios ranges from 9% in 1977 to 5% difference in 1980. On this point the report teams estimate is in agreement with the findings of the EPA/DOT Fuel Economy Study (5) and the testimony of DOT at the suspension hearings. The technology can be available by 1980 to produce engines that are essentially unaffected by differences in emission standards between 1.5 15, 3.1 and .41, 3.4, 2.0. The 5% and 2.5% higher fuel economy for 1980 in scenarios 1 and 2 respectively, results from the assumed use of leaded fuel and one full unit higher compression ratio. The minimal disadvantages of the systems that require unleaded fuel may be reduced or eliminated by future engine modifications that facilitate the use of higher compression ratio.

Sulfate emission levels are estimated to range from a high of .05 grams per mile for the systems which use high sulfur fuel and oxidation catalysts with air injection to a low of less than .005 gpm which can be met by non-catalyst systems or catalyst systems if a blending and allocation program is implemented. With minimal control over unleaded fuel sulfur levels and moderate vehicular sulfate control, levels of H_2SO_4 emission of .013 gpm are considered possible at the .41 HC, 3.4 CO, 2.0 NOx levels. This level is about 80% lower than the level assumed in the EPA sulfate issue paper officially released on January 24, 1975.

2.2 Conclusions

With respect to the possible decisions and recommendations the Administrator might make the report team concludes:

1. 1980 fuel economy is estimated to be 7-13% better than 1975 due to engine efficiency improvements for all emission standards between 1.5, 15, 2.0 and .41, 3.4, 2.0. With still lower NO_x levels (.8 gpm in 1980) fuel economy in 1980 will be about the same as for 1975 models. Further reductions of NO_x levels beyond this level of o.8 gpm would result in fuel economy penalties relative to 1975 models.

2. Low NO_x systems below 2.0 gpm are estimated at $250 more than '75 systems. Emission control system costs in 1980 for the four scenarios depicted in figure 2.1 are estimated to be between $30 more and $150 less than 1975 systems.

3. The eventual, circa 1980, first cost and fuel economy penalties for the 1977 statutory emission standards compared to the 1.5, 15, 2.0 level will be about $180 and -5% in economy. Due to the use of unleaded fuel, lower maintenance cost for the 41, 3.4, 2.0 system, however, will more than counter-balance the first cost penalty.

4. Sulfate levels will depend on the emission standard level and the extent to which the sulfur of gasoline is reduced. Tighter emission standards will result in higher sulfate levels unless fuel sulfur is reduced or a vehicular sulfate control program is implemented but significantly lower fuel sulfur levels than were assumed in the EPA sulfate issue paper appear to be achievable without desulfurization.

2.3 Discussion of Conclusions

A typical emission control system for a 1975 model costs about $200. The principal components of the '75 system are engine mods, EGR and an oxidation catalyst. Some models also use air pumps. By 1978 or 1979 the report team estimates that tighter emission standards, at least down to .41, 3.4, 2.0 can be achieved with a less costly system. Data available to the report team from tests run on GM, Dresser and Chrysler systems indicate that improved carburetors calibrated for "lean burn" should be able to meet the 1977 statutory standards with catalysts but without EGR and air injection. Combining the lean burn approach with improved catalysts (perhaps using less noble metal) should cost less than current systems. The report team estimates however, that about half of the market will not have started using the lean burn plus oxidation catalyst approach by 1980.

As shown in Section 3, lean burn systems capable of "engine out" emissions in the range that can be catalytically controlled to .41, 3.4, 2.0 are equal in fuel economy to the best of the 1975 models, which is about 7% better than the typical 1975 car. Advanced oxidation catalyst systems also have the potential to meet .41, 3.4, 3.0 with 7% better economy than the typical 1975 model, as is discussed in Section 3. By 1980 both lean burn-oxidation catalyst and advanced oxidation catalyst systems can be "optimized" for fuel economy. The only emission control related fuel penalty is likely to be due to the lower compression ratio required for the use of lead-free fuel. Lean burn systems without catalysts may be able to achieve about 5% better fuel economy by using higher compression ratio and leaded fuel. The report team concludes that non-catalytic, lead tolerant systems could be optimized for fuel economy for emission standards as low as .9, 9, 2.0.

With long term emission standards of .9, 9, 2.0, several manufacturers can be expected to eliminate catalysts and use leaded fuel by 1980. This will cause first cost to be lowered compared to systems that use catalysts but lifetime maintenance costs will be more than significantly lower for the catalyst system because of unleaded fuel usage. The vehicle using unleaded fuel will need fewer spark plug changes and, most importantly, few exhaust system replacements. The report team believes a significant fraction of the market (approximately 50%) will stay with catalysts and unleaded fuel at the .9, 9, 2.0 level unless action taken by the government prevents them from doing so. Total operating costs (including fuel economy) of the catalyst versus non-catalyst system will be so close that one technology will not have a clear advantage over the other. The catalyst systems may be used by some for better driveability. At .9, 9, and 2.0 the catalyst system may need very little noble metal by 1980, and if fuel sulfur levels are reduced, the use of base metal catalysts, which could be cheaper and have less impact on the balance of payments, might be possible.

With long term emission standards of 1.5, 15, 2.0, nearly all manufacturers might be expected to eliminate catalyst usage by 1980 of their own volition. The report team estimates, however, that a significant fraction of the market would still use catalysts at these levels in 1977 unless government action prevents it, System costs by 1980 would be about $90 less than with standards of .9, 9, 2.0 and about $180 less than with standards of .41, 3.4, 2.0. Fuel economy should be equal to that achievable at the .9, 9, 2.0 level of standards or about 5% better than with standards of .41, 3.4, 2.0.

Emission standards designed to minimize NOx emissions will reduce the gains in fuel economy that are possible between now and 1980. The level of cost and fuel economy associated with a low NOx emission scenario will depend on just how low the NOx standard is made. The report team selected a scenario that is estimated to keep fuel economy well above the 1974 level. .8 gpm NOx by 1980 should be possible with about 5-10% less economy than is possible with the other scenarios. The degree of this fuel penalty, however, is strongly dependent on model mix. If the market shifts toward smaller cars then it may be possible to achieve about .8 gpm NOx with little or no penalty compared to the higher NOx scenarios. Our estimate of 5-10% fuel penalty assumes no shift to small cars.

Sulfate emission levels depend on the level of sulfur in the fuel and the efficiency with which the vehicle converts SO_2 formed during the combustion process to SO_3. Oxidation catalysts with air injection have been shown to increase the SO_2 to SO_3 conversion from the 1%-3% that occurs with non catalytic systems to 20-30%. With the fuel sulfur level typical of current gasoline this results in tailpipe emissions of about .02 or .03 grams per mile of sulfuric acid, H_2SO_4. The EPA

- issue paper on sulfates projected a potential health problem if .05-07 gpm H_2SO_4 occurs. The .05-.07 gpm emission rate was based on the assumption that unleaded fuel would eventually become as high in sulfur content as the current total gasoline pool is. A study performed for EPA by M.W. Kellogg indicates, however, that this does not necessarily have to be the case. As discussed in Section 3.3 of this report the sulfur level of unleaded fuel can be cut drastically using a blending and allocation program. In the short term, the cost of providing nearly sulfur-free unleaded fuel will depend on the degree of lead phase-down required. If the lead phase-down originally promulgated by EPA (and since over turned by the Court of Appeals) is modified it should be possible to attain fuel sulfur levels approaching zero. Even with a modest blending and allocation program (assuming a stringent lead phase-down) and moderate vehicular sulfate control, tailpipe sulfate emissions 80% lower than those projected in the EPA sulfate issue paper can be achieved while meeting the .41, 3.4, 2.0 levels. A moderate vehicular control program might consist of catalyst reformulation and air injection modulation. Preliminary data indicate catalyst reformulation could cut the SO_2-SO_3 conversion efficiency to half of that projected in the issue paper. If further reductions are necessary, traps should be available before 1980 that are 90% efficiency.

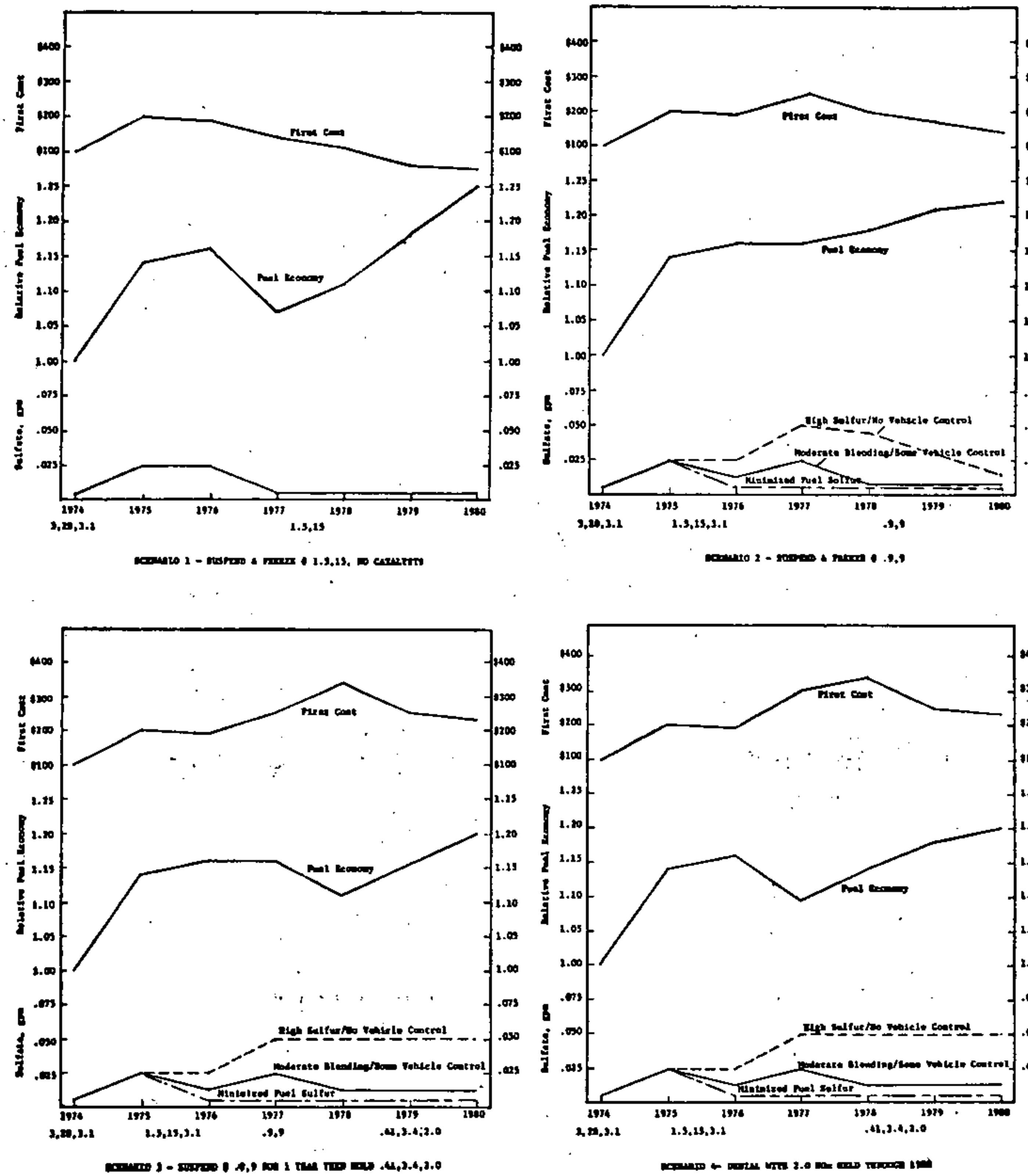


Fig. 2.1 Summary of the Scenarios

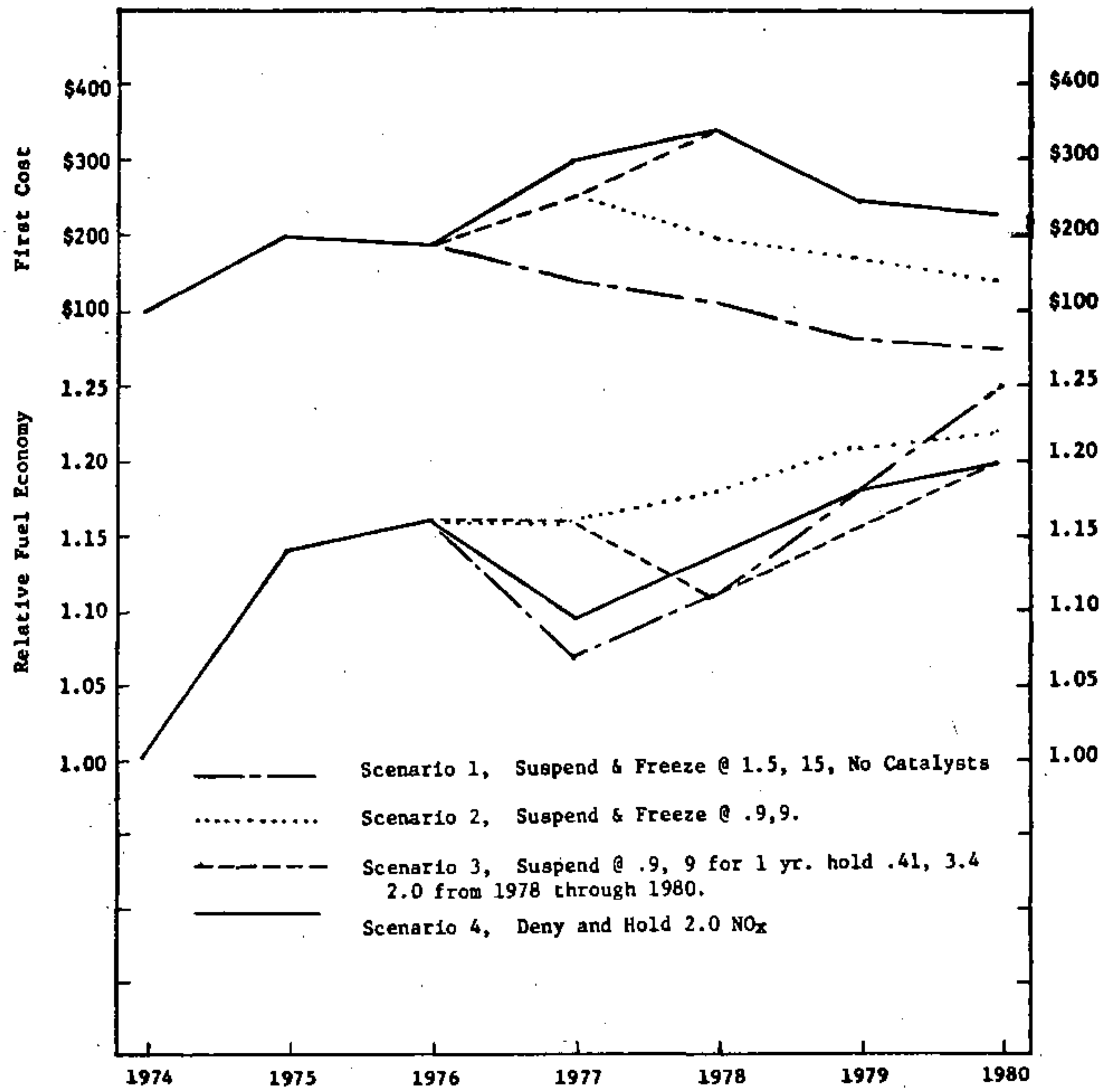


Figure 2.2 Summary of Scenarios

Table 1

Projected Emission Control System Usage
Scenario (Applicable Emission Standards in Parentheses)

Scenario Model Year	1	2	3	4	5
1974	EM-1 (3.0,28,3.1)	EM-1 (3.0,28,3.1)	EM-1 (3.0,28,3.1)	EM-1 (3.0,28,3.1)	EM-1 (3.0,28,3.1)
1975	OC-1 (1.5,15,3.1)	OC-1 (1.5,15,3.1)	OC-1 (1.5,15,3.1)	OC-1 (1.5,15,3.1)	OC-1 (1.5,15,3.1)
1976	OC-1 (1.5,15,3.1)	OC-1 (1.5,15,3.1)	OC-1 (1.5,15,3.1)	OC-1 (1.5,15,3.1)	OC-1 (1.5,15,3.1)
1977	LB-1 & EM-2 (1.5,15,3.1)	OC-2 (.9,9,2.0)	OC-2 (.9,9,2.0)	AOC-1 & OC-2 (.41,3.4,2.0)	AOC-1 & OC-2 (.41,3.4,2.0)
1978	LB-1 & EM-2 (1.5,15,3.1)	LB-2 & OC-1 (.9,9,2.0)	AOC-1 (.41,3.4,2.0)	AOC-1 (.41,3.4,2.0)	AOC-1 (.41,3.4,2.0)
1979	LB-1 (1.5,15,3.1)	LB-2 & OC-1 (.9,9,2.0)	AOC-1 (.41,3.4,2.0)	LBOC & AOC-2 (.41,3.4,2.0)	DC-1 (.41,3.4,1.2)
1980	LB-1 (1.5,15,3.1)	LB-2 & OC-1 (.9,9,2.0)	LBOC & AOC-2 (.41,3.4,2.0)	LBOC & AOC-2 (.41,3.4,2.0)	DC-1 (.41,3.4,.8)

Legend

EM-1	(engine mods.) Calibration changes, minor combustion chamber geometry changes, valve timing changes, EGR, etc.
EM-2	EM-1 with advanced cold start emission devices and air injection
OC-1	(Oxidation catalyst system) engine mods, EGR, no air injection
OC-2	OC-1 with air injection
AOC-1	(advanced oxidation catalyst system) OC-2 with start catalyst and advanced cold start emission control devices.
AOC-2	OC-2 with advance cold start devices, improved main catalyst over AOC-1
LB-1	(lean burn) improved carburetion and intake manifolding
LB-2	LB-1 with partial thermal reactors
LBOC	LB-1 with oxidation catalyst (no air pump, no EGR)
DC-1	(dual catalyst) NOx catalysts, oxidation catalyst, advanced cold start emission control systems, air injection

SECTION 3

BACKGROUND

3.1 Impact of Emission Control

3.1.1 Fuel Economy Impact

Some of the specific emission control related factors that affect both the emissions and fuel economy of current engines are air/fuel ratio and air/fuel ratio control, spark timing and spark timing control, degree of exhaust gas recirculation (EGR) and methods of EGR control, choke time, calibration and quick warm-up device control, intake air temperature control, choice of exhaust gas aftertreatment type, and system optimization. Table 3.1 gives the general effects these factors have on fuel economy and exhaust emissions. The varied effect of different emission control techniques such as the ones listed in Table 3.1 indicate that it is not enough to know the directional effect of a system change on exhaust emissions to deduce the directional change in fuel economy. Some of the most effective control techniques, such as catalytic converters, have no effect on fuel economy. The use of such devices allows the "decoupling", as NAS put it (7), of emission control and fuel economy. Aftertreatment devices such as catalysts and thermal reactors only affect fuel economy to the extent that engine calibration changes are made to optimize their effectiveness. With lean thermal reactors or catalysts, low emission levels can be achieved using engine calibrations for optimum fuel economy.

The net effect on fuel economy of a given emission standards depends on the combination of control techniques used to achieve compliance. Analysis of EPA certification data has clearly shown that the fuel economy performance of nominally identical cars (e.g. same weight, engine size, axle ratio, etc.) can be significantly different while the emissions are nearly the same. The difference in fuel economy is the result of the difference in the usage of fuel efficient control technology. At a fixed emission level fuel economy is a function of the usage of fuel efficient control technology.

At the 1974 emission standards of 3.0 HC, 28. CO and 3.1 NOx the typical car suffered a 12% loss in fuel economy compared to uncontrolled. This loss was due to the selection and use of emission control techniques such as spark retard, which reduced engine efficiency. It is important to point out that not all cars showed the losses of the "typical" car. As shown in Figure 3.1, the heavier vehicles (which needed more emission control) had losses greater than the average, while the lighter cars were able to meet the standards with no fuel penalty.

Table 3.1

Impact of Various Emission Control Techniques on Fuel Economy

Technique	Pollutants Controlled	Fuel Economy Effect
1. Retarded Spark Timing	HC, NOx	Negative
2. Rich air/fuel ratio	NOx	Negative
3. Lean air/fuel ratio	HC, CO, NOx	Positive
4. Port EGR	NOx	Negative
5. Proportional EGR	NOx	None or Positive
6. Quick Heat Intake Manifold w/fast choke	HC, CO	Positive
7. Heated intake air	HC, CO	Positive
8. Air injection	HC, CO	Almost none
9. Oxidation catalyst	HC, CO	None
10. Reduction catalyst	NOx	None
11. Thermal reactor	HC, CO	None
12. Reduced compression ratio	HC, NOx	Negative

FUEL ECONOMY vs. VEHICLE WEIGHT

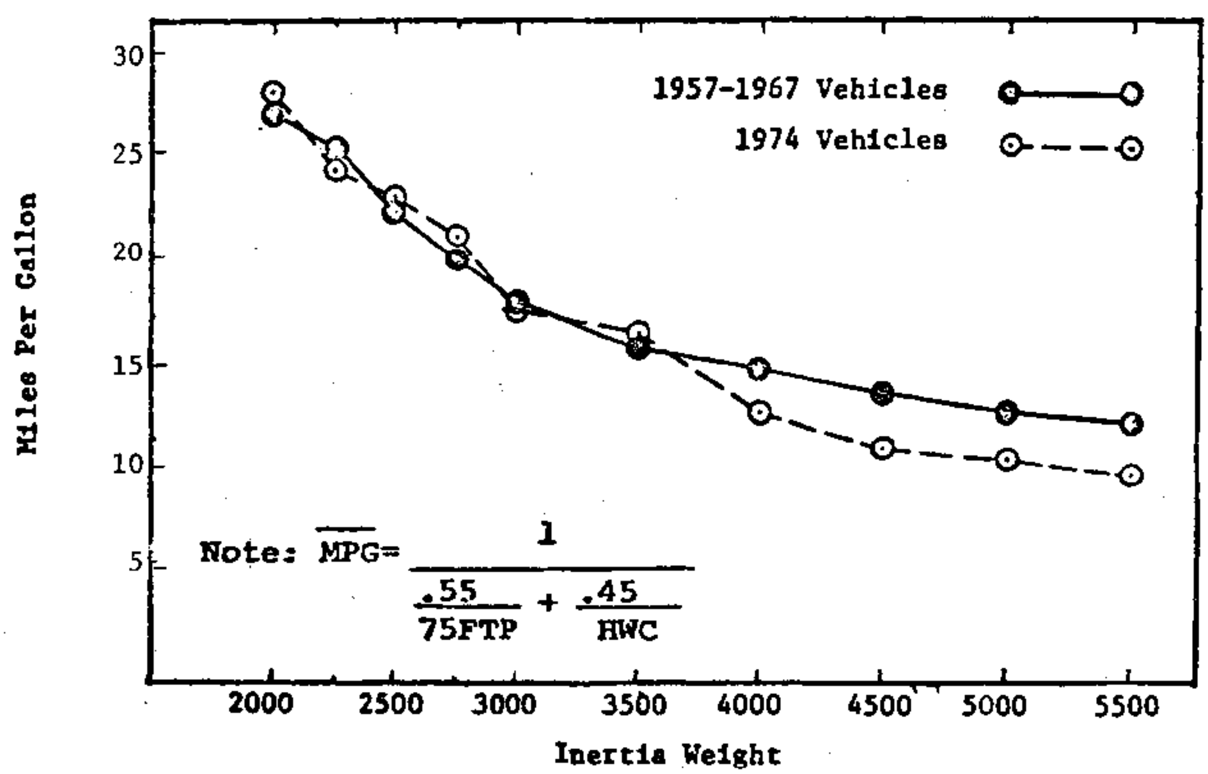


Figure 3.1

At the 1975 Federal interim standards of 1.5, 15, 3.1 it has been demonstrated that the use of oxidation catalyst systems allows fuel economy to be optimized except for a minor penalty due to the lower compression ratio required with unleaded fuel. Figure 3.2, taken from an SAE paper by GM (8) shows that "economy optimization" has been achieved on 1975 GM cars. The point labeled, "Potential Best Economy (No Emission Control)" and the point at the level labeled, "Gain adjusted for Weight and Compression Ratio" are showing the same economy. The lower compression ratio used on catalyst cars is estimated by GM to cause only a 2% loss in economy. Quoting from the paper, "For 1975, use of the oxidizing catalytic converter for after-treatment of HC and CO is seen to allow a recoup of virtually all emission-related fuel economy losses - except for the lowered compression ratio associated with low octane fuel."

Figure 3.3 compares the best of the 1975 model cars to the '57-'67 uncontrolled models. In the weight class region where GM sells most of their cars it can be seen that the fuel economy of the '75 models and uncontrolled cars are just about the same. In the lighter weight categories the best 1975 models are significantly better than uncontrolled cars because many small uncontrolled cars were not optimized for fuel economy. Many used excessively rich air-fuel ratios for better driveability and power.

Figure 3.4 compares the best of the 1975 models to the average of the 1974 cars. The report team agrees with GM (8) that the best 1975 models are essentially optimized for fuel economy. Comparing the curve for '75 models with the curve for the 1974 models, the report team estimated that the average optimized car could do 20% better in fuel economy than the average 1974 model car.

The levels of 1.5 HC, 15. CO, 3.1 NOx are -83%, -83%, and -11% respectively lower than the levels of uncontrolled cars and yet the selection of fuel efficient emission control technology has allowed these levels to be achieved (at least by one manufacturer) with essentially no fuel penalty. There is no technical justification for projecting that the capability for meeting emission standards without fuel penalty stops at 15., 15, 3.1. Work reported by GM (9) showed that NOx levels below 1.5 gpm could be achieved without fuel penalty with the use of proportional EGR (PEOR) and careful optimizing of spark timing and air/fuel ratio. The disadvantage of the PEOR/optimization method of achieving low NOx emissions is that HC and CO levels rise. A 5000 pound GM test car that achieved 1.1 gpm NOx had HC and CO emissions of 2.0 and 20. GM's production catalyst for 1975 would reduce these levels to .70 gpm HC and 7.0 gpm CO at 50,000 miles. The fuel economy of this car was 12.8 mpg on the urban test which is 17% higher than the average uncontrolled car in this

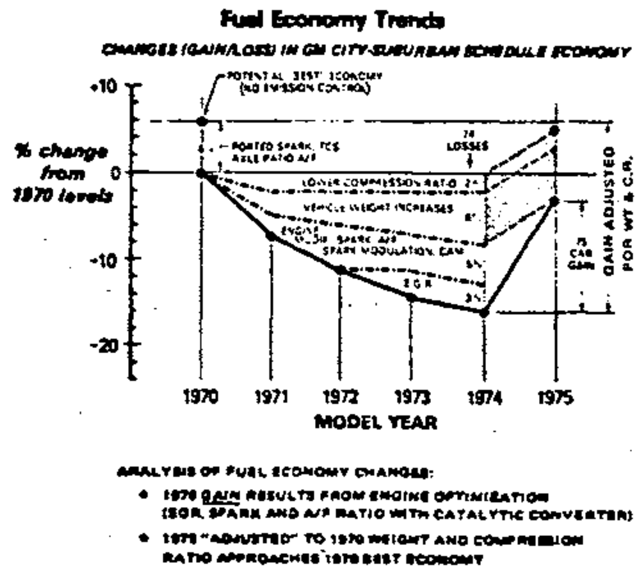


Figure 3.2

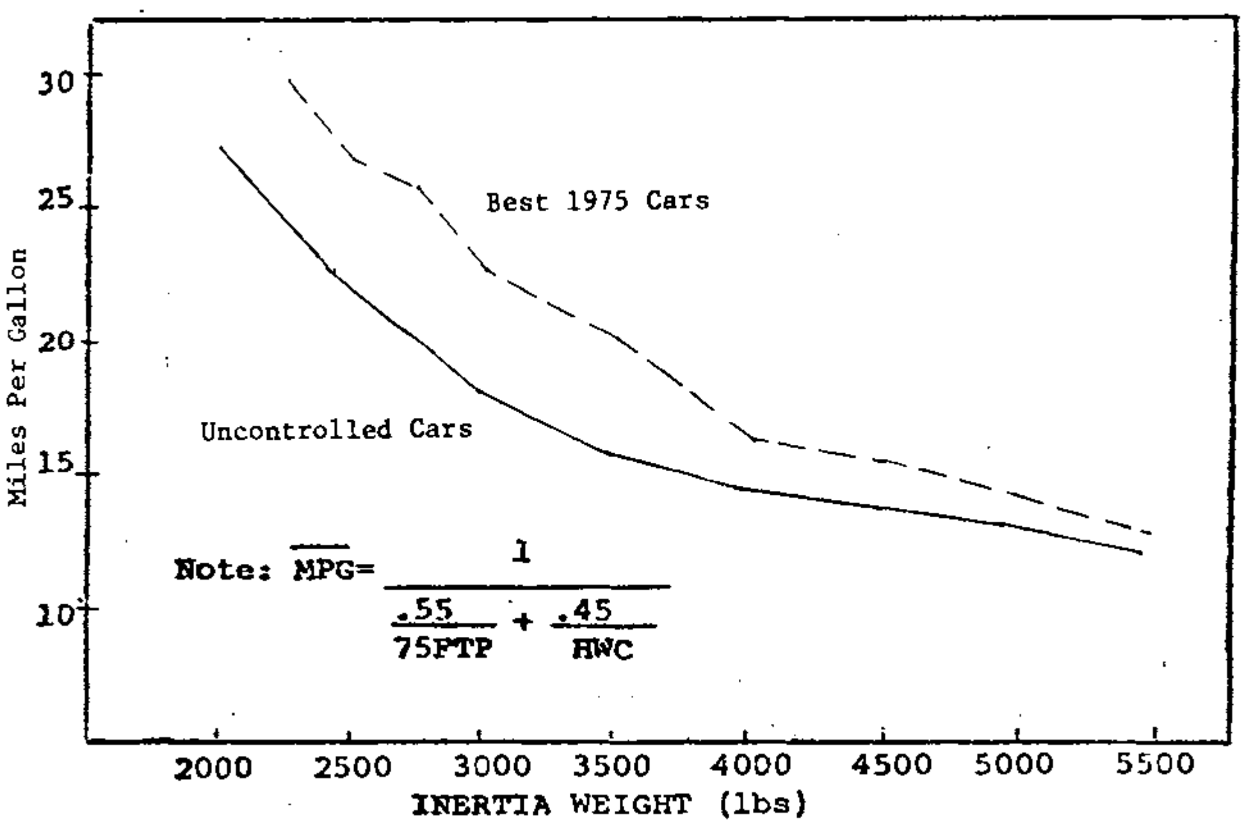
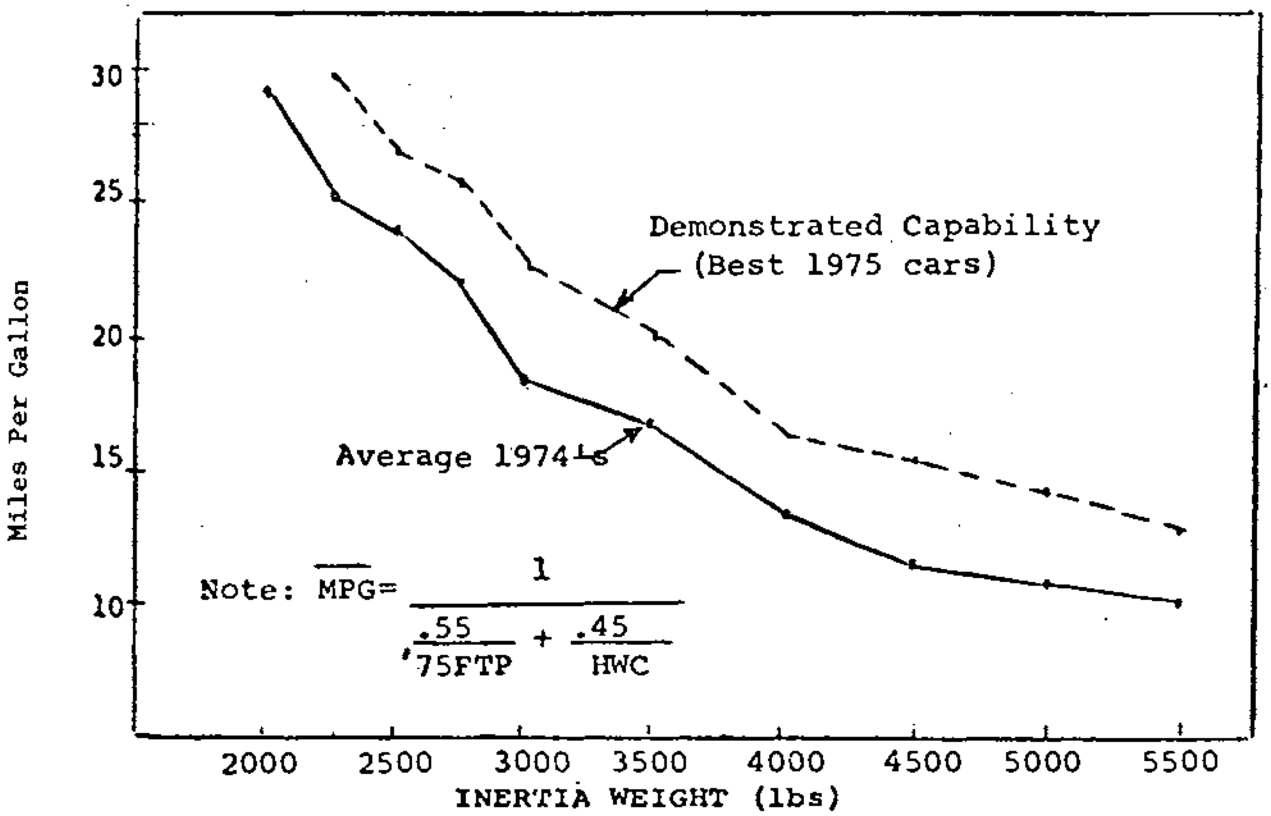


Figure 3.3

Figure 3.4



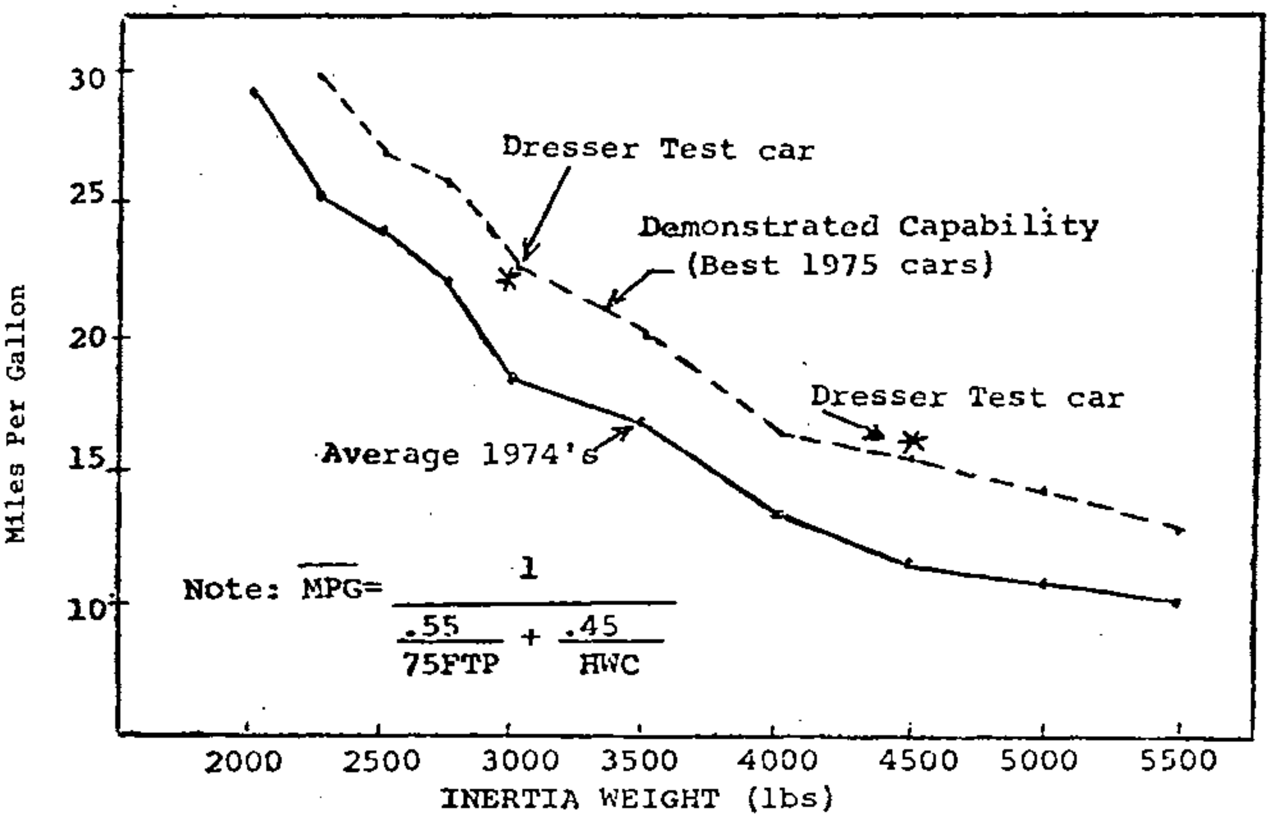


Figure 3.5 Advanced Lean Burn System versus 1974 Average and Best 1975 Data

weight class, 6% better than the average 1975 GM car in this weight class. Without advances in catalyst technology it appears that fuel economy can at least be optimized at the .9, 9, 2.0 level based on the results of tests like the one shown by GM in reference 9.

Below .9, 9, 2.0 the capability to avoid fuel economy penalties will depend on the development and implementation of more advanced emission control technology. It became apparent during this year's suspension hearings that one area where significant improvement is possible is catalyst efficiency. Two approaches looked promising, start catalysts and improved main catalysts. The kind of catalyst efficiency improvements already demonstrated by GM and the use of a "switched-out" start catalyst is projected to reduce the emissions of the low NOx, fuel economy optimized car from reference 9 to levels of .43 HC, 3.2 CO, 1.1 NOx at 50,000 miles. Such a system with NOx adjusted upwards would have a high probability of certifying at .41, 3.4, 2.0 with optimized fuel economy. The report team estimates that by 1980 the .41, 3.4, 2.0 standards will be achievable with optimum fuel economy even without the use of start catalysts. Two ways this might be achieved could be:

1. The PEGR/spark/air-fuel ratio optimization approach with further improved main catalyst efficiency.

2. The lean-burn approach with oxidation catalyst after-treatment.

The Dresser carburetor data from reference indicates this latter approach may be feasible. Dresser prototypes are already low enough to meet .41, 3.4, 2.0 with oxidation catalysts and reference 6 shows that the fuel economy of such a system would be as good as the best 1975 models (i.e. no fuel penalty). Figure 3.5 shows this graphically.

To achieve .41 HC and 3.4 CO with NOx levels below 1.5 it may be beneficial to use NOx catalysts. While the feed gas of the car described above may be NOx catalyst compatible, the addition of NOx catalysts to the system may degrade the HC and CO control efficiency to some extent because of the thermal inertia then will add to the system. This added thermal inertia may require the start catalyst to be left on stream longer than without NOx catalysts and this would result in degraded start catalyst efficiency at high mileage. It may be necessary to use some kind of fuel inefficient approach, such as spark retard, to make up for lost HC control.

Assuming that serious efforts are made by the manufacturers to achieve good fuel economy, the report team has estimated the type of systems that would be likely to be marketed given different assumptions about the time phasing and level of emission standards.

The estimates appear in Table 3.2. We are projecting that the system which could be initially used for any particular emission standard will evolve into a simpler and less expensive system with time. Down to standards as tight as .9 HC, 9.0 CO, 2.0 NOx we believe a significant fraction of the market will eventually use non-catalytic hardware. At the .41, 3.4, 2.0 level and lower we believe the catalyst will continue to be a part of any system designed with fuel economy in mind. Alternative engines such as stratified charge were not considered for two major reasons:

1. They will not represent a significant portion of the market by 1980.

2. They offer only minimal fuel economy benefit unless run as open-chamber unthrottled versions. Such versions have odor, noise and hydrocarbon carbon emission problems and they are significantly more expensive because of the high pressure fuel injection systems they require.

At least down to the emission levels of .41, 3.4, 2.0 the capability to optimize fuel economy by 1980 is projected by the report team. It does appear however that lead time problems will result in some fuel penalties in the interim, even at less stringent emission standards. This is because few manufacturers have been concentrating on optimizing fuel economy at emission standard lower than they have asked to be set as interim standards. Notable examples are several foreign manufacturers like Volkswagen, for instance who is already fuel economy optimized and is projecting no penalty at .41, 3.4, 2.0.

Appendix 1 to this report summarizes the short term fuel economy losses that can be expected based on prototype car tests.

Table 3.3 gives the report team's estimates of fuel economy relative to 1974 models for the same emission standard/model year combinations shown in Table 3.2.

3.1.2 Cost Impact

The system cost associated with any particular emission standard depends on the individual components used to make up the system. There is some difficulty in estimating costs for a particular standard because of the several combinations of individual components capable of achieving compliance. The component cost estimates used by the report team are based primarily on those estimates made in reference 1. Table 3.4 is taken directly from reference 1.

Table 3.5 gives the report teams estimates of the cost associated with the systems described in Table 3.2. As would be expected the cost of meeting a particular emission standard decreases with time as technology improves.

Table 3.2

Projected Emission Control Systems
Applicable Standards

Model Year	3,28,3.1	1.5,15,3.1*	.9,9,2.0	.41,3.4,2.0	.41,3.4,.4
1974	EM-1				
1975		OC-1	OC-2		
1976		OC-1	OC-2		
1977		EM-2 and LB-1	OC-2	AOC-1 and OC-2	
1978		LB-1 and EM-2	LB-2 and OC-1	AOC-1	DC
1979		LB-1	LB-2 and OC-1	LBOC and AOC-2	DC
1980		LB-1	LB-2 and OC-1	LBOC and AOC-2	DC

* No catalyst usage assumed starting 1977

Legend

EM-1 (engine mod) calibration changes, minor geometry changes (combustion chamber shape valve timing, etc), EGR

EM-2 EM-1 with advanced cold start emission control devices and air injection

OC-1 (oxidation catalyst) engine mods include EGR, oxidation catalyst, no air injection

OC-2 OC-1 with air injection

AOC-1 (advanced oxidation catalyst) OC-2 with start catalyst and advanced cold start emission control devices

AOC-2 AOC-1 without start catalyst but with improved oxidation catalyst

LB-1 (lean burn) engine mods without EGR, improved carburetion and intake manifold

LB-2 LB-1 with partial thermal reactors

LBOC LB-2 with oxidation catalyst

DC (dual catalyst) AOC system plus NOx catalyst

Table 3.3

Projected Fuel Economy Relative to 1974 Applicable Standards

Model Year	3.28,3.1	1.5,15,3.1*	.9,9,2.0	.41,3.4,2.0	.41,3.4,Low NOx
1974	EM-1 = 1.0				
1975		OC-1 = 1.14	OC-2 = 1.07		
1976		OC-1 = 1.16	OC-2 = 1.10		
1977		EM-2 = 1.03 LB-1 = 1.14 avg. = 1.07	OC-2 = 1.16	OC-2 = 1.03 AOC-1 = 1.14 avg. = 1.09	
1978		EM-2 = 1.03 LB-1 = 1.14 avg. = 1.11	LB-2 = 1.20 OC-1 = 1.16 avg. = 1.18	AOC-1 = 1.14	
1979		LB-1 = 1.18	LB-2 = 1.22 OC-1 = 1.18 avg. = 1.21	LBOC = 1.18 AOC-2 = 1.18 avg. = 1.18	DC = 1.09 @ 1.2 NOx
1980		LB-1 = 1.25	LB-2 = 1.25 OC-1 = 1.20 avg. = 1.22	LBOC = 1.20 AOC-2 = 1.20 avg. = 1.20	DC = 1.15 @ .8 NOx

* No catalyst usage assumed starting 1977

Table 3.4
Emission Control Component Costs
(Jan 75 Dollars)

Component	NAS Estimates 73	NAS Estimates 74	Range of Most Manufacturers Estimates	Report Team Estimate
1. PCV valve	$3.50	3.	2 - 3	3
2. Evap Control	$17.00	12.	5 - 18	15
3. Transmission Controlled Spark (TCS)	$4.50	-	7 - 34	5
4. Anti-Dieseling Solonoid	$6.00	-	2 - 6	6
5. Intake air heater	$4.50	-	5 - 12	5
6. OSAC spark control	$1.00	-	6	5
7. Hardened valve seats	$2.00	-	2	2
8. Port EGR	$11.50	15.	14 - 61	20
9. Air system	$52.50	35.	25 -	40
10. PEGR	$36.50	23.	35 -	40
11. QHI manifold	$6.00	-	-	10
12. Electric choke	$6.00	-	4 - 9	6
13. HEI	$11.50	-	27 - 116	30
14. Timing & other control modulation valves	$3.50	-	2 - 33	5
15. OX catalyst	$66.50	80 Pellet 61 Mono	36 - 300	80 Pellet 50 Big Monolith
16. NOx catalyst	$45.00	86 Pellet 78 Mono	75 - 178	60 Each
17. Misc. mods thru '74	$19.50	-	30 - 70	20
18. EFI	$53.00	120	250 - 556	250
19. O_2 Sensor	-	4	20 - 130	20
20. 3-way catalysts	-	97	175 - 220	100
21. Thermal Reactor	-	-	70 - 140	100
22. Improved Exhaust System	-	-	30 - 40	30
23. QA and other tests	-	-	5 - 39	10
24. Ox Pellet cat chg.	-	-	29 - 77	70
25. Mono cat chg.	-	-	- 178	150
26. EFE	-	-	10 - 15	15
27. Start catalyst	-	-	- -	50

Table 3.5

System Cost Estimates
Applicable Standards

Model Year	3,28,3.1	1.5,15,3.1*	.9,9,2.0	.41,3.4,2.0	.41,3.4,4
1974	EM-1 = $100				
1975		OC-1 = $200	OC-2 = $240		
1976		OC-1 = $190	OC-2 = $240		
1977		EM-2 = $150 LB-1 = $60 avg. = $140	OC-2 = $250	OC-2 = $270 AOC-1 = $340 avg. = $300	
1978		EM-2 = $150 LB-1 = $60 avg. = $110	LB-2 = $90 OC-1 = $210 avg. = $200	AOC-1 = $340	
1979		LB-1 = $60	LB-2 = $90 OC-1 = $200 avg. = $170	LBOC = $190 AOC-2 = $270 avg. = $250	DC = $450
1980		LB-1 = $50	LB-2 = $90 OC-1 = $200 avg. = $140	LBOC = $190 AOC-2 = $270 avg. = $230	DC = $450

* No catalyst usage assumed starting 1977

3.3 Sulfate Emission Impact

Sulfate emission levels from automobiles primarily depend on two factors:

1. Conversion efficiency of SO_2 formed during combustion to SO_3 in the vehicles exhaust system.

2. Fuel sulfur levels.

Reductions in vehicle sulfate emissions from changes in both of these factors appear possible without the expense of complicated vehicular sulfate traps or extensive fuel desulfurization.

3.3.1 Fuel Sulfur Levels

Gasoline is a blend of five major refinery products-butane, alkylate, reformate, virgin gasoline, and fluid catalytic cracked (FCC) gasoline. The percentages of the refinery products utilized in the refinery blend depend largely upon the desired octane of the product, the actual quantities of each product produced, and competitive price of gasoline at the retail level.

The first four components are inherently high in octane quality and are more costly to produce (except for butane). The fifth component FCC gasoline is low in octane quality but its production cost is lower. Because of the inherent characteristics of the refinery process the first four components are very low in sulfur content while the FCC gasoline component is very high in sulfur content.

Historically, the low octane quality FCC gasoline has been equally distributed between the premium and regular grades of gasoline. The poor octane quality of this component was offset by blending in varying fractions of the other four components and the addition of tetraethyl lead.

The introduction of no-lead requirements and the regulations for phase-down of lead average content in the total pool has required significant changes in the blending programs. Currently, most refiners have elected to blend the no-lead grade with little if any FCC stock. This is borne out by the surprisingly low sulfur content in the no-lead grades currently marketed as reflected by the latest MVMA gasoline survey.

This utilization of the high octane components in the no-lead grade is possible because of low sales volume and correspondingly decreases in sales of premium fuel which has freed the necessary blending components. Actually, since octane must be built up in the no-lead fuel through hydrocarbon composition alone there is a limit to the amount of FCC gasoline that could be utilized - a limit that in the opinion of the report team would hold sulfur content consequently to about 0.02-0.25 wt. %.

The phase-down regulation will require increased useage of high octane components in both regular and premium grades. By 1978, in the opinion of the report team, the refiners will face an octane shortfall which can most readily be solved by reformation of the FCC gasoline. Such processes require the almost complete desulfurization of feed stocks because of the sulfur poisoning of catalysts utilized in the processes.

Consequently, if the market demand for no-lead fuel continues to grow as EPA orginally projected and the lead-phase down regulations are successfully defended in the courts, the refining industry will have to begin operation of hydrodesulfurization equipment by 1978 regardless of government action.

A revocation of the phase-down regulations with no change in no-lead gasoline demand growth would delay the need for installation of reformer capacity and desulfurization to 1980-81.

In either case without governmental action the sulfur content would be expected to increase to a stable level of about .02-.25% by wt.[1] This number is about 20to 25% lower than that assumed for the 49 state case in the sulfate modeling studies and about 50% lower than the value assumed for California.

The "assumption " used for the scenario presented in this report projected a moderate blending and allocation program designed to result in the availability of unleaded fuel of .015% sulfur by weight. This calls for only 25% to 40% lower sulfur levels than the report team estimates will occur without any program to lower gasoline sulfur. This can be accomplished without desulfurization or allocation if the lead phase down is modified or eliminated. With the lead phase-down .015 could be achieved with modest de-sulfurization and no allocation program or without de-sulfurization if a program is implemented that allocated the low sulfur fuel to urban areas.

3.3.2 Vehicular Control

Three types of vehicular control techniques for sulfate emissions are already showing promise despite the modest level of sulfate control technology development effort underway:

1. Catalyst reformulation
2. Excess air control
3. Traps

Catalyst reformulation and excess air control have already demonstrated 50% reductions in sulfate compared to conventional '77 prototypes with

---

[1] This estimate is supported by the testimony of M.W. Kellogg Co. at the recent sulfate hearings. Kellogg projected (TR@544) .025% as the sulfur content of no lead fuel without installing additional desulfurization equipment. Under this assumption the lead phase-down was not achieved Meeting the lead phase-down would require more reforming capacity. The use of more reformation requires more desulfurization and sulfur levels would likely go below .025 in unleaded fuel-

air injection and catalysts. Traps have shown over 90% sulfate removal for 25,000 miles. The report team estimated, based on these promising preliminary results, that 50% control could be achieved by 1978. The report team considers it most likely that catalyst reformulation will receive primary emphasis as this technique has essentially no adverse emission control or cost impacts.

SECTION 4

POST '75 SCENARIOS

Each scenario runs from model year 1974 through model year 1980. Scenarios 2 through 5 are based on three different assumptions about sulfate emissions.

1. No program to reduce the sulfur of unleaded gasoline, no vehicular sulfate control, lead phase-down.

2. Blending and allocation program to reduce the sulfur level of unleaded gasoline, modified lead phase-down regulations, no vehicular sulfate control.

3. A moderate blending and allocation program to keep the sulfur levels of unleaded gasoline at one half of pool levels, modified lead phase-down regulations, and a moderate vehicular sulfate control program implemented

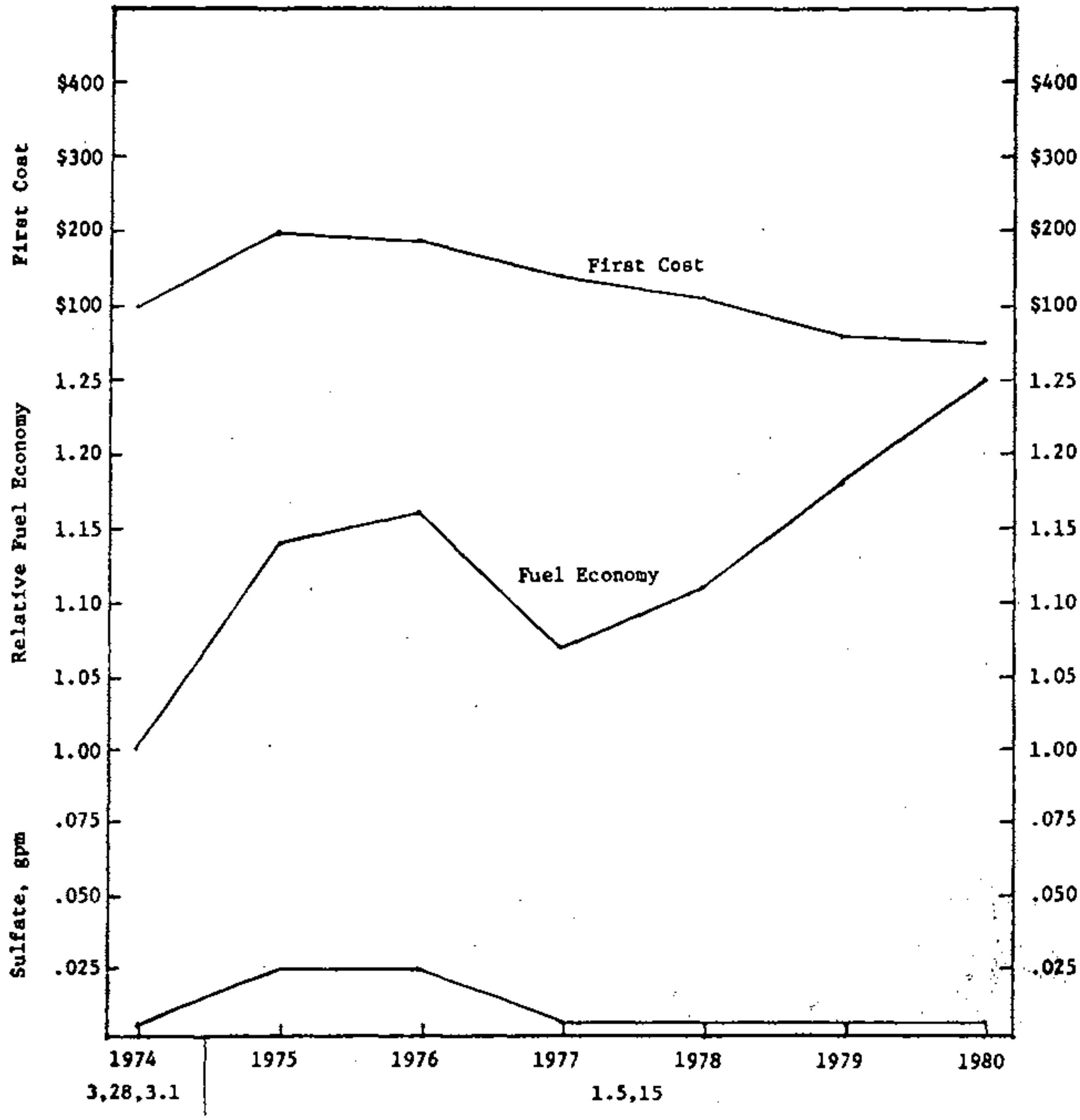
First cost over uncontrolled cars, fuel economy relative to 1974 cars and sulfate emission rate are projected for each scenario. In the text accompanying the graphs is an explanation of the types of systems used. These systems were also shown in Table 1 in Section 2.

4.1 Suspend and Freeze @1.5HC, 15CO Without Catalysts

This scenario assumes sulfates are considered such a serious problem that the industry removes catalysts from all models starting in 1977 as the result of some action taken by the government (e.g. repeal of unleaded fuel regs, ban of catalysts, etc.). Starting in model year 1977 mostly advanced engine mod (EM-2) and some lean burn systems (LB-1) are used to meet 1.5 HC, 15 CO Standards. Since the industry has not been developing systems to meet these standards without catalysts the report team projects that the fuel economy of the 1977 models under this scenario will be about like their 1977 proto-type cars which have sufficiently low feedgas to meet such standard. Average fuel economy is estimated at 1.07 relative to 1974 which is a 7% loss from '75 or a 9% loss from '76. Cost is reduced from the $200-$190 for 1975 1976 catalyst control systems to $140.

Eventually, as lean-burn technology is developed and produced the fuel economy under this scenario rises to1.25, 25% better than '74 models, 11% better than '75 models. System cost is reduced to $50 by the elimination of the EGR, air injection, etc. used on the EM-2 system.

Sulfate emissions under this scenario are a maximum of .025 gpm for the 1975 and 1976 models which use catalysts. 1977 and later models are below .005 gpm even with .03% by weight fuel sulfur. No programs to control fuel sulfur or vehicle emissions are considered under this scenario since sulfate levels are extremely low without such approachs.



SCENARIO 1 - SUSPEND & FREEZE @ 1.5,15, NO CATALYSTS

4.2 Suspend and Freeze at .9 HC, 9 CO

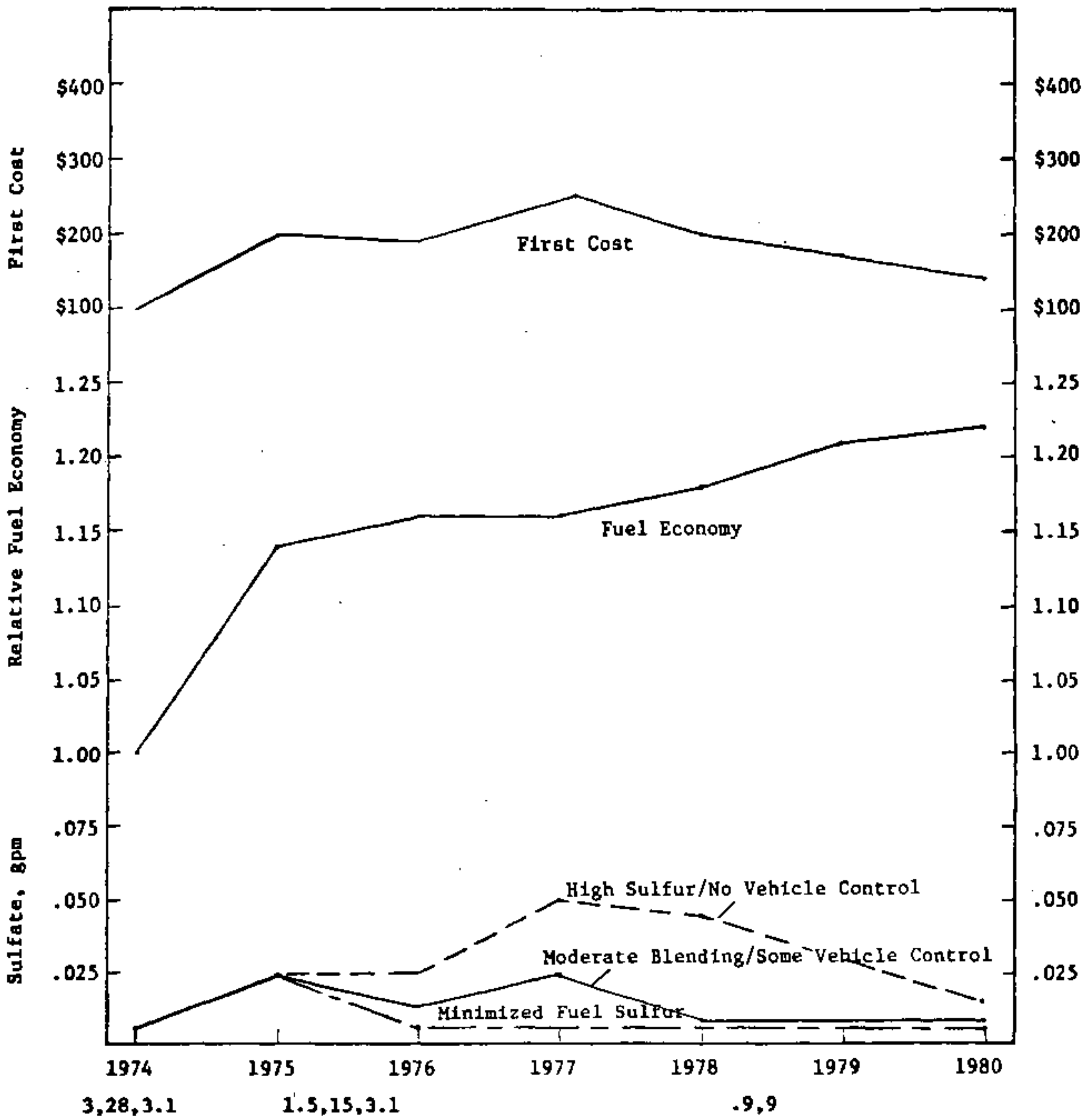
This is a minimum short term fuel economy loss scenario. 1975 California-type emission control systems, oxidation catalysts with air injection (OC-2) are used during the first effective year of the standard. Fuel economy is estimated to be better than the fuel economy of the 1975 California cars, however, due to system improvements (better catalyst technology, etc.) being available by 1977. Relative to 1974 the economy is estimated to be 1.16. System cost is like 1975 California system cost, about $250.

Beyond 1977 system cost continues to drop due to the phase-in of non-catalytic, lean-burn technology and further optimization of the oxidation catalyst sytem. By 1980 it is estimated that half of the market will use LB-2, a lean-burn system with thermal aftertreatment, and half of the market will use OC-1, catalyst, no air pump. The lean-burn cars could reach a relative fuel economy level of 1.25 and the catalyst cars could reach 1.20, the difference due to the use of leaded fuel and higher compression ratio with the lean-burn cars. Cost of the lean burn system is estimated at $90 and cost of OC-1 at $200 for an average cost of $140 in 1980.

Sulfates under this scenario depend heavily on the assumption about regulations on fuel or vehicular sulfate emissions. Under the high sulfur/no control assumption, sulfates are estimated to peak at .05 gpm in 1977. The phase-in of less expensive lean-burn and non-air injection catalyst technology results in a reduction to .013 gpm, by 1980.

With unleaded fuel sulfur levels at half of pool levels and 50% sulfate control from the levels of prototype 1977 cars implemented in 1978, the sulfate level of the '77 models is .025 and the 1980 cars drop to below .01.

A program to minimize fuel sulfur results in a sulfate emission rate below .005 gpm starting with the 1976 models.



SCENARIO 2 - SUSPEND & FREEZE @ .9,9

4.3 Suspend for 1 yr. @ .9 HC, 9 CO, Hold .41 HC, 3.4 CO, 2.0 NO_x for 1978 through 1980

This scenario gives the industry more time to work on the statutory systems before they are forced to certify them in 1978. The 1977 cost and economy levels are the same as for scenario 2, $250 and 1.16 relative economy.

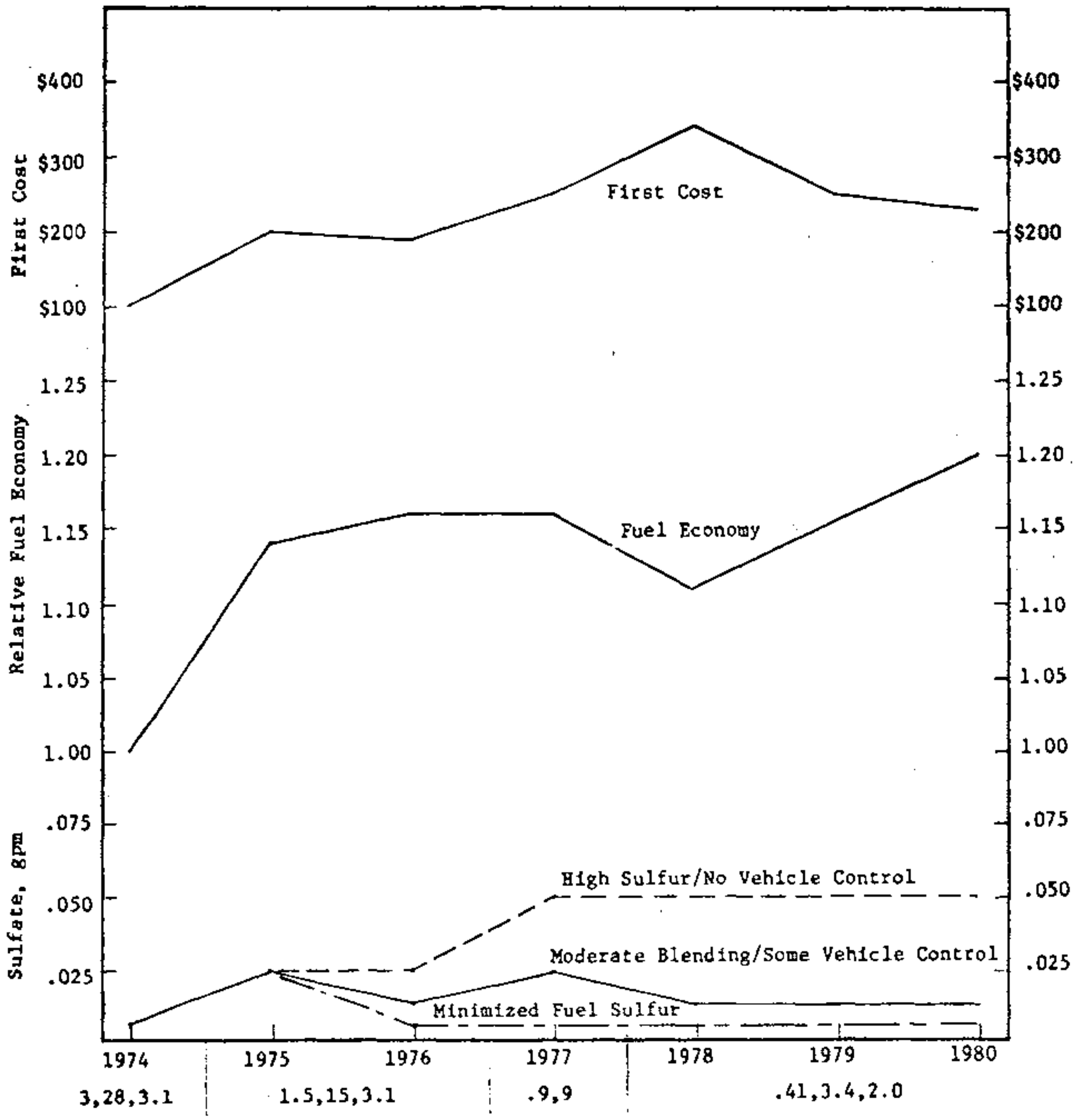
With the implementation of .41 HC, 3.4 CO, 2.0 NO_x in 1978 cost increases to $340 because of the use of start catalyst systems. Fuel economy is estimated to drop by 5% from 197 to 1.10 relative to 1974.

Fuel economy is projected to improve annually thereafter until fully optimized at 1.20 relative to 1974 by 1980. Cost continues to decrease as the industry meres toward less expensive systems like lean-burn with oxidation catalyst and advanced oxidation catalyst systems without start catalysts. By 1980 average system costs are projected to be $230.

Sulfates under this scenario are similar but somewhat higher than with scenario 2 because catalysts are still needed on nearly all models in 1980 to allow optimized fuel economy. With no control over fuel sulfur or vehicles, sulfate emission hit .05 gpm in model year 1977 and stay there.

With 50% control on the vehicle (which may only require reformulation of the catalyst) and unleaded fuel at one half of pool sulfur levels the peak sulfates would be .025 gpm in 1977 dropping to .13 by 1980.

Minimized fuel sulfur reduces sulfate to less than .005 gpm by 1976.



SCENARIO 3 - SUSPEND @ .9,9 FOR 1 YEAR THEN HOLD .41,3.4,2.0

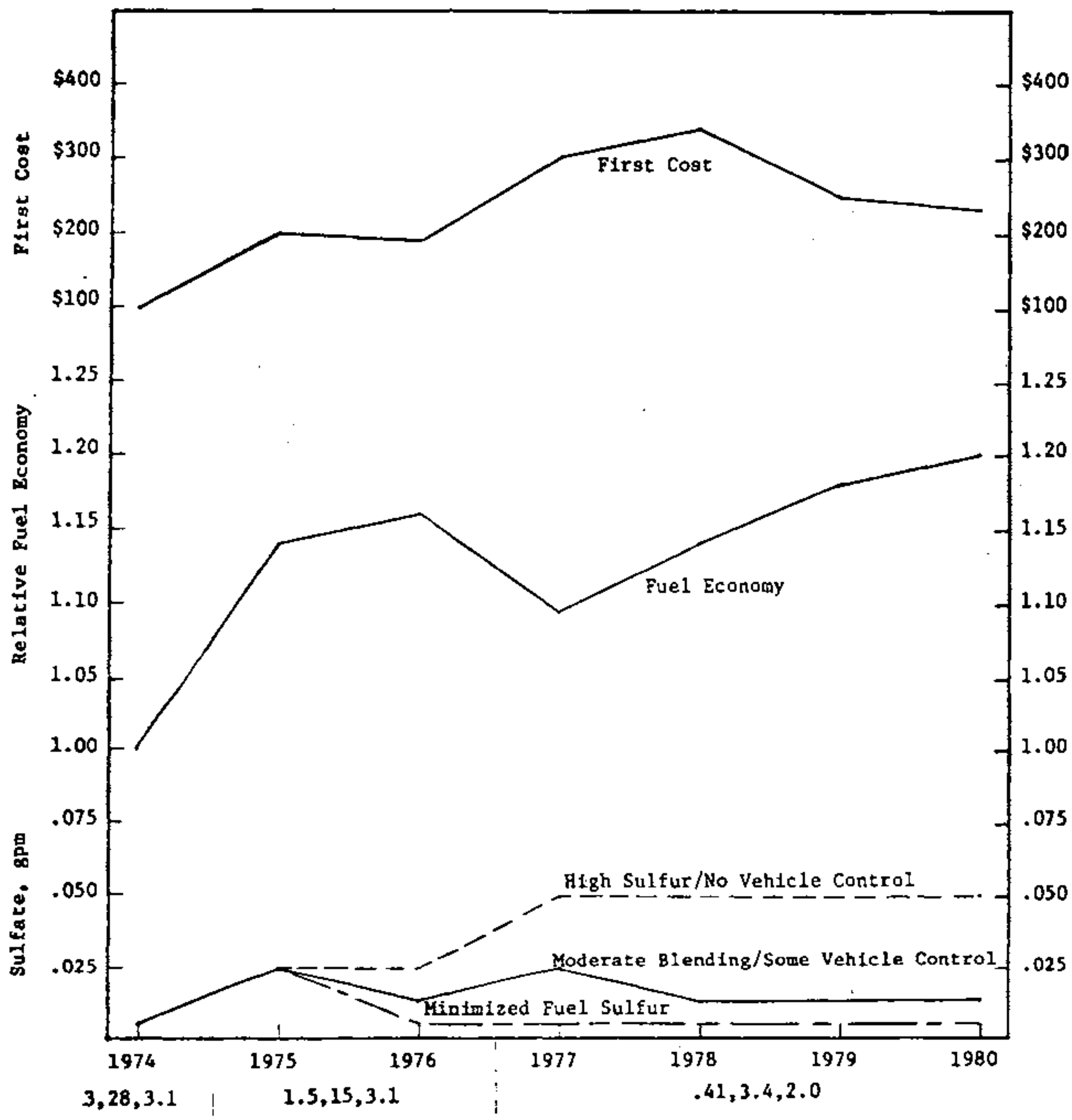
4.4 Denial with 2.0 NO_x Held Through 1980

The technical appendix to the NO_x decision and this years technical appendix indicate that these levels are achievable by 1977. Average first cost of systems to meet this level in 1977 is estimated at $300 increasing to $340 in '78 as efforts are made to maximize fuel economy.

Fuel economy is estimated to dip to 1.09 relative to 1974 cars in model year 1977 but steady improvement to 1.20 in 1980 is projected thereafter.

Cost of the systems used is projected to drop after 1978 and reach the same $230 level by 1980 as occured under scenario 3. A mix of lean-burn systems with oxidation catalysts and advanced oxidation catalyst systems is forseen.

The sulfates under this scenario are identical to scenario 3. Sulfates would rise to .05 gpm in 1977 and stay there if no controls of vehicular emissions or fuel sulfur levels are assumed. With a modest blending and allocation program and 50% control of vehicular emissions a .025 gpm sulfate peak in 1977 drops to .13 by 1980.

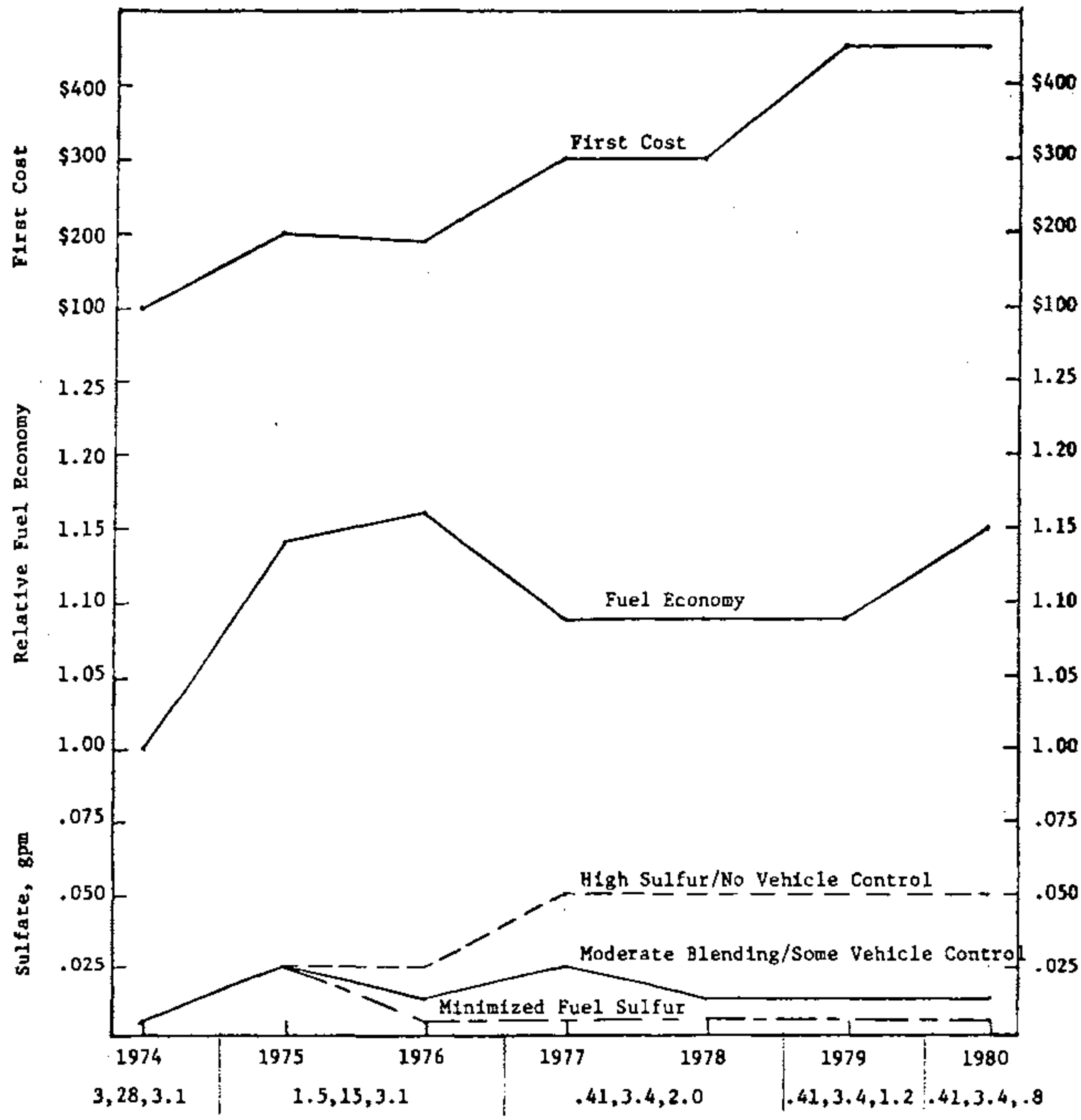


SCENARIO 4- DENIAL WITH 2.0 NOx HELD THROUGH 1980

4.5 Denial With a Push for Low NO_x

The basic assumption behind the development of this scenario was that the maximum NOx control acheivable with the 1975 level of fuel economy would be required. .41 HC, 3.4 CO, 2.0 NOx is required for 1977 and 1978. The cost and fuel penalties for the 1977 model year are identical to those for scenario 4 but no improvement in economy is realized in 1978 because the industry is projected to "carry over" 1977 cars and direct their efforts at developing dual catalyst systems for 1979 rather than concentrating on improving the 1977 system for only one more year of production.

Cost rises to $450 over uncontrolled in 1979 when the dual catalyst system is added and fuel economy drops to 1.09 relative to 1974 as more spark retard is needed to reduce the increase in HC emissions caused by the use of the dual cat system and higher EGR rates. By 1980 fuel economy is projected to be improved to 1.15, about the 1975 model year level. Sulfates under this scenario are identical to scenarios 3 and 4. Preliminary tests, however, indicate a slightly lower sulfate conversion rate for dual catalyst systems. This scenario would look a little better if a non-methane HC standard was assumed as dual catalyst cars have shown a high methane fraction in preliminary tests.



SCENARIO 5 - DENY & PUSH FOR LOW NOx

REFERENCES

1. "Automobile Emission Control-The Technical Status and Outlook as of December 1974," prepared by Emission Control Technology Division, Mobile Source Pollution Control Program, EPA, January 1975.

2. T.C. Austin and K.H. Hellman, "Fuel Economy of the 1975 Models," SAE paper 740970, October, 1974.

3. "Production of Low-Sulfur Gasoline," The M.W. Kellogg Co., EPA Contract 68-02-1308, March 1974.

4. "Production of Low-Sulfur Gasoline in California Refineries," The M.W. Kellogg Co., EPA Contract 68-02-1308.

5. "Potential for Motor Vehicle Fuel Economy Improvement," Report to the Congress by U.S. D.O.T. and U.S. EPA. October, 1974.

6. "Technology Panel Report for Potential for Motor Vehicle Fuel Economy Improvement - Report to the Congress" Draft report by U.S. DOT and U.S. EPA December 1, 1974.

7. Report by the Committee on Motor Vehicle Emissions, National Academy of Sciences, November 1974.

8. R.C. Stempel and S.W. Martens, "Fuel Economy Trends and Catalytic Devices," SAE paper 740594, August 1974.

9. J.J. Gumbleton, R.A. Bolton and H.W. Lang, "Optimizing Engine Parameters with Exhaust Gas Recirculation," SAE paper 740104, February 1974.