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APPENDIXES TO THE REPORT ON MANUFACTURABILITY AND COSTS OF PROPOSED LOW-EMISSION ENGINE SYSTEMS

Prepared by the Panel on
Manufacturability and Producibility

for the

COMMITTEE ON MOTOR VEHICLE EMISSIONS

of the

NATIONAL ACADEMY OF SCIENCES

January 1973

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NOTICE

The Committee on Motor Vehicle Emissions has evaluated the technological feasibility of meeting the light-duty motor vehicle emissions standards as prescribed by the Clean Air Amendments of 1970. This study was performed under the sponsorship of the National Academy of Sciences and with the express approval of the Governing Board of the National Research Council.

The Committee obtained much of its information from eight panels of consultants, each panel dealing with a particular subject area of importance in the Committee deliberations. Panel members were selected by the Committee on the basis of recognized competence in specific areas.

The panel reports are reports of the panels to the Committee. Before publication, each panel report was reviewed by appointed members of the Committee. The views represented by the panels are one of the sources of information provided to the Committee and were used as a partial basis for the Committee judgments.

PREFACE

The appendixes contained herein are appendixes to the report of one of the panels of consultants to the NAS Committee on Motor Vehicle Emissions, i.e., the report entitled "Manufacturability and Costs of Proposed Low-Emission Engine Systems." Some of these appendixes, notably VII through X, were derived from notes taken by the panel members during their visits to some of the companies contacted for information. Except for minor editing, no attempt was made to convert these notes into completely narrated documents. The appendixes are provided as backup documents to the panel report, and the panel members concluded that the notes themselves contain necessary information.

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APPENDIXES

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APPENDIX I

MEETINGS OF PANEL ON MANUFACTURING AND PRODUCIBILITY

Aug. 11, 1971	First meeting of Panel at National Academy of Sciences, Joseph Henry Building, Washington, D.C.
Aug. 16-17	American Motors in Detroit
Aug. 18, 19, 20	Ford Motor Company in Detroit
Aug. 25, 26, 27	Chrysler Corp. in Detroit
Aug. 30, 31; Sept. 1, 2	General Motors in Detroit
Sept. 3	Army Tank Automotive Command in Warren, Mich.
Sept. 13, 14	California Air Resources Board
Sept. 14	Evening meeting with William Lear in Calif.
Sept. 16	American Motors Corp. at Kenosha, Wisc.
Sept. 24	Engelhard in Newark, N.J.
Oct. 4	Return to Chrysler Corp.
Oct. 5	Return to American Motors in Detroit
Oct. 6	Return to General Motors
Oct. 7, 8	Return to Ford
Oct. 14	Panel Meeting at Boston University
Oct. 22, 23	Panel Meeting at National Academy of Sciences in Washington, D.C.
Oct. 25, 26, 27	Attended main committee meeting during which representatives of major automobile manufacturers presented testimony
Nov. 3	Oxy-catalyst, Inc., in Philadelphia
Nov. 4	Mobil Oil, Paulsboro, N.J.
Nov. 5	Matthey-Bishop at West Chester, Pa.
Nov. 16	Corning Glass in Corning, N.Y.
Nov. 17	Houdry at Marcus-Hook, Pa., and Paulsboro, N.J.
Nov. 18	Davidson Division of W. R. Grace, Baltimore, Md.
Nov. 19	Universal Oil Products in Chicago
Nov. 29-30	Attended meeting of main committee to discuss the January report
Jan. 10-11, 1972	Full Panel meeting in La Jolla to develop work plan for 1972 and method of operation

Jan. 25-27	M. Nelles visit Mazda and Mercedes dealerships regarding Diesel and Wankel passenger cars
Feb. 2	Full Panel meeting in Atlanta, Ga.
Feb. 15	M. Nelles and L. Lindgren visit Ford to arrange subsequent Panel visit
Feb. 16	M. Nelles visits Army Automotive Command regarding stratified charge engine
Feb. 17	M. Nelles visits NLPG Association and American Oil
Feb. 24-25	Panel visits Ford in Dearborn regarding "Proco" engine
March 23-24	L. Lindgren with Panel on Alternative Power Sources at Caterpillar Tractor Company, Peoria, Ill. and Cummins Engine, Columbus, Ind.
March 30-31	M. Nelles visits American Petroleum Institute and National Petroleum Refiners Association in Washington, D.C.
Apr. 20	D. Bartlett, G. Clayton, and L. Lindgren visit Detroit Diesel (GM) in Detroit regarding Diesel engine.
Apr. 27	Panel at Wankel Symposium of Society of Manufacturing Engineers at Chicago, Ill.
May 8	M. Nelles and D. Bartlett visit UOP, Des Plaines, Ill., regarding LPG.
May 9	M. Nelles visits Phillips Petroleum, Bartelsville, Okla., regarding LPG
May 17	M. Nelles visits Union Oil of California, Brea, regarding LPG
May 25	Panel at La Jolla to prepare midyear report for CMVE and future plans
June 26	Nelles, Lindgren, and Ebner visit Fiat at Torino, Italy (with J. Nolan--NAS)
June 27	Nelles, Lindgren, and Ebner (with J. Nolan--NAS) visit Volkswagen at Hannover and Wolfsboro, Germany
June 29	Ebner and Lindgren visit Perkins Engine Co., Peterborough, England
June 29	Nelles and Nolan visit Johnson-Matthey, in London, England
June 30	Ebner and Lindgren visit CAV in Sudbury, England
June 30	Nelles and Nolan visit British Leyland in Coventry, England

July 3	Nelles, Ebner, Lindgren, Nolan, and Panel on Alternative Power Sources visit Daimler Benz in Stuttgart, Germany
July 4	Nelles, Ebner, and Lindgren visit Bosch in Stuttgart, Germany
July 5	Nelles, Ebner, and Lindgren visit Citroen and Comotor in Paris, France
July 6	Nelles, Ebner, and Lindgren visit Drs. Opitz and Menges at Aachen University in Aachen, Germany
July 7	Nelles, Ebner, and Lindgren visit Ford Motor Co. England-Ford Diesel Div. in Dagenham, England
July 18	Nelles, Clayton, Ebner, Lindgren, and J. Nolan visit Ford Motor Co. at Detroit
July 19	Nelles, Clayton, Ebner, Lindgren, and Nolan visit General Motors at Warren, Mich. in the morning and Chrysler at Detroit in the afternoon
July 20	Nelles, Clayton, Ebner, Lindgren, and Nolan visit General Motors at Willow Run, Mich.
Aug. 21	Nelles, Ebner, and Lindgren visit General Motors at Warren, Mich.
Aug. 22-23	Nelles, Ebner, Lindgren, and Clayton meet at R&S Lexington, Mass. (J. Nolan--NAS and E. MacDonald) to format report
Aug. 24-25	Nelles, Ebner, and Lindgren edit report and submit draft to J. Nolan and E. MacDonald
Aug. 30-31	Nelles and Lindgren at NAS, Washington, D.C., to present Panel report

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APPENDIX II

EXTRACTS FROM STATUS REPORT

(DECEMBER 15, 1971)

The broad impressions of this series of visits were presented by the Panel Chairman to the Committee on November 29, 1971 (see Appendix I). The purpose of this report is to present the tentative findings of the Panel within its area of specific competence, with the supporting evidence for these findings. These findings follow.

a) That the U.S. automotive companies have greatly expanded their efforts on the design and production of emissions control hardware as a direct result of the requirements of the Clean Air amendments of 1970.

In the visits to the domestic automotive companies, the Panel found a high level of activity on emissions hardware by all producers. Investment by the big four automakers for emissions R and D is estimated to be $181 million for the current year, with GM and Ford at roughly comparable levels of investment. At GM, approximately 1800 people are involved in developing emissions control hardware.* The budget supporting this group is $75 million.

Over the period from 1966 to date and forward to 1975 the Federal and California emission control standards have been made progressively stricter. In response to this tightening legislation, progressively more emissions hardware has been put on American cars.

It is important to note that hardware through model-year 1973 is presently developed, designed, and committed to production. The accumulated cost of this hardware is estimated to be $100 per car (see Section d of this report). As will be noted in Section d, the principal element of cost through 1973 is the air pump. Industry estimates of the accumulated emissions hardware costs through 1973 are as follows: AMC, $90; Chrysler, $128; Ford, $70; and GM $90.** From these data, the expanding efforts by the auto companies in response to legislative initiative can be clearly seen.

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* Report by Mr. F. Bowditch to Committee on Motor Vehicle Emissions, October 25, 1971.

** As reported to the Committee on October 25 through 27, 1971.

b) That the likely configuration of 1975 automotive emission hardware is now apparent. Of the big four auto manufacturers, two are close to the likely configuration at present; two are not.

From the visits made by the Panel and the data supplied by the auto companies and their vendors, configurations of emissions hardware for 1974 and 1975 as presently contemplated by the auto companies were identified. It was necessary to determine one "likely" configuration for purposes of cost estimation and manufacturing capability assessment. Such a likely configuration was prepared and reviewed with the Panel on Emission Control Systems, which concurred with the configuration described herein. The bulk of the equipment will go on in the 1975 model year.

Two domestic auto companies are presently intending to produce this likely configuration: American Motors and General Motors.*

Two domestic auto companies, Chrysler and Ford, are presently planning emissions hardware that differs substantially from the likely configuration. The main differences, which are the same for both companies, are that the Chrysler and Ford systems have a thermal reactor (two for a V-8 engine), and a double-walled exhaust system. They also substitute a monolithic, noble metal catalyst for a pelletized, non-noble metal catalyst. It is the opinion of the Panel that the cost-effectiveness of this additional hardware is so low that it is quite unlikely that it will appear on commercial 1975 Ford and Chrysler vehicles.

c) That all automobile manufacturers have the experience and capability to make the 1975 hardware; but that two manufacturers are substantially ahead of the others in their production planning for the likely configuration.

In the course of the visits to the four major auto companies by the Panel, a considerable amount of data was gathered on the general progress of the various companies on model year 1975 hardware. The general configurations of 1975 systems are quite well defined within

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* Data gathered during Panel visits to companies.

each company even though considerable uncertainty exists as to the performance of those systems. Production schedules and reports of the present status of hardware with the big four is presented in Appendixes III through VI. In the opinion of the Panel, the production of 1975 hardware involves no technology new to the automotive industry, except for their limited experience with solid-state ignition. As the production schedules in the Appendixes show, the date by which the design of 1975 model year hardware must be finalized is March 1972. American Motors and General Motors, because they are "homing in" on the likely configuration, can probably finalize their designs in March 1972. Chrysler and Ford, on the other hand, are not presently homing in on the likely configuration and, therefore, will probably have considerable problems in finalizing their designs in March 1972.

d) That the cost of the likely 1975 configuration is approximately $214 over that of the 1973 configuration.

Before beginning to estimate the increase in the cost to the public of model-year 1975 emissions hardware over that of 1973, it was important to list the assumptions made by the Panel. These assumptions, listed in Figure 9, were acceptable to the Panel and by informal discussions were established to be acceptable to those sister Panels concerned.

The data on the cost of emissions hardware by model year from the big four automotive companies were considered. For 1973, the costs range from $70 to $128. An independent estimate of the sticker price was also made. These costs are for the "likely" configuration. For the 1973 model year, the estimated sticker price is $100 for all emissions hardware. The corresponding estimate for the likely configuration in the 1975 model year is $314, or $214 over that of the 1973 hardware.

Although an estimate of cost has been made, the Panel feels that it has not yet penetrated as far as desirable in costing. The Panel will continue to refine its cost estimates and will begin preliminary

Figure 9--ASSUMPTIONS MADE IN COST ESTIMATES BY PANEL

1. That all vehicles in the certification fleet will perform within the 1975 standard for 50,000 miles, assuming no more than one catalyst change and one tune-up is permitted.
2. That auto manufacturers will substantially increase their in-line testing and quality assurance of major components for both specifications and performance.
3. That based on assumption (2), no additional end-of-the-line rework will be necessary.
4. That end-of-the-line production testing will involve a short probe-type test which will identify the grossly malfunctioning vehicles. The full test (CVS) for emission performance will be done on a statistical sample by engine family.
5. That if customers follow the manufacturer's maintenance instructions, the average of emissions from their vehicles will meet the federal standard.

pricing of alternative automotive power systems.

e) That most major catalyst manufacturers are actively developing and testing new automotive catalysts in their own emissions laboratories and in cooperation with the automotive companies. Special emphasis has been on increasing chemical activity, reducing long-term deterioration, improving tolerance to lead and other poisons, and developing a single catalyst for HC, CO, and NO_x. Within one year after receipt of a firm purchase order, these manufacturers can install sufficient capacity to supply the projected needs of the U.S. automakers, once an acceptable catalyst is developed or identified.

To the date of this report, the Panel has visited eight catalyst manufacturers. The main purpose in these visits was to determine the ability of catalyst manufacturers to produce automotive catalysts with appropriate volume and quality, rather than to study in detail the performance of catalysts.

Most catalyst companies were reluctant to give us specific data on cooperative work with automobile companies because of secrecy agreements. The result is that the automobile companies control the data on test car durability tests. The catalyst companies were all expending substantial resources on the ongoing development of automotive catalysts. Since the sudden collapse of the potential market in California in 1964, the attitude of catalyst manufacturers has been to approach automotive markets with great caution. Experience in automotive catalysts goes back to about 1950. Several companies (Mobil, UOP, Matthey-Bishop) have automotive emissions testing and research laboratories comparable to those of the automobile manufacturers. The main effort is on increasing chemical activity, reducing long-term deterioration, and improving tolerance to lead and other poisons. There is a general assumption that lead levels will not drop below .05 grams per gallon, even if lead-free fuel is specified.

Three companies are working on single catalysts to eliminate HC, CO, and NO_x. This activity is particularly important since, if successful, it would provide a single configuration that might meet the 1975 and 1976 requirements.

While it is not the mission of the Panel to evaluate catalyst durability, the interval between catalyst changes is central to the amount of catalyst material required. Thus the companies were asked a single question on durability, Do you have catalysts which would meet the Federal standards for 1975 after 25,000 miles of operation? Although no specific data were made available to the Panel, there was a general optimism that the 1975 specifications could be met if the catalyst could be changed after 25,000 miles.

f) That the development of a major new automotive subsystem, such as an emissions system that must perform to tight standards, is a new type of problem for American automotive companies. Such a system problem has revealed major organization problems in the industry. Specifically, we see a close correlation between the organization of the companies and their performance to date in developing 1975 emissions hardware.

The necessity of meeting a strict performance specification for automobiles is new to the automotive industry. Their experience has been in producing cars to their own specifications. The necessity of considering an engine system that is essentially chemical rather than mechanical requires a strict systems approach to the development of a 1975 vehicle. Systems management techniques are new to the automobile industry although well tried and accepted by many other industries. To make more rapid progress toward meeting the 1975 values it will be necessary for all companies to manage their motor emission programs in this more effective manner.

In the opinion of the Panel, the General Motors' project-management system is a more effective technique for dealing with emission systems than the traditional line/staff organization used by Ford and Chrysler. This difference is organization is directly related to the relative progress by these companies on developing emissions control hardware.

APPENDIX III

PANEL'S WORK STATEMENT FOR 1972

(JANUARY 11, 1972)

January 11, 1972

TO: CMVE

FROM: Panel #5, Manufacturing and Producibility

RE: Report for CMVE Meeting of January 14, 1972

On January 10 and 11, 1972, a meeting of the Panel was held in La Jolla, California, for the purpose of evaluating past performance, developing a plan of action, and preparing a report to be submitted to CMVE for their January 14 meeting. The report submitted herewith is in three phases: a proposed set of actions by the Panel, if this meets with the Committee's approval; the functions of the Panel, upon specific request by CMVE; and the operational procedures of the Panel.

I. Work Plan for 1972

A. Cost review of each company's 1975 configurations. Define the significant differences among the car manufacturers.

B. Investigate the basic elements for each company's warranty costs. Include a review of actual warranty cost experience in California.

II. Functions of the Panel upon Specific Request by CMVE

A. Respond to specific requests from the CMVE for data related to manufacturing and producibility.

B. Review the manufacturing requirements and costs for alternative power systems as specified by the CMVE.

C. Review the 1976 configurations. Determine the manufacturing plans and the product costs after the Panel on Emission Control Systems specifies the configuration.

D. Review the catalytic manufacturing plans after the Panel on Catalysts determines the product definition and specifications required for 1975 and 1976.

E. Develop the procedures for the Panel's method of operation during 1972.

F. Monitor the most recent status of the manufacturing development and planning for each automobile company for 1975.

G. Investigate the fuel production capabilities after the CMVE specifies the fuel requirements.

III. Operational Procedures of the Panel

A. It shall be a policy of the Panel that all formal and informal or periodic interim status reports to the CMVE will be signed by each Panel member concurring.

B. As a normal practice, the Panel will convene approximately two weeks prior to any meeting of the CMVE at which the Panel will report for the purpose of preparing written documents for submission to, or communication with, the CMVE.

C. A secretary to the Panel will be selected from one of its members.

In summary, the duties of the secretary will include

1. Preparing in draft form any communications with CMVE.

2. Inter- and intra-panel communications, including purposes and scheduling of meetings and trips, as determined in conference with the Chairman.

3. Maintaining a file of all data, information, reports, and support documentation of the Panel.

D. Notification of planned meetings and field visits will be transmitted to each Panel member sufficiently in advance to allow for review of the purpose, scope, and methods to be employed.

E. For purposes of official Panel meetings, a quorum for conducting business will be three Panel members.

F. Trip reports will be prepared by a designated member and submitted to the Secretary as soon as practicable after such trips, in conformance with CMVE requirements.

Signed by:	Donald A. Bartlett	LeRoy Lindgren
	Geo. D. Clayton	Merrill L. Ebner

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APPENDIX IV

INTERIM STATUS REPORT

(MAY 26, 1972)

National Research Council

Committee on Motor Vehicle Emissions

PANEL NO. 5

Interim Status Report

to

Committee on Motor Vehicle Emissions

May 26, 1972

by: (signed)
Donald Bartlett

(signed)
George Clayton

(signed)
Merrill Ebner

(signed)
LeRoy Lindgren

(signed)
Maurice Nelles, Chairman

May 26, 1972

To: Committee on Motor Vehicle Emissions (CMVE)
From: Panel #5--Manufacturing and Producibility

This interim status report to the Committee is divided into three sections, as follows:

1. Charges to Panel #5
2. Actions taken in 1972
3. Planned future activities through September 1, 1972

1. Charges to Panel #5

A. Review catalyst manufacturers' response to CMVE report concerning high-volume production lead times and prepare written reply.

B. Explore LPG feasibility as volume fuel supply.

C. Review manufacturers' status and plans for the following:

Stratified Charge Engine
Diesel Engine
Wankel (rotary) Engine
Ford Fast-Burn Engine

2. Actions Taken

The actions taken by the Panel in response to these charges are summarized in terms of visitations and meetings in Appendix I.

Reasonable progress has been made in responding to CMVE charges with exception of those relating to the Wankel or rotary engine. Three meetings scheduled at GM to review the status of the Wankel have been postponed by GM, and no information or data in this connection has been made available to the Panel as of this date.

3. Future Plans

The Panel intends to culminate activities in response to present charges by submitting a draft report to CMVE by August 31, 1972.

Three major activities are planned as follows:

1. A computer simulation that will show the impact of alternative configurations on production resources.

2. Visits to manufacturers in Japan and Europe to gather first-hand and production information regarding the Wankel and Diesel engines and catalysts.

3. An intensive series of visits to the major domestic automotive producers to update information on the implementation of 1975-model production plans and to determine status of production plans for the 1976 models.

APPENDIX V

ESTIMATE OF LEAD TIME FOR CATALYST MANUFACTURE

(May 1972)

To: Professor James John, National Academy of Sciences
From: Maurice Nelles
Subject: Lead Time to Manufacture Catalysts

This is a rough draft of a suggested letter from Panel 5. I am sending it to LeRoy Lindgren who will check and possibly modify it and then will arrange for approval or modification with other panel members before sending it to you as a communication from the panel.

The letter follows:

To: Professor James John
From: Panel 5
Subject: Comments on letters from Universal Oil Products, Monsanto Company, and W. R. Grace & Co.

This letter is composed of two parts. One is concerned with the three letters from those who have declared they need approximately two years lead time and the other part is concerned with some who have not written and who have greater capability or present capacity.

W. R. Grace & Co.

They indicated they are the largest catalyst manufacturers in the world. They have four plants that manufacture catalysts; one plant is in the design phase and will use completely computer controlled processing. They have a large engineering group in New York that designs plants.

They indicated they would make their own catalyst support materials whether monolithic or pellets. However, they would buy their materials.

They indicated clearly in our visit with them that they needed two years lead time and I noted that at the time of our visit. Their letter was no surprise to us.

Their statement that "while someone may question our lead time versus other manufacturers, no one can change the time requirement for <u>monolithic</u> support facilities" does not match plans of, for instance, Corning, who are prepared to "start building the final plant in the first quarter of 1973 and be producing at the rate of 7 million units per year in the first quarter of 1974."

When one considers the capability and adaptability of W. R. Grace & Co., it must be remembered they had losses when California did not proceed with catalysts in 1965. W. R. Grace & Co. was very emphatic that their policy was to not commit large sums again and that if a one-year extension was granted, they would minimize activities related to catalysts for autos.

Universal Oil Products Co.

Essentially their position paper says they need two years lead time. Although they do not say specifically they need this lead time, it is presumed they include themselves in the term "manufacturers."

As of November 19, 1971, they had an 80-million-lb per year capacity and 2-million-lb excess capacity. They have catalyst plants in Illinois, Louisiana, Japan, and Europe and have their own designers and process engineers. They specifically said they needed two years lead time. Having built several plants and having plans available, it may be that they are thinking of a new catalyst made by a new process on new type equipment. They told us of an oxidation-reduction catalyst now under development.

Monsanto Company

Their GANTT Chart was noted, and this indicates they require 24 months. It is interesting to note from this chart that only 11 months are required to purchase equipment, construct the plant, and start the plant.

Monsanto has a subsidiary that has a turnkey capability for building catalyst plants.

Monsanto was undergoing a substantial management reorganization at the time of our conference.

They indicated preliminary plant designs were in existence and budgets made. They were explicit that they needed 20 to 24 months lead time.

Lead Times for Some Other Companies

Mobil Oil has a production capacity of 180 million lb per year in the U.S.A. The auto market might be 60 million lb per year for all cars. Although this would be a significant increase, especially with the follow-on market, they seemed reluctant to be enthusiastic. It should be noted Mobil has been the IIEC instrument for much of the research and they know the problems. They were conducting experiments on the making of catalysts in their well-equipped laboratory.

We left with the feeling that if they received an order for catalysts for half the cars, e.g., 30 million lb per year, they could schedule it in their present plant operations.

Houdry Division, Air Products and Chemical Corporation

They had capacity for providing catalysts for 1 million 1974 cars (1973 delivery). The schedule they would like is 20 months, which includes 5 months for engineering design and the preparation of contracts and orders.

We visited one of their catalyst manufacturing plants. The production equipment and processes were conventional chemical processing equipment for making pellets. Under normal circumstances this equipment can be obtained rapidly compared with the time needed to acquire special machines for the auto industry.

American Lava

They reported that for 8 million units per year, they have adequate paper facilities and adequate production space but will need more modular units, which will require 8 to 12 months, and a new warehouse, which will require 8 to 12 months. This schedule assumes the completion of work under way when we visited them last year. This was the building of certain modular units for 1 million units per year. Our notes indicate they really would like more time and costs would be lower if there were more time.

We did not contact alumina manufacturers. Possibly we should.

Matthey-Bishop pointed out that if all catalytic converters were to be platinum, there may have to be a mine opened and this takes time.

It is clear to the Panel that by utilizing present capacity and expanding present capacity the catalyst can be available for 1975 cars. The time required varies from company to company. It has been over three months since our contacts. Some companies, such as Corning, that had an all-out effort must be in a better position now to firm-up lead times.

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APPENDIX VI

STATUS OF LIQUEFIED GAS SUBSTITUTES FOR GASOLINE

(August 18, 1972)

This investigation is being made to provide substantiated data concerning the availability and cost of liquefied gas when produced in large enough quantities to be used in passenger motor vehicles. There are indications that the substitution of liquefied gas such as propanes and butanes for gasoline will reduce undesired emissions from motor vehicles. Liquefied gases for motor fuel on a limited basis have been used for many years with excellent performance. They have even been found to be suitable for vehicles used inside factories where exhaust composition is critical. In recent months there has been much publicity about the use of liquefied gases in increasing numbers of vehicles. Some reasons given for its use include decreased pollution from exhaust gases.

To prepare a plan of action to obtain the data required for this report, conferences were held with selected personnel at the headquarters of the National Liquid Petroleum Gas Association, the National Petroleum Refiners Association, and the American Petroleum Institute. Conferences were held with Phillips Petroleum in Bartlesville, Oklahoma, Universal Oil Products in Des Plaines, Illinois, American Oil Company in Chicago, and other major oil companies. Telephone contacts with others have also been helpful. Liquefied gases used for motor fuel are usually referred to as one of the following:

LPG--Liquid petroleum gas. This is composed mostly of propane and butane with some ethane.

LNG--Liquid natural gas. This is usually mostly methane, carbon monoxide, and hydrogren.

SNG--Synthetic natural gas. Essentially the same as LNG.

LIQUEFIED NATURAL GAS (LNG)

New gas fields have been brought into production in a wide variety of locations around the world. An example is in Brunei, Indonesia, near Lumut. To make this fuel available to areas of more concentrated populations and industry, the largest LNG plant is being built by a consortium between Shell, Netsubishi, and the Brunei government. The plant will liquefy 5 million metric tons of natural gas per year. This is primarily a cryogenic process. The facilities are expensive and special ships are required to transport the liquefied gases. At the present time these liquefied gases must be unloaded in the liquid state and changed to the gaseous state for use as a domestic or industrial fuel.

SYNTHETIC NATURAL GAS (SNG)

At the present time the need for additional gaseous fuel for household use is urgent. Some cities will no longer extend service to new homes or industries. An attractive source of additional gas is to produce it from crude oil. Table VI-1 is a summary of announced SNG Plants. Estimates of the cost of gas from these plants will be about \$1.25 ± 0.25 per 1000 ft^3 or 10^6 BTU. Roughly, in terms of gasoline this would be equivalent to \$0.125 ± 0.025 per gallon at the refinery. This is in the present range of gasoline selling process at the refinery.

It will be noted that at this time most new plants will use naphtha or liquid fractions as feed stock. These costs could change much if the mix from crude is changed including making smaller proportions of gasoline. These changed costs will be discussed later. For motor fuel uses it may be more advantageous to process crude to LPG rather than to LNG.

LIQUID PETROLEUM GAS (LPG)

LPG is composed of the compounds in crude oil that are normally gaseous at room temperature but liquid under moderate pressures. Their unintentional inclusion in gasoline causes carburetion problems. On the other hand, if they are specifically used for motor fuel there are excellent carburetor devices available that make its use simple, except for the pressure tanks required to store the fuel.

Historically, LPG has been a by-product of gasoline production. Over 50 years ago it was sold in tanks for use as gaseous fuel in remote locations. As a motor fuel it has favorable results such as low maintenance costs and less noxious exhaust emissions. The octane ratings are adequate for motor vehicles. Better cold-start characteristics have made favorable considerations for meeting the 1976 emission standards.

LPG sales in the United States have been increasing through the years. In 1971, LPG sales were 19.3 billion gallons for all purposes. This can be divided into engine fuel, 1.5 billion gallons; residential and commercial, 7.8 billion gallons; chemical, 7.7 billion gallons; industrial, 1 billion gallons. This is shown in greater detail in Table VI-2. It will be noted the difference of 4.3 billion gallons between production and sales probably disappeared in refinery operations including heating for processing.

The cost of LPG at the refinery now is about 5.5¢ to 7¢ per gallon, whereas gasoline is 10¢-13¢ per gallon. A gallon of LPG has about 90,000 BTU and a gallon of gasoline has 110,000 BTU. Both are taxed federally and by many states for vehicle use. Even at these prices there has not been much desire to convert vehicles to operate on LPG.

It is becoming increasingly evident that if LPG is going to be used for motor fuel on a broad basis, it will be necessary to obtain it through skillful processing of crude oil. Products such as gasoline may not have a market if LPG is used in all vehicles. Fortunately enough data and know-how are available within the petroleum industry to create mathematical models of what might constitute a refining process with associated equipment for LPG. These models can then be used to obtain optimized data including investment cost, product cost, yields, etc. Computers are very helpful in making these computations. One blocked model is shown in Figure VI-1. A model for obtaining the maximum amount of LPG has been used to obtain yield and cost data that is included in this report.

Table VI-3 shows the cost of various percentages of gas from crude. This was prepared by Universal Oil Products for a 100,000 bbl/day refinery using Arabian crude. Note that this is for SNG and LPG. Calculations for the latter have been made by others. However, it can be expected that as the ratio of weight of LPG to crude in-

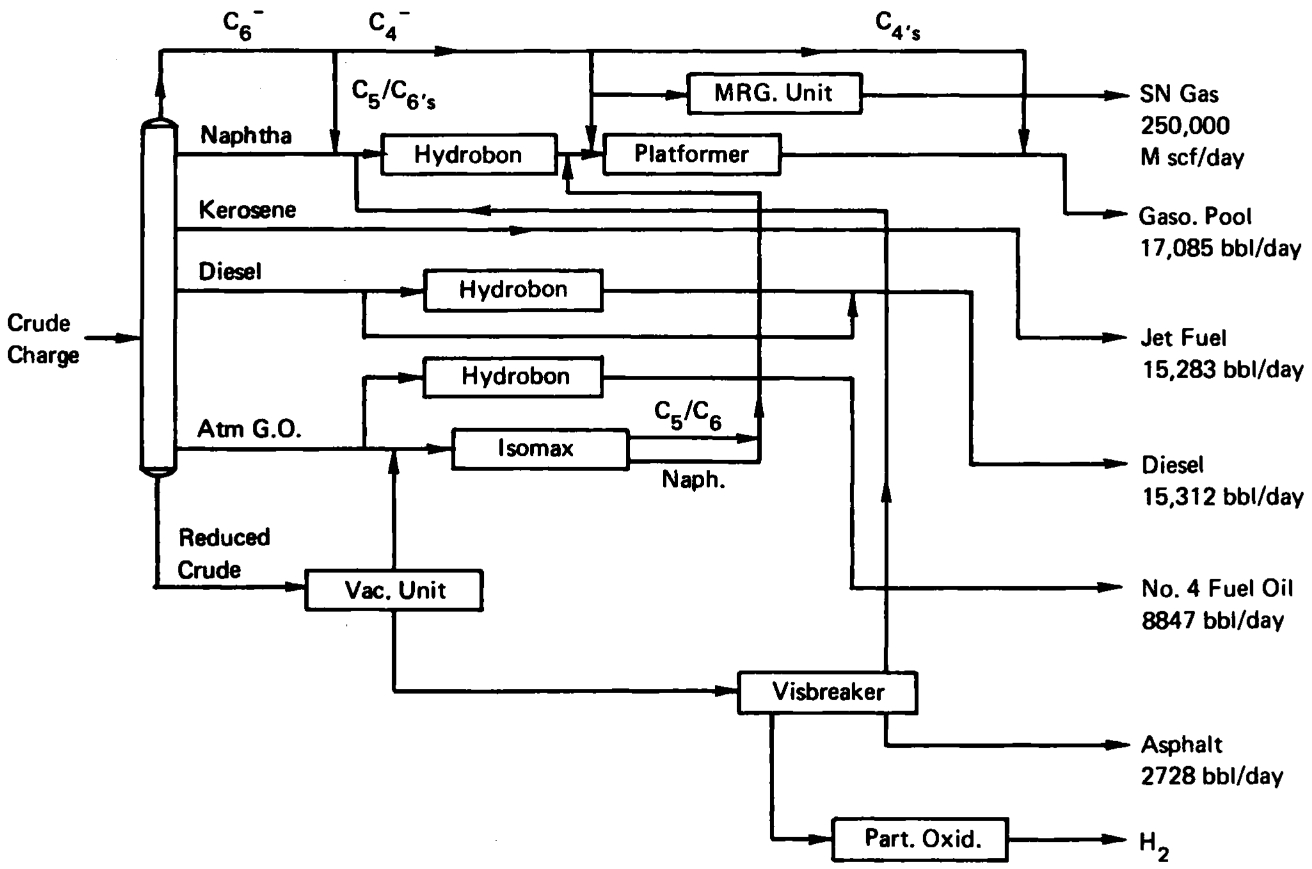


FIGURE VI-1 250,000 M scf/day energy.

creases it will be in a linear manner, and some extrapolation can be made. This is shown in Figures VI-2 and VI-3.

The prices of SNG are closely related to the price of crude and the price obtainable for other products resulting from the process. In some instances lower-priced crude not desired for gasoline production may be very much desired for LNG and LPG production.

The cost of refineries for obtaining large percentages of gas from crude increases in a linear manner. Figure VI-4 shows the degree of linearity.

Increasing the price of LPG will take more from industrial uses, and refineries may not use LPG in their processes.

The Stanford Research Institute, in cooperation with many petroleum companies has issued a report entitled "Oil Gasification of Methane, Hydrogen and other Fuel Gases; An Engineering and Economic Analysis," vols. 1 and 2. (SRI/Project ECC 1203); B. Louki and S. Field were among the authors. It is a proprietary report. An exhaustive study of the subject should include consideration of this report.

Tables VI-4-16 show detail on different crudes. It is especially interesting to note from Table VI-4 that as the SNG is maximized the internal fuel consumption increases much more; for Tia Juana crude 14.67% of the crude is required for the processing. This would be a serious drain on oil reserves.

Two major oil companies have made calculations using their models to obtain

1. Cost per gallon LPG for each year including capital costs per year for a 10-year period. This also includes calculations of cost of distribution in one of the calculations.
2. Costs as if a new grade of gasoline is to be made and introduced including service station costs.
3. Costs if naphtha and/or gas oil were used as fuel stocks to obtain LPG.

Figures VI-5 and VI-6 were prepared from data obtained especially for this report by a major oil company using their computer

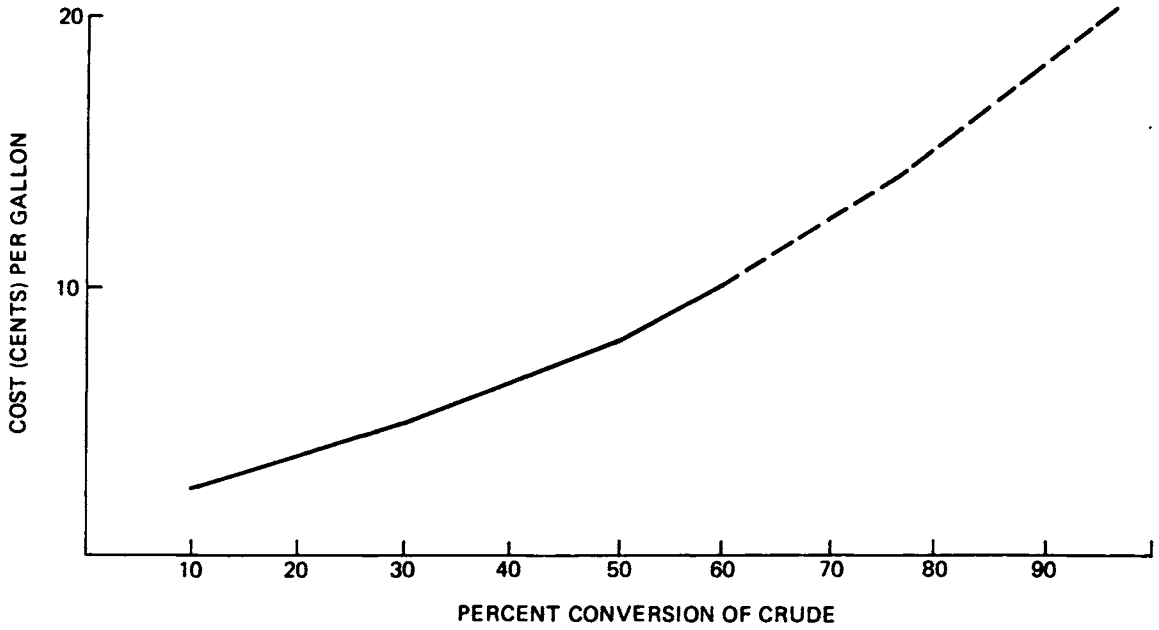


FIGURE VI-2 Cost of LPG from Arabian crude, 100,000-bbl refinery, using various percent conversions.

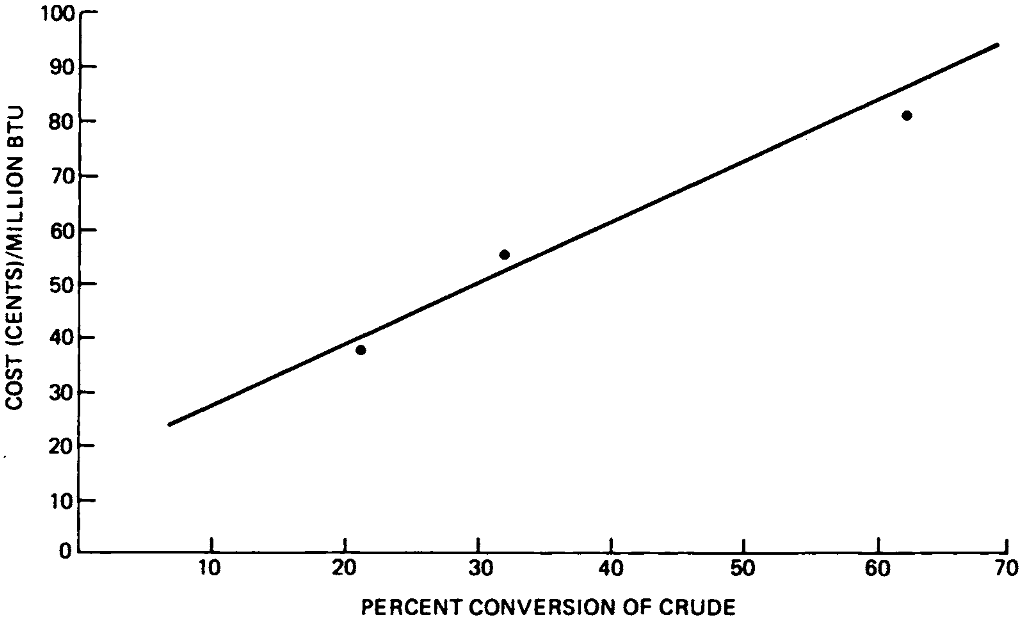


FIGURE VI-3 Cost of LPG from Arabian crude, 100,000-bbl refinery, using various percent conversions.

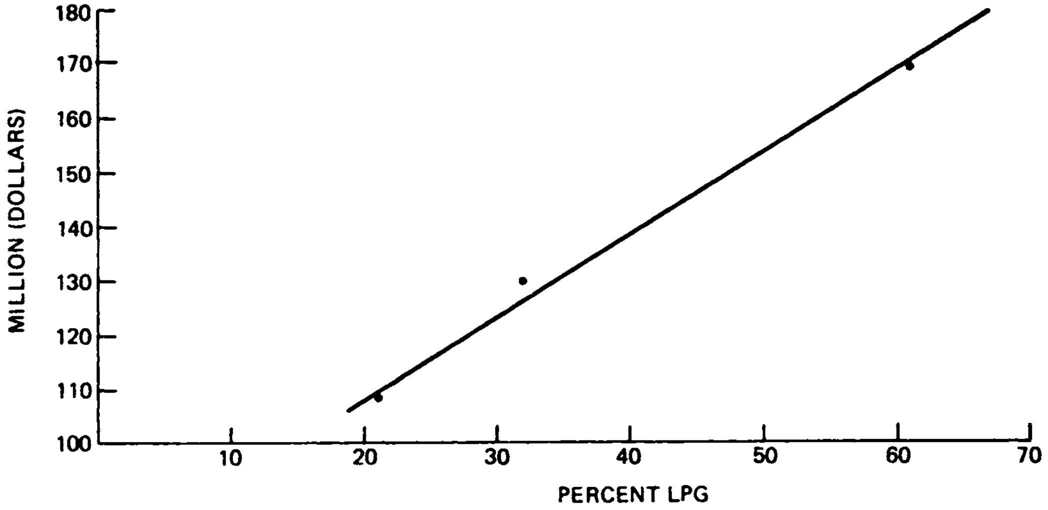
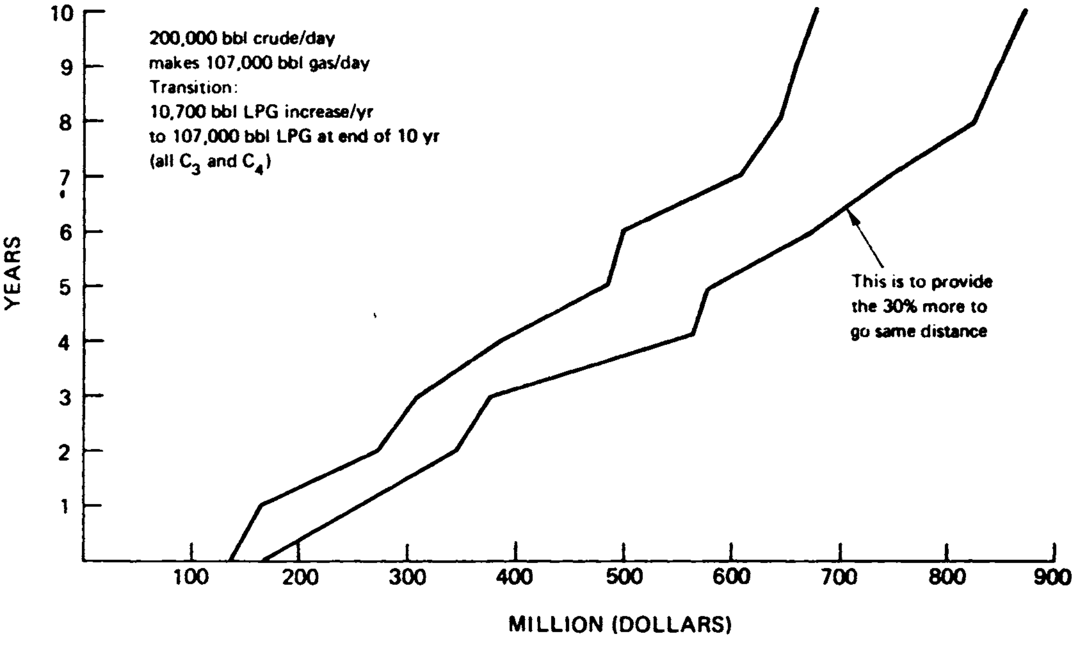


FIGURE VI-4 Capital investment for 100,000 bbl/day refinery to obtain various percentages of LPG from Arabian crude.



200,000 bbl crude/day
makes 107,000 bbl gas/day
Transition:
10,700 bbl LPG increase/yr
to 107,000 bbl LPG at end of 10 yr
(all C_3 and C_4)

This is to provide
the 30% more to
go same distance

FIGURE VI-5 Capital costs to convert refineries to LPG.

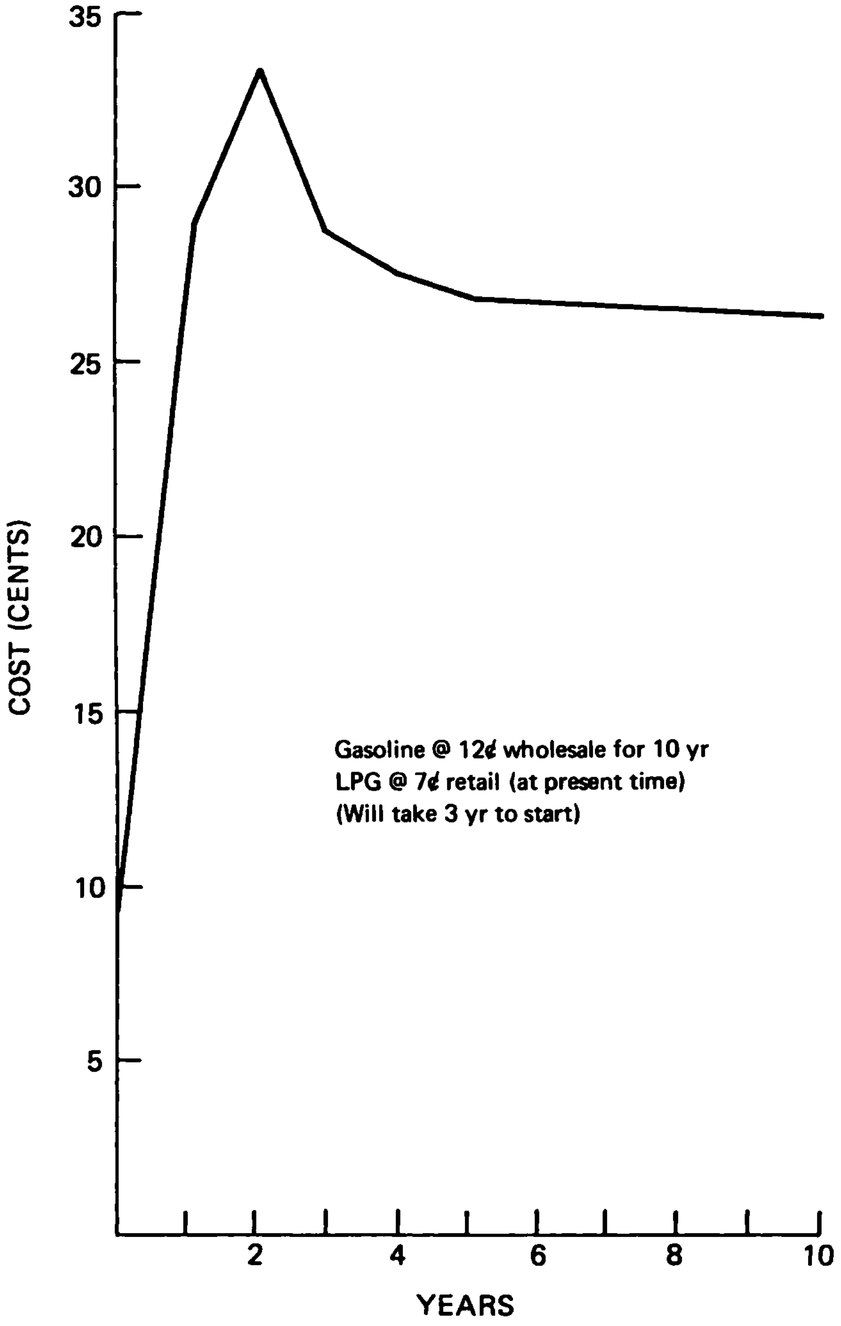


FIGURE VI-6 Cost to customer for equivalent energy LPG (without tax; no inflation).

model and data bases. It was agreed their identity would be withheld because of the time required to obtain executive release of the data. The data are consistent with data obtained from other sources.

Figure VI-5 anticipates an orderly conversion from gasoline to LPG over a 10-year period. The cost of a 200,000 bbl/day refinery that would provide LPG to go the same distance as gasoline from the same refinery is about $900 million. The crude refined at the present time is about 11,200 million bbl per year so the capital expenditures would be about $50 billion. This is only to modify refineries.

Another major oil company made computer runs on the production of LPG from either naphtha or gas oil.

LPG MANUFACTURE BY HYDROCRACKING

Representative yields and costs are compared for making LPG from either 30,000 bbl/d gas oil or 30,000 bbl/d naphtha. The information is presented in Tables VI-17-20.

Table VI-22 shows the feedstock properties used in the estimates. These properties are typical of Mid-Continent feedstocks.

Table VI-18 gives estimated yields and hydrogen consumption. The case with gas oil as feed requires about one-third more hydrogen than when naphtha is used as feed, namely 2590 scf/bbl standard cubic feet per barrel against 1958 scf/bbl. Because C_5's and C_6's are less desirable feeds for making LPG, a C_5/C_6 fraction is produced as by-product and used, along with dry gas, as plant fuel and hydrogen plant feed. Not all of the C_5/C_6 fraction are nearly equal for the two cases, 116.0 vs. 115.9 for naphtha and gas oil feed, respectively, although the LPG yield from gas oil is only 91.7 volume percent of feed against 102.8 percent from naphtha feed.

Table VI-19 compares estimated capital investments for the two cases. The battery limits investments, including hydrogen plant, are $26 million for the naphtha feed case and $38 million for the gas oil feed case. The total capital required is estimated at about $43 and $61 million, respectively. Table VI-19 shows that the utility requirements are considerably less for the naphtha feed case.

Table VI-20 presents the LPG cost estimates for the two cases. As a basis it is assumed that fuel is valued at 75¢/MM BTU and that the feedstocks and the by-product C_5/C_6 fraction are also valued as fuel. On this basis, after allowing for a 10 percent return on investment (ROI), the LPG cost is estimated to be 11.5 and 14.4¢/gal, respectively, when using naphtha or gas oil as feed. Table VI-20 also shows how the LPG cost will change as feed or C_5/C_6 by-product values change, or as the capital requirement or the ROI change.

The two costs per gallon at the refinery have been shown on Figure VI-2 to indicate correlation with Universal Oil Products data. These two sets of data on extrapolation and inclusion of providing dispensing equipment are compatible with costs shown in Figure VI-6.

In summary:

1. It is possible to modify the petroleum refinery process so that LPG can be substituted for gasoline for motor vehicles.
2. The capital costs will be in the $50 billion range.
3. The fuel costs to the customer over present gasoline costs will be about twice as much as gasoline costs.
4. There is a serious loss of energy in changing from gasoline to LPG. The percentage of crude used in the processing operations will increase from about 4% to about 14%. This is an unrecoverable waste of natural resources.
5. There is not enough LPG, LNG, or SNG currently available to be significant if conversion to LPG were desired now.
6. Although models are easy to use and the theory of high conversion percentages to LPG is well understood, there are many practical innovations that must be developed to reach the theoretical indications.
7. A three-year lead time for making changes for supplying alternative fuels is minimum.

Table VI-1 Summary of Announced SNG Plants

Company	Location	Capacity 10^6 cu ft/D	Feed
Algonquin SNG	Freetown, Mass.	120	Naphtha (U.S.)
Brooklyn Union Gas	Brooklyn, N.Y.	50	Naphtha (U.S.)
Columbia Gas Systems	Green Springs, O.	250	Naphtha (Canada)
Northern Illinois Gas	Northern Illinois	150	Naphtha
Public Service Elec. & Gas	Northern New Jersey	125	Naphtha (Foreign)
Texas Eastern/ Consolidated	So. Plainfield, N.J.	500	Naphtha (U.S. & Foreign)
Transco	East Coast	125	Naphtha (U.S.)
Trunkline Gas	Midwest	300	Naphtha (Foreign)
Zapata Norness	Unspecified	800	Naphtha (Foreign)
Boston Gas	Boston, Mass.	40	LPG (U.S.)
Consumers Power	Marysville, Mich.	100	LPG (Canada)
Continental Oil	East Coast	125	LPG

Table VI-2 LP-Gas Statistics and Estimates
(billion gallons)

Official 1970 data[a]		Estimate for 1971	% change 1970-1971
22.075	U.S. production	23.150	4.9
18.789	LP-gas sales[b]	19.340	2.9
	By end use:		
7.569	Residential and commercial	7.760	2.5
7.730	Chemical	7.660	- .9
1.336	Engine fuel	1.480	10.8
.897	Industrial and refinery fuel	1.040	15.9
.791	Synthetic rubber	.825	4.3
.212	Utility gas	.280	32.1
.255	All other uses	.295	15.7
	Product use:		
11.854	Propane	12.300	3.8
2.208	Butane	2.100	- 4.9
1.209	Butane-propane mixes	1.140	- 5.7
3.518	Ethane	3.800	8.00

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[a] Bureau of Mines data. All other figures are NLPGA estimates based on NLPGA TIMES surveys.

[b] Difference between production and sales accounted for by gasoline use, exports, and additions to inventory.

Table VI-3 Environmental Fuels Processing Facility

100,000 bbl/day Lt. Arabian Crude Capacity

Economic Summary

	Case 1 150 MM scf/day	Case 2 250 MM scf/day	Case 3 250 MM scf/day No Gasoline or Distillate Fuels	Case 4 500 MM scf/day
Plant investment[a] (assumed all debt)	$108,400,000	$129,700,000	$109,500,000	$163,600,000
Estimated payout time	3.5 years	3.59 years	4.30 years	4.70 years
Gas co. rate of return[b]	26.3%	25.6%	20.58%	18.72%
Price of gas @ 12% return[c]	37.7¢/MM BTU	55.5¢/MM BTU	73.3¢/MM BTU	82.0¢/MM BTU
Products				
Gas wt.% on crude	21.09	32.59	35.26	62.09
Butanes			1,936	
Gasolines bbl/day (lead-free)	17,085	17,085		
Jet fuel bbl/day	15,283	15,283		13,978
Diesel bbl/day	16,987	15,312		
No. 4 fuel oil bbl/day (0.25%S)		8,847	44,651	
No. 6 fuel oil (0.5%S) bbl/day	20,961			
Asphalt bbl/day	2,350	2,728	6,710	
Sulfur S ton/day	133	130	136	140

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[a] This plant investment includes process units and offsites and does not include land, catalyst, crude inventory, or working capital.

[b] $\frac{\text{Profit after taxes and interest}}{\text{Total investment}}$ x 100, using gas price of 95¢ per million BTU.

[c] Rate of return fixed at 12%, and gas price calculated. Other product prices same as in Rate of Return calculation.

Table VI-4 ENVIRONMENTAL FUELS CAPABILITY STUDY
ECONOMIC SUMMARY

	Case 1 Tia Juana Max Fuel Oil	Case 2 Tia Juana 500 MM + Fuel Oil	Case 3 Tia Juana Max SNG	Case 4 Kuwait Max Fuel Oil	Case 5 Kuwait 500 MM + Fuel Oil	Case 6 Kuwait Max SNG
Investment Summary						
Plant investment	$156,376,000	$218,017,000	$295,720,000	$161,690,000	$231,616,000	$280,852,000
Interest during construction	6,255,000	8,721,000	11,829,000	6,468,000	9,265,000	11,234,000
Subtotal	$162,631,000	$226,738,000	$307,549,000	$168,158,000	$240,881,000	$292,086,000
Working capital						
30 days crude inventory	$ 14,640,000	$ 14,640,000	$ 14,640,000	$ 16,800,000	$ 16,800,000	$ 16,800,000
30 days catalyst and chemicals	233,000	261,000	479,000	219,000	299,000	461,000
Accounts receivable, 11% of total operating cost	21,223,000	22,831,000	25,473,000	24,179,000	25,964,000	27,637,000
Total working capital	$ 36,096,000	$ 37,732,000	$ 40,592,000	$ 41,198,000	$ 43,063,000	$ 46,898,000
Total capital investment	$198,727,000	$264,470,000	$348,141,000	$209,356,000	$283,944,000	$336,984,000
Average price of gas[a]	0.0	44.9¢	69.74¢	6.79¢	55.89¢	76.80¢
Estimated cash flow payback, years	3.68	4.43	5.33	5.31	5.52	6.53
Products						
SNG wt.% of crude	9.97	33.28	66.66	12.86	34.71	68.29
No. 4 fuel oil 0.15%S B/SD	1,876			947	776	
No. 4 fuel oil 0.3%S B/SD	135,285	88,965		141,941	94,080	
No. 6 fuel oil 0.3%S B/SD	13,380					
Sulfur S tons/day	347	405	492	560	601	554
Internal fuel consumption, wt.% of crude	4.32	8.56	14.67	4.44	9.33	13.76
Off spec. unblended material zero value	11,153	12,547	7,017	8,516	1,524	7,146
" " " " (wt.% crude)	(7.07)	(7.46)	(4.17)	(5.65)	(1.01)	(4.43)

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[a] Using Dept. of Interior, Office of Coal Research Procedure, June 4, 1965.

Table VI-5 Environmental Fuels Capability Study
Plant Investment Summary (M$)

	Case 1 Tia Juana Max Fuel Oil	Case 2 Tia Juana 500 MM + Fuel Oil	Case 3 Tia Juana Max SNG	Case 4 Kuwait Max Fuel Oil	Case 5 Kuwait 500 MM + Fuel Oil	Case 6 Kuwait Max SNG
Process Units						
Crude distillation	$ 13,919	$ 13,918	$ 13,919	$ 14,389	$ 14,389	$ 14,389
Vacuum distillation	7,560	7,560	7,560	7,737	7,737	7,737
Visbreaker		8,280	8,280		2,425	7,382
Naphtha + LSR hydrobon	3,219	3,751	3,751	4,093	4,167	4,492
Distillate hydrobon	7,589	9,290	3,146	10,737	7,728	3,376
MRG unit	18,237	39,027	68,081	24,527	39,603	67,344
Cracking isomax		25,841	57,652		23,665	51,662
Partial oxidation		32,748	55,730		31,012	46,612
RCD isomax	19,506	----		12,000	10,452	
Steam reformer H_2 plant	6,652			7,640		
Deasphalt unit	7,056			6,803	6,038	
Total processing unit investment	$ 83,738	$140,416	$218,119	$ 87,926	$147,216	$202,995
Offsites						
Steam plant	$ 4,426	$ 7,617	$ 10,991	$ 5,481	$ 8,102	$ 10,881
SO_2 removal plant (Shell Flue Gas Rec.)	2,360	4,674	2,931		8,804	3,892
Sulpel	1,140	200	1,320	1,350	1,400	1,350
H_2S removal plant (sulfox)	4,505	4,877	5,662	6,254	6,137	6,076
Crude storage & intermediate tankage @ $3/bbl	22,890	24,908	26,881	23,868	24,796	26,523
Fixed offsites	20,000	20,000	20,000	20,000	20,000	20,000
Product tankage 30 days @ $3/bbl	13,549	8,007	----	12,860	8,537	----
Total offsites	68,870	71,283	67,785	69,813	77,776	68,722
Total processing unit and offsites investment	$152,608	$211,699	$285,904	$157,739	$224,992	$271,717
Startup expenses x 1.5% process unit	1,256	2,106	3,272	1,319	2,208	3,045
Spare parts x 3.0% process unit	2,512	4,212	6,544	2,638	4,416	6,090
Total investment less catalyst	$156,376	$218,017	$295,720	$161,696	$231,616	$280,852
Initial catalyst loading	4,194	8,179	15,535	5,289	8,466	16,060
Total investment cost	$160,570	$226,196	$311,255	$166,985	$240,082	$296,912

Table VI-6 Environmental Fuels Capability Study
Economic Summary

	Case 4		Case 5		Case 6	
	Quantity	$/Day	Quantity	$/Day	Quantity	$/Day
Sales						
Gas MM scf/day @ .95¢ MM BTU	185.3	$ 176,060	500	$ 475,000	983.9	$ 934,704
No. 4 fuel oil 0.15% S @ $4.50/bbl	947	4,262	776	3,492		
No. 4 fuel oil 0.3% S @ $4.50/bbl	141,941	730,999	94,080	423,360		
Sulfur short ton @ $20/S ton	560	11,208	601	12,029	554	11,075
Total $/year		$278,479,000		$310,719,000		$321,565,000
Raw material purchased						
Crude Tia Juana @ $2.44/bbl						
Crude Kuwait @ $2.80/bbl	200,000	$ 560,000	200,000	$ 560,000	200,000	$ 560,000
Crude Brega @ $3.33/bbl						
Total $/year		$190,400,000		$190,400,000		$190,400,000
Operating cost						
Labor, maintenance, taxes, and Insurance		$ 14,627		$ 28,738		$ 38,132
Utilities						
Power MKWH @ 1.0¢/KWH	756.8	7,568	1,419	14,193	2,408	24,080
Cooling water MM 3¢ M gal	62.6	1,878	64.8	1,943	64.3	1,930
Catalyst cost $/day		7,299		9,969		15,383
Running royalty $/day		7,273		11,984		19,081
				----		----
Internal fuel consumption, S ton/day	1351	----	2838		4186	
Total $/year		$ 13,140,000		$ 22,721,000		$ 33,527,000
Off spec material	8516	----	1524	----	7146	----
Gross profit $/year		$ 74,939,000		$ 97,598,000		$ 97,638,000

Table VI-7 Environmental Fuels Capability Study

Operating Expenses (MM $/yr)

	Case 1 Tia Juana Max Fuel Oil	Case 2 Tia Juana 500 MM + Fuel Oil	Case 3 Tia Juana Max SNG	Case 4 Kuwait Max Fuel Oil	Case 5 Kuwait 500 MM + Fuel Oil	Case 6 Kuwait Max SNG
Raw material cost	$165.92	$165.92	$165.92	$190.40	$190.40	$190.40
Direct operating labor + supervision and maintenance	4.61	8.80	14.41	4.97	9.77	12.96
Supplies (15% of maintenance)	.23	.44	.72	.25	.48	.65
Other operating cost	7.51	12.01	22.69	8.17	12.95	20.56
Payroll overhead (10% of labor + supervision)	.23	.23	.23	.23	.23	.23
General overhead (50% of labor, except material)	2.53	4.74	7.68	2.73	5.24	6.92
Plant operating expenses, Subtotal	181.03	192.14	211.65	206.75	219.07	231.72
Depreciation (5% of total fixed investment)	8.13	11.34	15.38	8.41	12.04	14.60
Local taxes and insurance (included above)						
Subtotal	189.16	203.48	227.03	215.16	231.11	246.32
Contingencies (2% of subtotal)	3.78	4.07	4.54	4.30	4.62	4.93
Total operating expense	192.94	207.55	231.57	219.46	235.73	251.25

Table VI-8 Environmental Fuels Capability Study

Price of Gas Calculations (MM $/yr)

	Case 1 Tia Juana Max Fuel Oil	Case 2 Tia Juana 500 MM + Fuel Oil	Case 3 Tia Juana Max SNG	Case 4 Kuwait Max Fuel Oil	Case 5 Kuwait 500 MM + Fuel Oil	Case 6 Kuwait Max SNG
1st year calculation						
Gross return (8.5% of rate base)	$ 16.89	$ 22.48	$ 29.59	$ 17.79	$24.14	$ 28.64
Interest (8% of investment)	10.37	13.75	18.10	10.89	14.76	17.52
Federal income tax	6.04	8.06	10.61	6.37	8.66	10.26
Total operating expense	$192.94	$207.55	$231.57	$219.46	$235.73	$251.25
Total revenue required	$215.87	$238.09	$271.79	$243.62	$268.53	$290.15
Revenue generated from products other than SNG	$232.68	$138.87	$ 3.35	$222.43	$149.22	$ 3.77
Revenue required for sale of SNG		99.22	268.42	21.19	119.31	286.38
Price of SNG¢/MM BTU 1st year	0.0	58.36¢	78.87¢	33.63	70.18	85.61¢
Average year calculations						
102% of plant operating expense	$184.65	$195.98	$215.88	$210.88	$223.45	$236.35
13% of total fixed average investment	10.57	14.74	19.09	10.93	15.66	18.99
11.9% of working capital	4.29	4.49	4.83	4.90	5.12	5.34
Average year total revenue required	195.22	215.21	240.70	226.71	224.23	260.68
Revenue from other products	232.68	138.87	3.35	222.43	149.22	3.77
Revenue required for sale of SNG	0.0	76.34	237.35	4.28	95.01	256.91
Average price of SNG ¢/MM BTU	0.10	44.90¢	69.74¢	7.69	55.89	76.80¢

Table VI-9 Environmental Fuels Capability Study
Cash Flow Calculations

	Case 1 Tia Juana Max Fuel Oil	Case 2 Tia Juana 500 MM + Fuel Oil	Case 3 Tia Juana Max SNG	Case 4 Kuwait Max Fuel Oil	Case 5 Kuwait 500 MM + Fuel Oil	Case 6 Kuwait Max SNG
Sales	$281,070,000	$300,372,000	$326,806,000	$278,479,000	$310,719,000	$321,565,000
Raw material purchased	165,920,000	165,920,000	165,920,000	190,400,000	190,400,000	190,400,000
Operating cost	12,123,000	20,808,000	37,011,000	13,140,000	22,721,000	33,527,000
Gross profit	$103,027,000	$113,644,000	$123,875,000	$ 74,939,000	$ 97,598,000	$ 97,638,000
Total investment	$198,727,000	$264,470,000	$348,141,000	$209,356,000	$283,944,000	$336,984,000
Depreciation on total investment 5%/year	$ 9,936,000	$ 13,224,000	$ 17,407,000	$ 10,468,000	$ 14,197,000	$ 16,849,000
Interest on total investment 4% on average	$ 7,949,000	$ 10,579,000	$ 13,926,000	$ 8,374,000	$ 11,358,000	$ 13,479,000
General and administrative overhead	500,000	500,000	500,000	500,000	500,000	500,000
Profit before federal income taxes	$ 84,642,000	$ 89,341,000	$ 92,024,000	$ 55,597,000	$ 71,543,000	$ 66,810,000
Allowance for federal income taxes @ 48%/year	$ 40,628,000	$ 42,884,000	$ 44,188,000	$ 26,686,000	$ 34,341,000	$ 32,069,000
Profit after taxes	$ 44,014,000	$ 46,457,000	$ 47,862,000	$ 28,911,000	$ 37,202,000	$ 34,741,000
Cash flow	$ 53,950,000	$ 59,681,000	$ 65,269,000	$ 39,379,000	$ 51,399,000	$ 51,590,000
Estimated payout time, years	3.68	4.43	5.33	5.31	5.52	6.53

Table VI-10 Environmental Fuels Capability Study

Unit Capacities (B/SD, unless otherwise stated)

	Case 1 Tia Juana Max Fuel Oil	Case 2 Tia Juana 500 MM + Fuel Oil	Case 3 Tia Juana Max SNG	Case 4 Kuwait Max Fuel Oil	Case 5 Kuwait 500 MM + Fuel Oil	Case 6 Kuwait Max SNG
Crude distillation	200,000	200,000	200,000	200,000	200,000	200,000
Vacuum distillation	77,783	77,783	77,783	68,008	68,008	68,008
Visbreaker		47,398	47,398		7,218	40,020
Naphtha + LSR hydrobon	29,999	38,086	38,085	43,991	70,373	50,769
Distillate hydrobon	89,389	102,155	30,963	110,186	82,998	29,059
MRG unit	32,717	92,749	188,265	47,789	92,186	184,347
Cracking isomax		34,318	75,092		29,307	95,095
Sulfox S ton/day	313	409	514	599	582	573
Partial oxidation MM scf/day H_2		117	265		108	201
RCD isomax	61,702			30,694	25,158	
Steam plant S tons/day Fd.	265	610	1,072	367.4	670	1,055
SO_2 removal process S tons/day	8.7	23	11.9		57.0	17.79
Steam reforming H_2 Plt. MM scf/day H_2	43.8			54		
Deasphalt	45,340			40,020	32,802	

Table VI-11 Environmental Fuels Capability Study

Economic Summary

	Case 7 Tia Juana + Brega	Case 8 Tia Juana + Brega	Case 9 Kuwait + Brega	Case 10 Kuwait + Brega
Investment summary				
Plant investment	$154,996,000	$202,523,000	$156,391,000	$194,850,000
Interest during construction	6,200,000	8,101,000	6,256,000	7,794,000
Subtotal	$161,196,000	$210,624,000	$162,647,000	$202,644,000
Working capital				
30 days crude inventory	$ 16,416,000	$ 16,416,000	$ 17,857,000	$ 17,857,000
30 days catalyst and chemicals	195,000	237,000	188,000	259,000
Accounts receivable, 11% of total operating cost	23,339,000	24,604,000	25,193,000	26,243,000
Total working capital	$ 39,948,000	$ 41,257,000	$ 43,238,000	$ 44,359,000
Total capital investment	$201,144,000	$251,881,000	$205,885,000	$247,003,000
Average price of gas[a]	21.89¢	50.68¢	45.45¢	60.07¢
Estimated cash flow payback, years	4.23	4.67	5.23	5.30
Products				
SNG wt.% of crude	18.77	34.3	21.85	35.3
No. 4 fuel oil 0.15%S B/SD				
No. 4 fuel oil 0.3%S B/SD	129,099	93,775	122,012	92,886
No. 6 fuel oil 0.3%S B/SD				
Sulfur S tons/day	227	281	288	330
Internal fuel consumption, wt.% crude	4.31	8.06	4.74	7.82
Off spec. unblended material zero value	12,275	7,187	10,515	5,793
" " " " (wt.% crude)	7.52	4.40	6.63	3.65

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[a] Using Dept. of Interior Office of Coal Research Procedure, June 4, 1965

Table VI-12 Environmental Fuels Capability Study
Plant Investment Summary

	Case 7 Tia Juana + Brega	Case 8 Tia Juana + Brega	Case 9 Kuwait + Brega	Case 10 Kuwait + Brega
Process Units				
Crude distillation	$ 14,286	$ 14,286	$ 14,597	$ 14,597
Vacuum distillation	5,516	5,516	5,645	5,645
Visbreaker	6,366	6,367	5,676	5,676
Naphtha + LSR hydrobon	4,160	4,160	4,638	4,638
Distillate Hydrobon	8,681	6,024	8,157	6,475
MRG unit	30,005	39,357	32,640	39,518
Cracking isomax	10,082	23,528	8,801	18,777
Partial oxidation		28,583		24,441
RCD isomax				
Steam reformer H_2 plant	7,422		7,203	
Deasphalt unit				
Total process unit investment	$ 86,518	$127,821	$ 87,357	$119,767
Offsites				
Steam plant	$ 5,470	$ 7,486	$ 5,875	$ 7,446
SO_2 removal plant (Shell flue gas removal)	---	4,387	---	4,898
Sulpel	1,000	1,100	1,100	1,200
H_2S removal plant (Sulfox)	3,477	3,795	4,054	4,217
Crude storage and int. tankage @ $3/bbl	23,018	23,742	23,093	23,573
Fixed offsites	20,000	20,000	20,000	20,000
Product tankage 30 days @ $3 /bbl	11,619	8,440	10,981	8,360
Total offsites	$ 64,584	$ 68,950	$ 65,103	$ 69,694
Total processing unit and offsites Investment	$151,102	$196,771	$152,460	$189,461
Startup expense x 1.5% process units	1,298	1,917	1,310	1,796
Spare parts x 3.0% process units	2,596	3,835	2,621	3,593
Total investment less catalyst	$154,996	$202,523	$156,391	$194,850
Initial catalyst loading	6,465	8,122	7,278	7,715
Total investment cost	$161,461	$210,645	$163,669	$202,565

Table VI-13 Environmental Fuels Capability Study
Economic Summary

	Case 7		Case 8		Case 9		Case 10	
	Quantity	$/Day	Quantity	$/Day	Quantity	$/Day	Quantity	$/Day
Sales								
Gas MM scf/day @ 95¢/MM BTU	273.7	$ 259,968	500.0	$ 475,000	309.5	$ 294,022	500.0	$ 475.00
No.4 fuel oil 0.15% S @ $4.50/bbl								
No.4 fuel oil 0.30% S @ $4.50/bbl	129,099	580,946	93,774	421,983	122,011	549,049	92,886	417.98
No.6 fuel oil 0.3% S @ $4.50/bbl								
Sulfur short tons @ $20/S ton	227	4,541	281	5,618	288	5,754	330	6.60
Total $/yr		$287,745,000		$306,884,000		$288,600,000		$305,862.00
Raw Material Purchased								
Crude Tia Juana @ $2.44/bbl	133,500	$ 325,740	133,500	$ 325,740				
Crude Kuwait @ $2.80/bbl					133,500	$ 373,800	133,500	$ 373.80
Crude Brega @ $3.33/bbl	66,500	221,445	66,500	221,445	66,500	221,445	66,500	221.44
Total $/yr		$186,042,000		$186,042,000		$202,383,000		$202,383.00
Operating Cost								
Labor, maintenance, taxes, and insurance		$ 12,224		$ 21,550		$ 12,229		$ 20.15
Utilities								
Power M kwh @ 1.0¢/kwh	726.2	7,262	1,238.2	12,381	732.4	7,321	1,092.9	10.92
Cooling cost MM gal @ 310¢/M gal	46.3	1,389	49.0	1,469	50.9	1,529	52.7	1.58
Catalyst cost $/day		6,511		7,906		6,252		7.60
Running royalty $/day		5,506		9,267		5,881		8.73
Internal fuel consumption S ton/day	1,326	---	2,481	---	1,418	---	2,340	---
Total $/yr		$ 11,183,000		$ 17,875,000		$ 11,293,000		$ 16,661.00
Off spec. material	12,275	---	7,187	---	10,515	---	5,793	---
Gross profit $/yr		$ 90,520,000		$102,967,000		$ 74,924,000		$ 86,818.00

Table VI-14 Environmental Fuels Capability Study

Operating Expenses (MM $/yr)

	Case 7 Tia Juana + Brega	Case 8 Tia Juana + Brega	Case 9 Kuwait + Brega	Case 10 Kuwait + Brega
Raw material cost	$186.04	$186.04	$202.38	$202.38
Direct operating labor + supervision and maintenance	4.16	7.33	4.16	6.85
Supplies (15% of maintenance)	.21	.55	.21	.51
Operating cost, utilities, and cat., R. royalty	7.27	10.55	7.13	9.81
Payroll overhead (10% of labor + supervision	.23	.23	.23	.23
General overhead (50% of labor, except material)	2.30	4.06	2.3	3.79
Plant operating expenses, Subtotal	$200.21	$208.76	$216.41	$223.57
Depreciation (5% of total fixed investment)	8.06	10.53	8.13	10.32
Local taxes and insurance (included above)	---	---	---	---
Subtotal	$208.27	$219.29	$224.54	$233.89
Contingencies (2% of subtotal)	4.16	4.38	4.49	4.68
Total operating expense	$212.43	$223.67	$229.03	$238.57

Table VI-15 Environmental Fuels Capability Study

Price of Gas Calculations (MM $/yr)

	Case 7 Tia Juana + Brega	Case 8 Tia Juana + Brega	Case 9 Kuwait + Brega	Case 10 Kuwait + Brega
1st year calculation				
Gross return (8.5% of rate base)	17.10	21.41	17.50	20.99
Interest (8% of investment)	10.46	13.10	10.71	12.84
Federal income tax	6.13	7.67	6.27	7.52
Total operating expense	212.43	223.67	229.03	238.57
Total revenue required	235.66	252.75	252.80	267.08
Revenue generated from products other than SNG	199.07	145.38	188.63	144.36
Revenue required for sale of SNG	36.59	107.37	64.17	122.72
Price of SNG, ¢/MM BTU 1st year	39.3¢	63.16¢	60.98¢	72.19¢
Average year calculations				
102% of plant operating expense	204.21	212.94	220.74	228.04
13% of total fixed average investment	10.48	13.69	10.57	13.17
11.9% of working capital	4.75	4.91	5.15	5.28
Average year total revenue required	219.44	231.54	236.46	246.49
Revenue from other products	199.07	145.38	188.63	144.36
Revenue required for sale of SNG	20.37	86.16	47.83	102.13
Average price of SNG, ¢/MM BTU	21.89¢	50.68¢	45.45¢	60.07¢

Table VI-16 Environmental Fuels Capability Study
Cash Flow Calculations

	Case 7 Tia Juana + Brega	Case 8 Tia Juana + Brega	Case 9 Kuwait + Brega	Case 10 Kuwait + Brega
Sales	$287,775,000	$306,884,000	$288,600,000	$305,862,000
Raw material purchased	186,042,000	186,042,000	202,383,000	202,383,000
Operating cost	11,183,000	17,875,000	11,293,000	16,661,000
Gross Profit	$ 90,550,000	$102,967,000	$ 74,924,000	$ 86,818,000
Total investment	$201,144,000	$251,881,000	$205,885,000	$247,003,000
Depreciation on total investment 5%/yr	10,057,000	$ 12,594,000	10,294,000	$ 12,350,000
Interest on total investment 4% on average	8,046,000	10,075,000	8,235,000	9,880,000
General and administrative overhead	500,000	500,000	500,000	500,000
Profit before federal income taxes	$ 70,947,000	$ 79,798,000	$ 55,895,000	$ 64,088,000
Allowance for federal income taxes @ 48%/yr	34,536,000	38,303,000	26,830,000	30,762,000
Profit after taxes	37,411,000	41,495,000	29,065,000	33,326,000
Cash flow	$ 47,468,000	$ 54,089,000	$ 39,359,000	$ 46,576,000
Estimated payout time, yr	4.23	4.67	5.23	5.30

Table VI-17 LPG Manufacture by Hydrocracking--Feedstock Properties

	Feedstock (Mid-Continent)	
	Naphtha	Gas Oil
Gravity, °API	52.6	34.5
Distillation, °F	D-86	D-1160
IBP	218	400
10%	245	468
50	289	580
90	351	726
EP	380	800
Hydrogen Content, wt %	14.9	-
Nitrogen, ppm	0.1	230
Sulfur, ppm	0.7	3000

Table VI-18 LPG Manufacture by Hydrocracking-- Yields and Hydrogen Consumptions

Feedstock Hydrocracker Yields	Naphtha scf/bbl	 Vol %	Gas Oil scf/bbl	 Vol %
Dry Gas				
C_1	12		13	
C_2	13		16	
Subtotal	25		29	
LPG				
C_3		29.4		24.8
iC_4		55.5		48.8
nC_4		17.9		18.1
Subtotal		102.8		91.7
C_5/C_6		36.2		58.2
Total, C_3^+		139.0		149.9
Hydrogen consumed				
Chemical	1948		2590	
Solubility	105		134	
Net yields, if all of the gas and C_5/C_6 as required are used as H_2 plant feed and fuel:				
LPG		102.8		91.7
C_5/C_6		13.2		24.2
Total, C_3^+		116.0		115.9

Table VI-19 LPG Manufacture by Hydrocracking-- Capital Investment and Utility Requirements

	Feedstock	
	Naphtha	Gas Oil
Capital investment, $MM		
Hydrocracking unit	8.0	14.0
Fractionation and gas plant	5.0	7.5
Hydrogen plant	13.2[a]	16.2[b]
Battery limits subtotal	26.0	37.7
Initial catalyst charge	0.8	1.8
Subtotal	27.0	38.9
Offsites, spare parts, startup costs	15.5	22.4
Total	42.5	61.3
Utilities		
Power, kw[c]	12,800	21,500
Fuel, MM BTU/hr[d]	1,380	2,040
Cooling water circulation, gpm	15,800	24,000
Process water, gpm	575	750

---

[a] 65 MM scf/sd.
[b] 86 MM scf/sd.
[c] Includes power for circulating cooling water.
[d] Includes hydrogen plant feed.

Table VI-20 LPG Manufacture by Hydrocracking--
LPG Cost Estimates

	Feedstock	
	Naphtha	Gas Oil
Cost of LPG, ¢/gal		
Feed, at 75¢/MM BTU	9.36	11.36
Other direct costs	2.56	4.25
Credit for C_5/C_6 by-product at 75¢/MM BTU	-2.98	-5.42
Overheads, depreciation, taxes, profit (10% ROI)[a]	2.57	4.20
Net cost of LPG, FOB, ¢/gal	11.52	14.39
($/MM BTU)	(1.14)	(1.43)
LPG cost in ¢/gal will change as follows when feed changes 10¢/MM BTU:	1.25	1.52
Feed and C_5/C_6 change 10¢/MM BTU	1.11	1.22
Investment (total capital) changes 10%	0.21	0.34
The ROI increases to 15%	0.54	0.87

---

[a] 10% ROI, discounted, 15-yr life, double-declining-balance depreciation.

APPENDIX VII

REPORTS OF VISITS TO U.S. DIESEL MANUFACTURERS

CUMMINS ENGINE

Columbus, Indiana
March 24, 1972

Attending:

Panel on Manufacturing and Producibility - LeRoy H. Lindgren
Panel on Alternative Systems - John W. Bjerklie
NAS - John E. Nolan

Cummins Managers:

David Wulfhorst - Director, Environmental
Roger Bascom - Manager, Combustion Engineering
W. T. Lyn - Senior Technical Advisor
Roy Kamo - Director, Adv. Engine Systems
E. D. Manlin - Director, Adv. Engine Manufacturing
Lamont Eltinge - Manufacturing

Mr. Wulfhorst stated that Cummins has no expertise in designing Diesels for light-duty vehicles. They do have considerable heavy-duty Diesel engine experience in the emissions control designs. They made an unsolicited proposal to EPA in May 1970 to build a LDV Diesel engine.

The design criteria for emission controls for Diesel engines are

Turbo-charging
Injection Timing
Improved Combustion System
Aftercooling
Reduced Compression Ratio
Exhaust Gas Recirculation
H_2O Injection

Cummins has developed a simulation combustion model for evaluating an emission control Diesel engine. The current status of the model is

- Development of a coupled model integrating mixing with kinetics
- Possibility of extending to smoke and HC models
- Extensive use of the existing model as a design tool

The Cummins model forecasted the following:

$$HC/CO/NO_x - HC = .26 - CO = 2.60 - NO_x = .37$$

using a PC Diesel and EGR.

Cummins has no interest in building LDV engines. They do feel that Diesels have the best emissions potential. Odor will be a major problem for the Diesel engine. Fuel economy is favorable to the LDV Diesel.

CATERPILLAR TRACTOR

Peoria, Illinois
March 23, 1972

Attending:

Panel 5 - LeRoy H. Lindgren
Panel 4 - John W. Bjerklie
NAS - John E. Nolan

Caterpillar Managers:

R. R. Robinson
J. W. Vallentine
J. E. Mitchell
M. R. Gibson
R. E. Bosecker
E. W. Landen
R. D. Henderson

Caterpillar tractor is doing design research on Diesel engines to improve emissions, noise, smoke, and odor. The design approach is

1. To develop exhaust gas recirculation - limit EGR to 22/1 to avoid smoke
2. To review H_2O injection versus NO_x emissions
3. To develop timing advance relation to NO_x
4. No catalyst exists for reducing NO_x in a Diesel
5. Exhaust emissions do not increase as the engine hours increase
6. Fuel evaporation is negligible

The conclusions of the design review are as follows:

a. Conventional tooling can be used to produce Diesel engines
b. 1976 standards could be met without a catalyst
c. No evaporation control is required
d. No sacrifice in driveability is incurred
e. There is low in-use maintenance
f. A weight penalty has to be absorbed
g. There is improved fuel economy over gasoline engines
h. Odors will be within desired limits

If a LDV Diesel engine were to be designed the lead times to produce a production design are as follows:

1. Technical feasibility - 6 months
2. Prototype design - 12 months
3. Test prototype - 6 months
4. Production design - 6 months
Total lead time 30 months

Caterpillar Tractor Co.
Technical Center
Peoria, Illinois 61602
April 14, 1972

Mr. John Nolan
Assistant Executive Director
National Academy of Sciences
2101 Constitution Avenue
Washington, D. C. 20418

Dear Mr. Nolan:

During your March 23 visit to Caterpillar Tractor Co. concerning the feasibility of the diesel engine as an alternate powerplant for automobiles, additional information was requested in two areas:

1. Engine factory
2. Emission control hardware and cost estimates

This is to respond to item 2 while consideration is being given to item 1.

Attached is a chart similar to that shown as Table 6.1 on page 41 of the semi-annual report prepared by the National Academy of Sciences Committee on Motor Vehicle Emissions, dated January 1, 1972. Required additional emission control hardware for a precombustion chamber diesel engine is shown in relation to gasoline engine hardware along with the expected year of application. This assumes that a diesel engine is in production and these are the changes and time schedule necessary to meet the automobile standards. Also shown is an annual cost accumulation for gasoline engine emission hardware as shown in Appendix H for comparison with the few add-on items for the diesel. The diesel hardware costs are estimates which try to account for high volume, automotive production. Even if low by a factor of two or three, the required add-on hardware for the diesel is minimal, requiring no expensive materials.

The chart basically shows that the precombustion chamber diesel requires very little auxiliary equipment to achieve low emission levels. However, the basic diesel engine is more expensive than the spark ignition reciprocating engine. We are not in a good position to evaluate this difference. Caterpillar Tractor Co. builds heavy duty diesel engines, and we do not know how their costs relate to light duty passenger car engines that are built in quantities at least 20 to 30 times greater than we build. There is no reason to believe the difference is prohibitive, considering the auxiliary equipment required by the spark ignition engine. In addition, higher first cost of the diesel engine is to some degree justified by its higher efficiency and demonstrated durability.

There are additional items to consider which favor the diesel engine:

1. Conservation of fuel - It is expected that an automotive diesel powering a standard size car would use less than 60 percent as much fuel as its gasoline engine counterpart in typical urban driving. Even if diesel fuel costs the same per gallon as regular grade gasoline, the fuel saving cost would be about $350 at the end of 50,000 miles. This should more than pay for any higher first cost for the diesel.
2. Malfunction detection is easy for the diesel engine in that black smoke would indicate need for maintenance or repair. This could aid enforcement and prevent extended running periods with high levels of invisible carbon monoxide.
3. Evaporative emission controls at filling stations would be unnecessary.
4. Experience indicates that, over the life of the car, diesel maintenance costs may be well below that required for the 1976 gasoline engine with its emission control hardware.

We hope these comments will assist your Panel members in their evaluation of the precombustion chamber engine as an automobile powerplant. Please call if clarification is needed.

Very truly yours,

(signed)
R. R. Robinson
Director of Research

RRRobinson
Telephone: (309) 578-6777
sg
attach

AUTOMOTIVE EMISSIONS HARDWARE LISTING AND COST ESTIMATES

YEAR	ITEM/OTTO CYCLE AUTO	ITEM/DIESEL CYCLE AUTO	COST/OTTO	COST/DIESEL
1966	PCV Valve	Not needed but available	$ 3.00	0 or $ 3.
1968	Fuel evap.-control sys.	Not needed	15.00	0
1970	a. Retarded ignition timing	Not needed	---	0
	b. Decreased comp. ratio	Not needed	---	0
	c. Change of F/A ratio	Not needed	---	0
	d. Transmission Control sys.	Not needed	8.00	0
1972	a. Anti-dieseling solenoid val.	Not needed	---	0
	b. Thermostatic air valve	Not needed	---	0
	c. Choke-heat by-pass	Not needed	14.00	0
1973	a. Exhaust gas recirc. (EGR)	Not needed	---	0
	b. Air-Injection Reactor	Not needed	---	0
	c. Induction hardened val. seats	Not needed	---	0
	d. Spark Advance control	Not needed	---	0
	e. Air pump	Not needed	60.00	0
1974	Precision Cams, Bores, & Pistons	Not needed	20.60	0
1975	a. Proportional EGR	Not needed	---	0
	b. Carb w/altitude compensation	Apply Aneroid Rack Stop	---	4.00
	c. Advanced air-injec. cont.	Not needed	---	0
	d. Air/fuel preheater	Not needed	---	0
	e. Electric choke	Not needed	---	0
	f. Electronic distributor	Not needed	---	0
	g. Improved timing control	Apply quality control	---	1.00
	h. Catalytic (oxidizing) conv.	Not needed	---	0
	i. Catalyst pellet charge	Not needed	---	0
	j. Cooling system changes	Not needed	---	0
	k. Improved underhood matl.	Not needed	---	0
	l. Body revisions	Not needed	193.40	0
		1975 Totals =	$314.00	$ 8.00
1976	Not Defined *	Proportional EGR Control		$12.00
		1976 Total	?	$20.00

* Semi annual report does not include 1976 costs or items for the otto cycle engine. Diesel engine costs were estimated through 1976.

GENERAL MOTORS
DETROIT DIESEL

Warren, Michigan
April 20, 1972

Attending:

Panel 4 - John W. Bjerklie
Panel 5 - LeRoy H. Lindgren, George B. Clayton
NAS - John E. Nolan

General Motors:

See attached list.

The manufacturing engineering efforts on Diesels is limited to heavy-duty applications. No plans for reviewing or designing a LDV Diesel engine exist.

The general feeling was that a Diesel is a low-maintenance engine. The heavy truck diesel engines have virtually replaced the gasoline engines.

A discussion of a simulated production plan for a mass produced LD engine revealed that a further investigation of fuel-injection manufacturing was necessary.

GENERAL MOTORS PERSONNEL
PARTICIPATING IN
NATIONAL ACADEMY OF SCIENCES
CONFERENCE ON DIESEL ALTERNATE POWERPLANTS
GM TECHNICAL CENTER - WARREN, MICHIGAN - APRIL 20, 1972

Dr. F. W. Bowditch, Director, Automotive Emission Control
  G. P. Hanley, Staff Engineer, Automotive Emission Control

K. L. Hulsing, Director of Engineering, Detroit Diesel Allison Division-Detroit; C. J. Karrer, Manufacturing Manager, Detroit Diesel Allison Division-Detroit; D. F. Merrion, Assistant Staff Engineer-Emissions, Detroit Diesel Allison Division-Detroit

H. N. Zoet, Works Manager, Diesel Equipment Division

Dr. W. G. Agnew, Technical Director, GM Research Laboratories; W. H. Percival, Head, Mechanical Research Dept., GM Research Labs.; R. W. Talder, Senior Research Engineer, GM Research Labs.

D. J. LaBelle, Manager-Forward Planning (Trucks), GM Engineering Staff

APPENDIX VIII

REPORT OF PANEL VISIT TO EUROPE

(JUNE 26 to JULY 7, 1972)

TRIP REPORT

Panel European Visit
June 26 to July 7, 1972

Visitors: Maurice Nelles, Merrill Ebner, LeRoy Lindgren, and John Nolan.

Purpose: To visit light-duty Diesel, Wankel, and gasoline-reciprocating engine manufacturers in Europe. Also, to visit manufacturers of Diesel fuel-injection pumps and injectors who are mass-producing these devices for passenger-car applications and some European catalyst producers.

Schedule of visits:

Monday, June 26 - Fiat S.P.A. Torino, Italy
Tuesday, June 27 - Volkswagen - Hannover & Wolfsburg, Germany
Thursday, June 29 - Perkins Engine Co., Peterborough, England
Thursday, June 29 - Johnson-Matthey, London, England
Friday, June 30 - CAV/SIMS, Sudbury, England
Friday, June 30 - British Leyland, Coventry, England
Monday, July 3 & 4 - Daimler-Benz, Stuttgart, Germany
Monday, July 4 (PM) - Robert Bosch, Stuttgart, Germany
Wednesday, July 5 - Citroën-Comotor - Paris, France
Thursday, July 6 - Opitz-Technical University, Aachen, Germany
Friday, July 7 - Ford-Diesel - Dagenham, England

FIAT VISIT

Date: Monday, June 26, 1972--Fiat, Torino, Italy

Hosts: Giovanni Savonuzzi; Director of R/D
Ettore Cordiano; Chief Engineer, Automobiles
Carlo Pollone; Head, Emissions Control

GENERAL

Dr. Savonuzzi stated that Fiat produces 1,500,000 cars/year, with only 50,000 exported to the United States. They employ 185,000 people. A decentralized reorganization is presently taking place following the General Motors organizational concepts:

1. Passenger car group
2. Truck group
3. Diversified products group

Within 5 years R/D will have 5,000 employees in a 2 million-sq. ft facility including safety labs, emission testing labs, climatic tunnels, and R/D engineering laboratories. No consortium exists within Fiat to combine R/D with research. The R/D group does participate with the IIEC Group in the United States. They are studying emission systems, interactions on resources, and requirements for lead-free gas.

Their production plans for the U.S. market include the following car types:

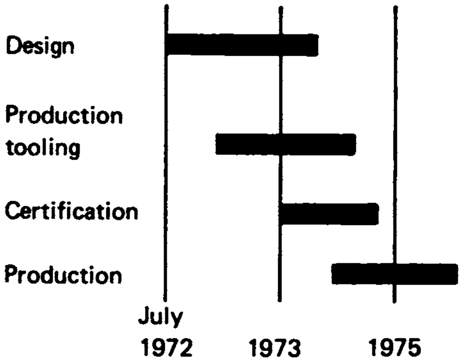
128-series front-drive models 1100 and 1300 for sedan, coupe, station wagon, and Spider (weight 2250 lb)
132-series back-drive (front engine) models 1600-1800 for sedans, station wagons, and sports cars (weight 2500 lb)

An Emission Standards group is working in Europe on developing standards. Sweden and Switzerland have adopted U.S. standards. Fiat feels that Europe will move toward the U.S. standards within one year. European emissions work is concentrating on CO; smoke regulation for

Diesels to be published later this year. Photochemical smog (HC/NO_x) data have not been developed in Europe, although air monitoring is in process. Fiat has three monitoring stations in Torino to measure $HC-CO-NO_x$, particulates, and sulfur. Fiat plans to increase the air-monitoring facilities to four, with a mobile unit for area testing. They are now planning to monitor lead and expect to have 10 stations by 1973. Dr. Savonuzzi stated the "lead content in the air has not been studied enough nor has the medical research been sufficient." A regulation for lead content in the air is expected by the late 1970's. Diesel smoke and smell is a planned prime regulation requirement in Europe. Smoke tests at full power and with free (no load) acceleration are expected for all Diesel-powered cars and trucks.

EMISSION CONTROL CONFIGURATION

The 1975 systems will be firmed up by 1973. The lead-time schedule for 1975 systems is as follows:



The tooling schedule assumes no body changes for the 50,000 car production for the United States

The IIEC - Test Vehicle - Fiat Configuration

1. Air injection
2. HC/CO catalyst - noble metal
3. NO_x catalyst - noble metal
4. EGR (might be added)
5. Carburetion - Weber (Fiat-owned)
6. Choke (manual)
7. Driveability - reasonably good
8. Fuel--10 to 15 percent lower than 1972 cars

Catalyst Manufacturers: Engelhard, W. R. Grace, Johnson-Matthey, UPO, and Gould.

Johnson-Matthey is believed to have the best test data on a monolith catalytic converter. Engelhard has an agreement with Kali-Chemie in Germany to produce pellet and monolith catalytic converters.

In the 1976 design, the air-injection and EGR systems will be linked to water temperature to make adjustments during the driving cycle. By-pass systems will be required in Europe because of the high speeds. In the United States, the by-pass valves will not be required. The R/D tests are in effect now. Fiat is planning to send 11 1973 cars to Ann Arbor for 4000-mile tests and 50,000-mile tests. The tests should be completed by the end of 1972.

FIAT CONFIGURATION CONTROL FOR EMISSION CONTROL DEVICES

Model	Device	Notes
1974	Air pump	GM Saginaw/Japanese license
	Air injection	Now on test vehicles
	EGR 7 to 8 percent	
1975	Air pump	GM Saginaw
	Air injection	
	EGR 7 to 8 percent	
	Catalyst HC	

	Induction-hardened seats or inserts	
1976	Air pump	GM Saginaw/Japanese license
	Air injection	
	Catalyst HC	
	Catalyst NO_x	
	EGR (might be required)	
	Thermal reactor	
	By-pass valve (Europe)	
	Variable timing (of cams and valves)	
1977	Electronic ignition system	(might be added in 1975)
	Altitude comp carburetor or electronic fuel injection	

Fiat stated that they are having space problems installing emission devices in front-engine-drive systems.

CONFIGURATION CONTROL AND QUALITY ASSURANCE

Fiat has plans for intensive controls of components at the following stages of manufacturing:

1. Cam shaft - computer or master-cam inspection
2. Hydrometer tappet test unit
3. Hot test engines in production
4. Spark plug gap inspection controls
5. Production line timing-setting test
6. Cylinder-piston class fits
7. Production line friction test of green engine
8. Production line compression pressure test
9. Carburetor-flow A/F test at Weber

OTHER R/D EFFORTS AT FIAT

1. Light-duty Diesel Direct Injection Development Group has a contract with Ricardo in Brighton, England. Ricardo has prepared a report of this design that can be made available to NAS by requesting both Fiat and Ricardo for a copy. The first prototype will be built by the end of the year.
2. Fiat has a new design turbine with 499 HP (+) prototype in R/D to be tested this year.
3. Steam and electric designs are in R/D.

Diesel-Light-Duty Engine

Dr. Savonuzzi stated that the light-duty Diesel has low-maintenance advantages. They are designing an engine with Ricardo. The Diesel has emission advantages for 1975. The size and weight disadvantage can be stated as 4#/HP compared to 3#/HP for petrol powered engines. The noise and smoke problems are a major design effort. The Ricardo Design is a 75-HP engine for a Porsche. The Ricardo report is said to recommend proceeding with the development. (The Panel felt that an intensive effort should be made to obtain this report.)

Manufacturing Facilities

The engines, bodies, components, and car assemblies are all made on very modern mass production line equipment with extensive use of automatic material-handling devices. The production rate was good on mechanical equipment, but the work pace per operator was average or less (using ratio delay methods of observation).

VOLKSWAGEN VISIT

Date: June 27, 1972 - Volkswagen-Hannover & Wolfsburg, Germany

Attending: L. Lindgren, M. Nelles, M. Ebner, and J. Nolan

Hosts (Hannover):

- Dr. Dencker - Head of Engine Assembly
- Mr. Knapp - Head of Production Planning (engines)
- Mr. Bollwein - Head of Quality Control (plant Hannover)
- Mr. Braun - Assistant to Chief Engineer
- Mr. Mandersheid - Emissions Staff Engineer
- Mr. Neumann, Manager, Emissions Control
- Dr. W. E. Bernhardt, Basic Research
- Mr. W. Lee, Basic Research

The Volkswagen managers presented a complete review of the various planned configurations that would be used for emission controls and maintenance. The four configurations discussed are illustrated in Table VIII-1.

The prime design (Configuration I with fuel injection and electronic control) is being reviewed this month to determine an implementation plan. The informal assessment was that VW was very close to committing to this system, at least for the cars sold in the United States for 1975 and 1976. The manufacturing facilities were the most modern available. The productivity was above average. (The Panel estimated activity at between 118-133% of engineered standards.) The quality-control procedures for significant control dimensions used the statistical precontrol techniques.

The changes in production equipment required to produce Configuration I would require new castings and dies and new boring stations for the revised combustion chambers. The electronic controls will be made by Volkswagen divisions, the fuel injection system will be made by Bosch, and the 3-way catalyst will be supplied by Johnson-

TABLE VIII-1 Emission Configurations Components

Configuration	Air Pump Injection	Thermal Reactor	Conv. HC/CO	Conv. NO_x	3-way Cat. Conv.	O_2 Sensor	Catalyst Mono	Catalyst Pellet, Noble	Catalyst Pellet, Base	Carburetor	Elect. IGN	Elect. Emiss. Control	Fuel Injection
I[a]					x	x		x or	x		x	x	x
II			x	x		x	x			or	x	x	x
III	x		x	x			x			x			x
IV	x	x	x	x			x	x		x			

[a] The 3-way catalyst is supplied by Johnson-Matthey (German Div). This design includes a by-pass valve.

[b] This design includes a heater between HC/CO and the NO_x reactor and the by-pass valve.

Matthey German division. The implementation schedule for the fuel-injection system is shown in Figure VIII-1.

We observed an end-of-line emission test (full test). Every car is tested for CO and adjustments are made to correct those cars that do not pass the test standard.

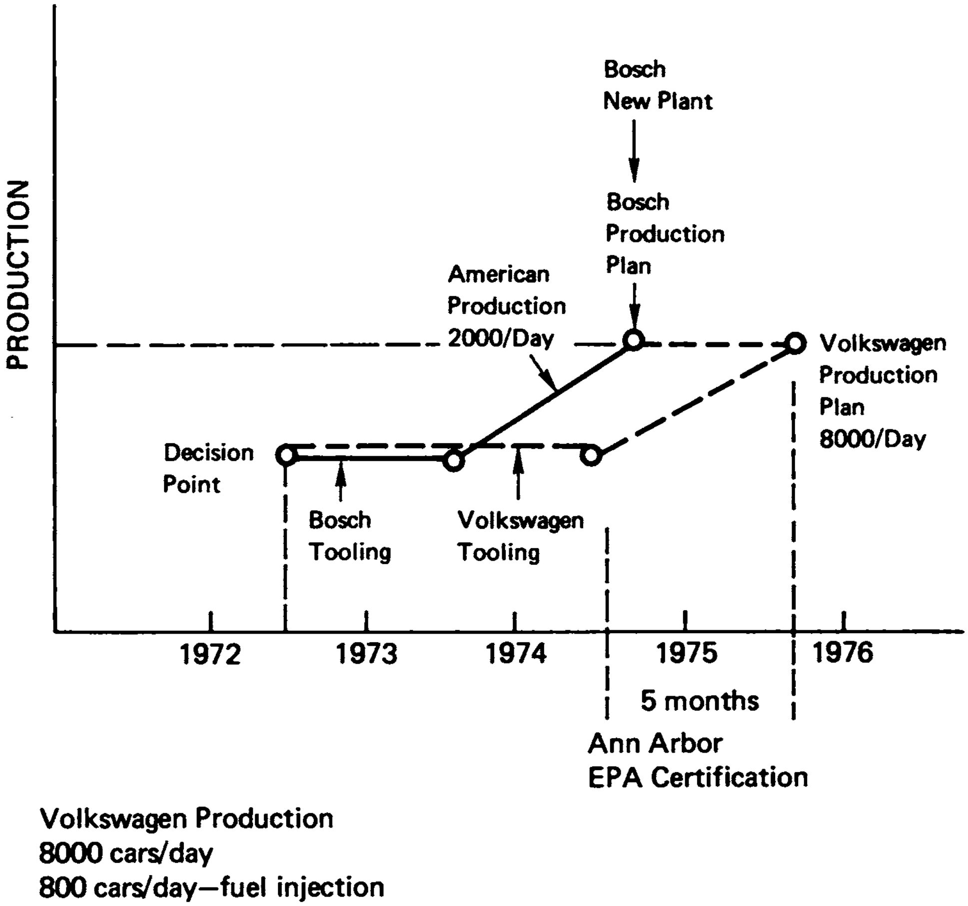


FIGURE VIII-1 Fuel-injection implementation plan, Volkswagen and Bosch electronic control system.

JOHNSON-MATTHEY VISIT

Date:	June 29, 1972 - Johnson-Matthey, London, England
Attending:	M. Nelles and J. Nolan
Hosts:	H. R. Hewitt, Main Board, Director and Chairman of J-M Chemicals
	P. D. Barker, Commercial Director, J-M Chemicals
	J. E. Hughes, Research Director, J-M Group
	G. J. K. Acres, Head, Catalyst Research
	B. S. Cooper, Manager of Chemical Production
	H. Connor, Manager, Technical Services

Our reception was cordial and all questions were answered in a direct and very competent manner.

Johnson-Matthey is prepared to manufacture catalysts that will meet the 1975 standards. The design work for the plants to produce the catalysts is completed. Drawings are in hand and they have obtained suitable sites in the United States. The same plants will be used for producing the 1976 catalyst requirements, so no additional capital investment will be required. August 1, 1972 is the last date they can guarantee to meet production commitments for much, most, or all of the requirements. Japanese companies have been active in testing J-M catalysts and the Japanese have men in London and J-M men in Japan coordinating the activities..

We explored the arrangements that might be made with container companies. It was their opinion that they would coat the substrate with a catalyst and ship the product to container companies so the finished device could be sent to the car assembly plants.

We questioned present arrangements to ensure enough platinum. They reported that as far as platinum requirements are concerned there are large reserves and all plans are laid including PERT charts. There are monthly meetings with the platinum group of J-M and U.S. auto companies on the supply question. Although platinum is not absolutely essential for 1975, it is for 1976.

J-M feels the recovery of platinum from spent catalysts will be handled by junk dealers. In general, they feel that 50 percent will be recoverable but that it may take some time to achieve this. They expect to use about $12.50 of platinum per car. Their process is such that they can recover 97 percent of the platinum that comes to their plant.

Although they are prepared to use either monolith or granular carrier, at present they prefer monolith. They could make their own carrier but prefer American Lava or Corning, at least for units sold in America.

It was especially interesting to hear that their major effort for 1976 is a single-bed catalyst using fuel injection. The possible use of carburetors to reach the 1976 standards seemed remote. This checks with other contacts in Europe such as Bosch and Volkswagen.

In summary: They can supply catalysts to meet the 1975 standards with 18 months lead time. Their most extensive work in motor vehicles has been with the Japanese motor car companies.

PERKINS VISIT

Date: June 29, 1972 - Perkins Diesel, Peterborough, England

Attending: L. Lindgren and M. Ebner

Hosts: Bernard P. Dyer, Director, Manufacturing
Dennis Eassom, Facilities Manager
Allen Basley, Chief Production Manager

GENERAL

The Perkins Engines Group is a Division of Massey Ferguson. The facility in Peterborough produces diesel engines at a volume of 1100 engines/day, using a 2-shift production schedule with some overtime.

They produce seven major types of engines for tractors, light trucks, and taxis. The taxi volume has been lost to BMC who now make the 4-cylinder London cab engine (50 HP). The light-duty 3-, 4-, and 6-cylinder in-line engines account for about 800/day production. The truck engine is a V-8 engine comparable to the Cummins 180-HP engine.

The various engine types that are related to light duty are shown in Table VIII-2.

The 4.165 engine is the most recent light-duty design that has the best weight-to-horsepower rating. This 80-HP rating reportedly can be increased by 40 percent by adding a supercharger ($65 estimated cost).

	Engine Size	Cyl	CID	HP	Weight	$\frac{\text{lb}}{\text{HP}}$	$\frac{\text{HP}}{\text{lb}}$
Diesel	4.165	4	165	80	450	5.6	.18
Diesel	4.165 sc	4	165	112	480	4.3	.23
Gasoline	427 in.^{3}	8	427	210	710	3.5	.296

Perkins confirmed what the panel had learned earlier, that the London cabbies pay 100 pounds Sterling (about $260) added cost over a petrol engine for a Diesel 4-cylinder (BMC Austin) engine. The

TABLE VIII-2 Perkins Diesel Engines

Type	CID in^3	Cyl	Weight	HP	Injection Chamber	Injection Pump
3.152	153	3	400	40	DI	Rotary
4.107/108	107	4	330	58	IDI/PC	Rotary
4.154[a]	154	4	430	70	IDI/PC	Rotary
4.165[b]	165	4	450	80	IDI/PC	Rotary
4.203	203	4	477	56	DI	Rotary
4.236	236	4	580	82	DI	Rotary
4.248	248	4	600	80	DI	Rotary
4.270	270	4	670	85	DI	Rotary
6.247	247	6	836	108	IDI/PC	Rotary
6.347	348	6	960	155	DI	Rotary
V 8.510	510	8	1415	160	DI	In line piston
V 8.605	605	8	1430	180	DI	In line piston

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[a] 4.154 engine block and heads, pistons, and manifolds are produced in Japan by Toyo Koygo - licensed in Japan for domestic vans. The blocks are shipped to Perkins where the assemblies are completed.

[b] 4.165 new design light-duty engine that is planned for production by Perkins in Peterborough. The rotary pumps are sealed for life. Injection nozzles give 50,000-mi service. There are service facilities for reworking nozzles by reboring and using oversize needles and springs (15 min each rework time @ 10¢/min = $1.50 each cost).

fuel consumption saving of the Diesel over the petrol is about $260 in the first year. The maintenance is negligible for the Diesel. They run these engines up to 500,000 miles with no maintenance except for an occasional injection-nozzle change.

The current R/D projects are directed toward minimizing noise in the Diesels. The noise was said to be caused by

1. High combustion pressure
2. Mechanical sounds produced by worn pistons and rings
3. Pump noise (The piston pumps do produce noise as noted at Bosch and at M/B at the test stands.)
4. Cold engine noise (RAP)

The corrections being considered are

1. Two pilot injection system
2. Improved combustion swirl
3. Revised nozzle shape
4. Lower peak pressure in combustion chamber (This tack was pursued vigorously by the Panel since it had the potential for using light-weight aluminum heads. The engineers at Ford subsequently stated that the McCulloch Corporation has produced a piston and chamber design that smoothes out the peak pressure, thereby reducing noise.)
5. Full control--Higher cetane rating creates higher noise. Higher gravity fuels need higher temperatures and pressures and therefore create more noise. Cetane must be lowered and controlled.

MANUFACTURING PROCEDURES AND QUALITY TESTS

The engines and the major components are produced on modern transfer lines at a rate of 80,000/year. This is about one-fourth the output of a U.S. automotive transfer line but the production machinery was the same. At Perkins, the number of machining stations was less and the move time was 2 minutes as compared to 1 minute in the U.S. equipment.

The quality-control procedures were adequate but there was no particular evidence of precise control. The engines get a 100 percent test at full speed and full load so that an adequate run-in is made before shipment. All Perkins engines are shipped to customers for installations into vehicles, so it is essential that the engine is fully tested and reliable before shipment. No emission tests for CO/HC or NO_x are made by Perkins. The incoming fuel pumps are given a sample test using comparison against master pumps and procedures. The nozzles are given sample tests for spray charcteristics and setting pressure. The setting pressure is critical for DI (direct injection) installations but not critical for IDI (indirect injection) installations.

The IDI nozzle is a simpler design and therefore costs less than a DI nozzle. The DI nozzles require carefully inclined hole drilling operations (diameter, .012-.014) and the DI (direct injection) requires 10 to 15 percent more fuel than the IDI. Smoke is more easily controlled with IDI.

A production simulation plan was developed by the Panel and Perkins based on the assumption that some U.S. companies would buy some engines from Perkins delivered to the United States. The engines would be installed in U.S. assembly plants. The delivered costs were estimated to be equal to U.S. production costs. We asked them to give us their best estimates of how many engines they could produce at what costs and at what investment, and they responded as follows:

1. The engine production was estimated to be 800,000/yr.
2. The costs would be equal to U.S. gasoline engine costs for comparable horsepower.
3. The investment would be about $20 million.
4. The lead time would be three years after the designs had been proved, tested, and certified.

This plan is included as Table VIII-3.

TABLE VIII-3 Perkins Hypothetical Implementation Plan for Light-duty Diesel Production of 4-, 6-, and 8-Cylinder Engines

	Gasoline		Diesel		Production year USA		Engine Production Qty x 1000							
Car Type	CID	CYL	CID	CYL	Gas	Diesel	72	73	74	75	76	77	78	79
Subcompact	153	4	165	4	100,000	20,000	Dec	Tool des	Tool test	20	20	20	20	20
Compact	170 200	6	165	4sc[a]	400,000	80,000	"	"	"	30	50	80	80	80
Intermediate	225 250	6	247	6	1,500,000	300,000	"	"	"		40	100	250	300
Intermediate	302 318	8	247	6sc[a]	2,000,000	400,000	"	"	"		40	100	250	400
Standard	340 360	8		8	3,000,000									
Std/Lux	383 402	8		8sc	2,000,000									
Luxury	426 500	8			1,000,000									

Note: This table assumes that the Design Specs-Test and Certification will be completed by 1973 for 4- and 6-cyl cars, the Engineering Resources will be available, and the investment in plant will be $20,000,000 for 70,000 engines per month or 800,000 engines per year. The 8-cylinder engine was not considered in the assumption.

[a] The 4- and 6-cyl engines are supercharged.

LEYLAND MOTORS - IMPERIAL CHEMICAL INDUSTRIES VISIT

Date: June 30, 1972 - Leyland Motors - ICI - Coventry, England

Attending: M. Nelles and J. Nolan

Hosts: Dr. John H. Weaving, Leyland
Mr. Hawkins and Mr. Musidy, ICI

Dr. Weaving explained the organization of Leyland Motors and the working arrangement of the Pollution Control Committee. Each division has its own laboratory. Jaguar's was small with a low level of activity. The Committee meets each week with representatives of ICI.

Direct questioning of Leyland representatives indicated they were relying primarily on a class of catalyst that could be built into the exhaust system. They had no PERT or GANTT charts and were waiting developments. They did not seem knowledgeable of what was going on in the rest of the world nor were they especially interested. They have passed their "dropdead" date for the committing of new facilities for automotive catalysts.

ICI is the world's largest chemical company and has decades of experience with catalysts - especially with catalysts concerned with compounds of nitrogen. Because of this their major effort has been on 1976 standards.

ICI has a research agreement with Shell Oil Co. Present inidcations are they will not use thermal reactors and a two-bed catalytic converter will be used as well as an air pump.

ICI plans to use particulate catalysts and they could provide 2 to 4 million pounds in a short time in present facilities. Thus far the only catalyst for automotive use has been in the laboratory.

They did not have a plan for the catalyst containers. They took the position they could either make or buy. They have no plans for new plants for making catalysts or for making containers. They felt that if they were to be in the business they could achieve the desired results with a crash program.

ICI would not be in the recycle business (precious metal recovery).

Costs for catalyst were estimated by ICI to be between $1 and $10 for the oxidation catalyst and probably a similar amount for reduction catalysts. The smaller cars would require 3 to 4 pounds and the larger cars, 4 to 8 pounds. Their cost estimate seemed vague.

They indicated they felt more stainless steel would have to be used in the exhaust system. Some platinum would have to be used but they were not sure how much.

CAV VISIT

Date: June 30, 1972 - CAV, Sudbury, England
Attending: M. Ebner and L. Lindgren
Hosts: S. E. Barber, Manager, Advanced Product Planning
P. J. Hibbard, Company Production Engineer
K. A. Ward, Production Manager
J. H. Williams, Production Engineer
A. D. Boyd, Supplies Manager

The CAV facility for manufacturing nozzles was exceptionally modern and highly productive. The manufacturing methods were fully automatic at all operations. The quality-control measurements were controlled in the machine cycles. The final assembly of the precision nozzles was accomplished by a statistical measuring system and a final flow test. The spray tests were an assurance test that the final assembly was performing according to engineering standards.

The manufacturing managers were developing new methods to improve costs and quality for a new 80,000 sq ft expansion of the current facility. The current facility occupies 160,000 sq ft with 80,000 sq ft available. They have available land for 160,000 sq ft without interfering with the recreation areas. They can more than double their capacity within a 2-year lead time. They employ 1300 people now on a two-shift basis. They can easily draw another 2000 people from the area.

The pump facility in Rochester, England, has similar capabilities with expansion plans (80,000 pumps/month).

The implementation plan was developed by the Panel and CAV for a simulated Diesel production light-duty engine. This plan is included as Table VIII-4 and Table VIII-5.

The costs for a Diesel fuel pump are included in the simulation indicating that cost reductions could be realized as production increased. The cost reductions would come from improved methods and new equipment investments.

TABLE VIII-4 CAV Fuel Injection Pumps

Hypothetical Implementation Plan Using Current Capacity for 75/76 Light Diesel

		Cyl	Production Yearly	72	73	74	75	76	77	78	79	80
DPA	(4)	4	20,000				20	20	20	20	20	20
DPA	(4)	4s	80,000				30	50	80	80	80	80
DPA	(6)	6	300,000					40	100	250	300	300
DPA	(6)	6s	400,000					40	100	250	400	400
				Possible Capacity with Additional Facilities								
Pump		4-6			120	250	375	500	650	800	950	950
Injectors		4-6			900[a]	900	4750[b]	5600	6700	8100	9700	9700

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[a] 1973 - Production could be accomplished with current facilities. Production allows for replacement part - after market.

[b] 1975 - New facility for pumps and injectors required costing $2,800,000 for each 1 million nozzles. The pump production facility will be $3 to $5,000,000 for each 200,000 pump increase in production.

TABLE VIII-5 Hypothetical Implementation Plan CAV Fuel Injection

Production Data:	Nozzle Production
New Facility -	80,000 sq ft @ $35/sq ft = $2,800,000 includes 20-ft high bays, electricals, heat and vent
Present Facility:	160,000 sq ft for 80,000 nozzle sets/mo - 1300 production workers - 160,000 nozzle sets/month

Cost Data for Diesel Fuel Injection Pumps
(Estimated OEM costs in England)

		75	76	77	78	79	80
DPA pump	4	43	40	37	32	30	28
DPA pump	6	65	61	54	47	44	42
Injectors	4	20	19	18	17	16	11[a]
Injectors	6	30	28	27	26	24	19[a]
Filter	4	1.50	1.50	1.50	1.50	1.50	1.50
Filter	6	1.50	1.50	1.50	1.50	1.50	1.50
Preheater thermo		2.50	2.50	2.50	2.50	2.50	2.50
Leak off pipe		1.00	1.00	1.00	1.00	1.00	1.00
Added cost	4	68	64	60	54	51	44
For FI system	6	100	94	86	78	73	66
Cost Volume Reduction							
Pump		0%	5%	15%	25%	30%	
Injector		0%	5%	7%	15%	20%	

---

[a] New Poppet design; volume baseline #675 Injector

A CAV manufacturing facility analysis is included with this report.

CAV has a licensed facility in the United States at Hartford Machine Co. and foreign facilities in Spain, Romania, Brazil, and Mexico.

DAIMLER-BENZ VISIT

Visitors: Panel 5: M. Nelles, L. Lindgren, M. Ebner
Panel 4: J. Bjerklie, D. Wilson
CMVE Staff: J. Nolan

Hosts: Mr. Wittig, Export Technical Consultant
Mr. VanWinsen, Head, Passenger Car Design
Mr. Oblander, Head, Engine Testing
Dr. Derndinger, Deputy Head, Engine Design
Mr. Schumann, Chief, Diesel Engine Testing
Dr. Kraft, Chief, Emissions Laboratory
Mr. Dodener, Development and Scheduling
Mr. Hoeschele, Computer Development
Mr. Schmit, Emissions Coordination

The engineers discussed the current status of development in emissions control for gasoline and diesel engines. The present 60 horsepower diesel engine will meet the 1975 standards and maintain these emissions performances over 50,000 miles with normal service of injection timing and air cleaners. The ranges of emissions performance are:

CO	2.0 to 3.0 grams per mile
HC	0.6 to 1.0 grams per mile
NO_x	1.5 to 1.8 grams per mile

Odor data were not available. Filters were introduced in the exhaust system to capture particulates (carbon particles). They estimate 0.2 grams per mile for particulates. They stated that the PC (IDI) design was cleaner than the direct injection. The PC (or prechamber) design operated at 24° retard, and the direct injection operated at 21° retard.

They felt that the supercharger was not cost-effective although later data altered this statement. The 6-cylinder engine is too long for the engine compartment and not a likely configuration because of safety requirements (crushing strength characteristics). They therefore have deferred any R/D work on the 6-cylinder design.

The EGR systems combined with retard did not meet the 1976 emissions requirements but they did obtain 0.6 to 0.7 NO_x. A supercharged engine was thought to be better, but no figures are available. The supercharged engine without EGR and retard might provide 0.6 to 0.7 NO_x.

The fuel penalty using EGR and retard would be 10 percent over the 1975 system. The increased maintenance costs resulting from EGR will occur at 15,000 km. A NO_x catalyst is not feasible due to CO absence.

The supercharger is effective at high speeds and not effective for emissions controls at low speeds. It is possible that automatic transmission might help the effectiveness of emissions at low speeds.

Water injection would help but the penalties of H_2O freezing and other problems make this design ineffective.

The smoke and odor problems are directly related to retard timing and fuel. The average German fuel (CETANE 55) is satisfactory.

The fuel consumption data are as follows:

1. The 1975 system is the same as the 1972 system.
2. The 1976 system will cause an 8 percent fuel penalty and an increase in noise.
3. The glow plug is electrically heated so the battery for a Diesel will be larger.

The combustion chamber improvements are related to the following:

1. PC chamber redesign will give slight improvements in emissions.
2. Supercharger will not alter the chamber design.

The weight and horsepower ratio of the Diesel versus the gasoline engine is illustrated by the following chart:

	Cyl	RPM	HP	WT	HP/Lb	Lb/HP	German kg/ps
Caterpillar computer diesel composite	8	3600	156	825#	.19	5	--
Ford 427 CID gasoline	8	3400	210	710#	.296	3.5	--
Perkins-Diesel - Planned 4.154	4	--	70	430#	.167	6	--
Perkins-Diesel - Planned 4.165	4	--	80	450#	.18	5.6	--
Mercedes-Benz 220D 134CID	4	--	60	205 kg	--	--	3.41
Mercedes-Benz 220 134ID	4	--	105	176 kg	--	--	1.67
Mercedes-Benz 2.8 169CID	6	--	160	213 kg	--	--	1.33
Mercedes-Benz 276CID	8	--	225	263 kg	--	--	1.16

The reason for the excess weight of the Diesel over the gasoline engine is directly related to heavier

- Cylinder head
- Piston
- Crankshaft
- Flywheel
- Longer connecting rod

The peak pressure requires heavier castings. The low rpm and a wide torque variation requires heavier components.

The selling price in Germany of the Diesel versus the gasoline M-B 220 and 220D is

14,374 DM for the 220 gasoline
14,929 DM for the 220D Diesel
550 marks ($183) difference

The price strategy favors the Diesel. The German sales of M-B are two-thirds gasoline and one-third Diesel. A supercharger is available in Germany for 500 DM ($167). As far as costs are concerned, they estimated that the Diesel is 30 percent more than the gasoline.

The cold-starting problem is not serious. Tests in Sweden showed that 30-sec preheat was necessary in extreme cold conditions. The warm-up emissions favor the Diesel in the CVS tests.

The Diesel-Wankel is not a feasible design. It requires a two-stage design with losses between stages and, because of the pressures involved, the weight per horsepower is poor.

The current production volume of M-B is 300,000 engines per year. If 4-cylinder production were increased to 120,000/year, an investment of $40 to $47 million in machines and tooling would be required. This does not include the Bosch investment in injector pump production. All the tooling and machine tools would come from Europe with the exception of the Norton Grinders. The lead time required would be one to two years after the design had been certified.

The V-8 Diesel design would require seven years from design to production.

The manufacturing facilities were equal to U.S. production methods and tooling. The quality-control procedures were very precise on all the critical dimensions of the engine. Several operations were added to ensure concentricities, bore roundness, and size control in the cylinder block and the valve assemblies.

A sample timing production schedule is included as Figure VIII-2.

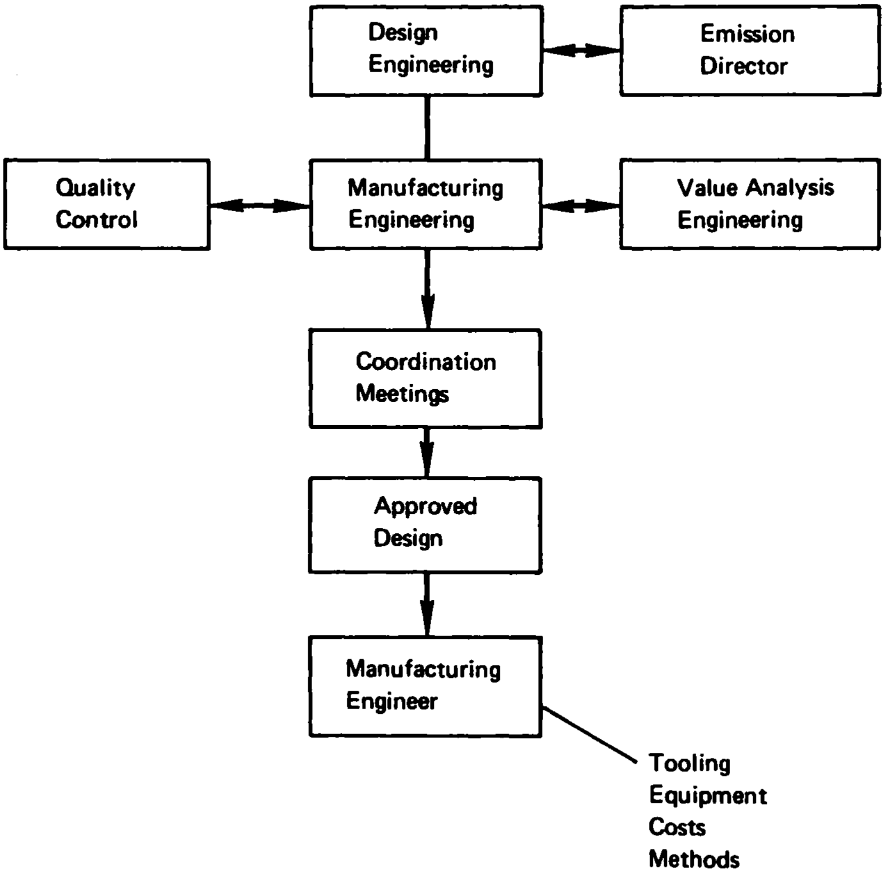


FIGURE VIII-2 Manufacturing organization to implement a Diesel production schedule.

BOSCH VISIT

Date: July 4, 1972 Bosch - Fuel Injection Systems
Stuttgart, Germany
Attending: M. Nelles, M. Ebner, L. Lindgren
Host: Ing Richard Zechnall

We arranged for discussion with the manufacturing managers and a visitation of a pump manufacturing facility.

Most of the discussion centered around the D and L Jetronic fuel-injection systems. They have produced over a million D-Jetronic (electronic fuel-injection system) systems to date. The L-Jetronic system is planned for production in 1973. The decision to proceed with the L-Jetronic into mass production will be made by Volkswagen this Fall. The L-Jetronic configuration involves an integrated Electronic subsystem that controls an air-flow meter and the fuel injection nozzles.

The advantages of the L-Jetronic system are

- Dynamic response
- Automatic compensation
- Simplification
- Compatibility
- No Air Pump (no power loss 5 to 7 HP)

EGR control of 2 to 3 percent is used to maintain a precise control of NO_x with an adequate margin.

The 1974 configuration includes proportional EGR and an O_2 sensor. The production schedule for this system will start one year from July 4, 1972. The Bosch engineers stated that they had no driveability problems with this system. A 3-way catalyst supplied by Johnson-Matthey was their first choice.

They have tested a similar system with a thermal reactor on 4-cylinder gas engines with the following CVS results:

	1976 Standards	Average Result of 8 Tests
HC	.41	.21
CO	3.4	1.8
NO_x	.4	.25

These data involved low mileage. The catalysts or the sensor have not reached 50 M miles. The gasoline must be lead-free.

The catalysts for the 1976 configuration that are being considered are as follows:

1. Noble metal. They felt that this catalyst is expensive and therefore will require a 50,000-mile life to be cost-effective.
2. Non-noble metal. They felt that the low replacement costs of $10-$15 for 5,000 to 10,000 miles are economically feasible. Using this approach, the engineers have time to develop new catalysts and thereby obtain improved catalyst life.

The production plans for the L-Jetronic Gasoline system are as follows:

1. Bosch and Bendix have a cross-licensing agreement with engineering interchange of designs.
2. Production could be implemented in the United States by using Bosch manufacturing know-how and their current production methods.
3. The production rate is now 50,000/month, of which three-fourths is allocated to Volkswagen.
4. They could manufactire 500,000/month (6 million/year) if required. The new tooling and facilities would require an investment of 300 million DM to 400 million DM.
5. The current production forecast for Diesel fuel-injection systems does not include any plans for U.S. light-duty vehicles.

6. The electronic subsystems would be produced in a separate Bosch manufacturing facility.

7. Oxygen sensor will be made by Bosch at a manufacturing cost of \$1 to \$2 each. The sensor will require the use of platinum and zirconia.

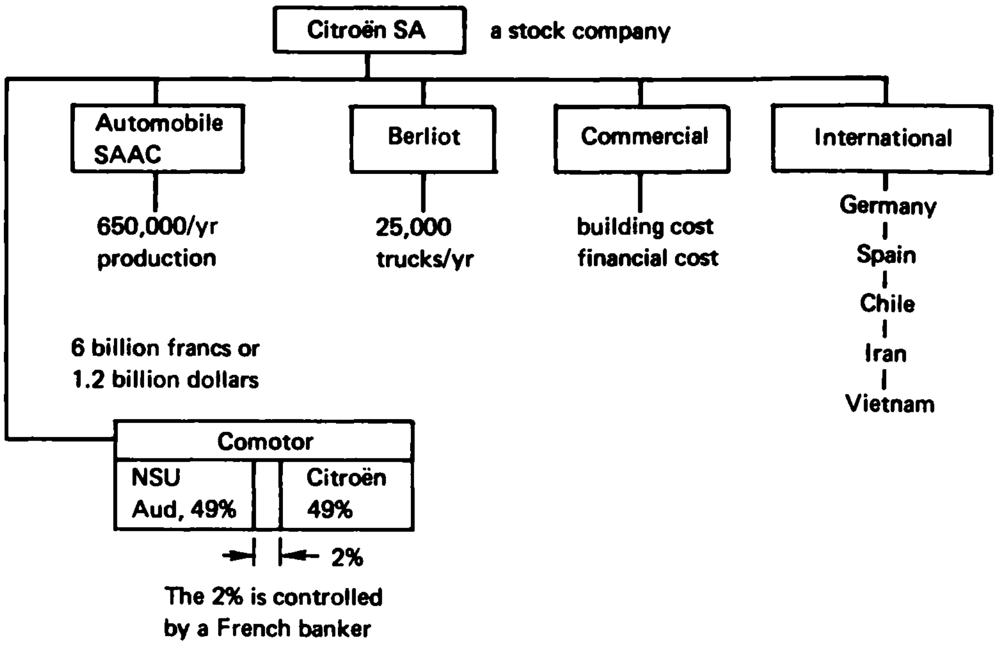
The manufacturing facility for the piston-type pumps was a well-organized, low-cost, high-production facility. The component manufacturing was highly automated, with automatic material-handling between operations. The quality-control procedures were adequate. They admitted that they had some problems with the test procedures and the test equipment. Current costs of testing were excessive, but they were installing some computer test equipment that would reduce testing costs from hours to minutes. The outgoing quality will be improved if they convert all their testing to computer-aided test systems.

CITROËN VISIT

Date: July 5, 1972--Paris, France

Attending: M. Nelles, M. Ebner, L. Lindgren

The organization structure was outlined by the Chairman of the Board as follows:



The Comotor organization was formed to design and manufacture the Wankel engine. The production plans are to produce 1 and 2 rotor engines in a proposed manufacturing plant in Saar, Germany. The facility (120,000 sq ft) in Germany is now producing Wankel engines for test vehicles. They have 500 M-35 Citroёns on the road undergoing tests in France. The German facility will produce engines for Audi, Porsche, Volkswagen and Citroёn. They are prepared to sell engines to other buyers also. The M-35 Citroёn will be built in France by Citroёn. Volkswagen has purchased Audi so they will have co-ownership of Comotor.

The RO-80 is being produced by Audi NSU. Citroёn has purchased 80 of the RO-80's for test purposes. The Panel rode in the M-35 and the RO-80 cars on the way to lunch. The cars were responsive, quiet, and reasonably comfortable.

The first Wankel 1-Rotor engine was produced by NSU/Citroёn in 1965. The R/D groups have been building and testing prototype test engines and cars from 1965 through 1970. The tests for reliability and maintenance have been conducted during 1970 and 1971. The current R/D group is directing efforts toward design improvements. Some information is available from NSU.

The current status of the Wankel engine for the RO-80 and the M-35 Citroёn car (1600 lb) is as follows:

1. From 1969 to 1971 the prime problems evolved around the wear characteristics of the tungsten carbide seals and cast iron apex seals. They managed to obtain mileages of 25,000 to 70,000 km before significant wear occurred.

2. During 1972 vehicles equipped with apex material using Alloy 3 (TiC + Fe + Ni) they achieved an average of 100,000 km before significant wear on the seals occurred.

3. An RO-80 equipped with Alloy 4 (TiC + Fe + Ni) was run over 100,000 km.

The current production facility in the Saar has production (in a job shop environment) tooling to produce 100 engines/day. The facility occupies 120,000 sq ft. The rotors and housings (seven parts) are produced in this facility. The other parts are purchased from Weber and other high-production component manufacturers.

Comotor has planned to build two plants, each with areas of 1,200,000 sq ft for a total production of 5000 to 6000 engines per day. Each facility will be equipped with

- Production transfer lines for the housings and the rotor
- Production grinding equipment--Blanchards
- Production nickel-plating equipment
- Cam-grinding equipment for the rotor
- Trochoid grinding equipment for the rotor housing
- Production foundry transfer line for the castings and rotors
- Titanium carbide and Ferritic compacting presses and sintering equipment for the seals
- Transfer line for the crankshaft and flywheel
- Production equipment for the manifolds
- Established vendors used by Citroën and NSU are carburetor, Solex; alternator, Bosch; and electronic ignition, Citroën.

The marketing plans of Comotor are to build engines for licensees Daimler-Benz and Audi. Potential customers include Ford Europe, Fiat, and others.

The configuration that is planned is

- 2-rotor 2-liter displacement--100 HP for a 2500-lb car
- 1 carburetor
- Electronic timing (under consideration)
- No fuel injection
- Without emissions hardware

The M-35 Citroën has not been extensively studied for emissions. They have tested some 1- and 2-rotor engines for emissions and found that the 1972 standards were met, but the 1975 standards were not assured. An emission exhaust system has been designed by R/D engineering. The design for 1975 involves temperature controls, EGR, lower combustion, and retarded timing. They did not plan for a thermal reactor or a catalytic converter at this time.

The price of a Wankel engine will be comparable to a competitive 6-cylinder engine. The major costs for production operations involve the trochoid grinder and the plating facility and the surface preparation equipment.

1. The grinding equipment investment would total \$5 million for a 7-min grinding cycle at a volume of 6000 engines per day
2. The nickel plating equipment would probably cost \$2,500,000
3. The entire facility would probably cost \$100 million for equipment and \$70 million for plant

TECHNISCHE HOCHSCHULEAACHEN VISIT

Date: July 6, 1972--Technische Hochschule Aachen, Aachen, Germany
Attending: M. Nelles, M. Ebner, L. Lindgren

The purpose of our visit to Professor Opitz's Technical Institute was to review how the Institute trained new managers for manufacturing and how they interfaced with industry on joint research projects for manufacturing.

The Institute was sponsored by 180 companies. Eleven percent of the Institute's income came from the University at Aachen. The other income came from the member companies and the German government.

The research projects are developed jointly by the Institute and the member companies.

The facility comprised the following:

- Plastic processing
- Numerical control manufacturing
- Welding processes
- Machining research

During the visit, the research in progress in the laboratories of Prof. Opitz (metal cutting) and Prof. Menges (plastics processing) was reviewed.

FORD (ENGLAND) VISIT

Date: July 7, 1972--Ford Motor Co. Diesel Engine Plant

Attending: M. Nelles, M. Ebner, and L. Lindgren

Hosts: R. Worters--General Operations Manager, Engine and Power Train
H. Bickenbach--Manufacturing and Plant Engineering, Power Train
John Pask--Executive Engineer, Product Development Engineering
Ian MacPherson--Executive Engineer, Product Development Engineering
Wayne Brehob--Ford USA

This production facility of the Ford Motor Company produces

Pinto Engines - 4-cyl. 153 Gasoline--1500/day, 330,000/yr
Diesel - 4-cyl. - 144 CID 59 HP-3600 RPM
Diesel - 4-cyl. - 144 CID 62 HP-3600 RPM
Diesel - 6-cyl. - 216 CID 86 HP-3600 RPM

The Diesel engines are precombustion chamber IDI designs. The Diesel production volume of light-duty configurations is 50,000 engines/ year. The current facility could be expanded to 90,000 engines per year. To produce 200,000 engines/year would require a new engine manufacturing facility costing $50 million. The current facility is running at capacity. The gasoline transfer lines could be replaced or converted to Diesel engines with major conversion costs. The current facility occupies 2,500,000 sq ft, so at $30/sq ft a new facility would cost $75 million.

If 500,000 Diesel 4- and 6-cyl. engines per year were scheduled (assuming the design were firm) they would need the following:

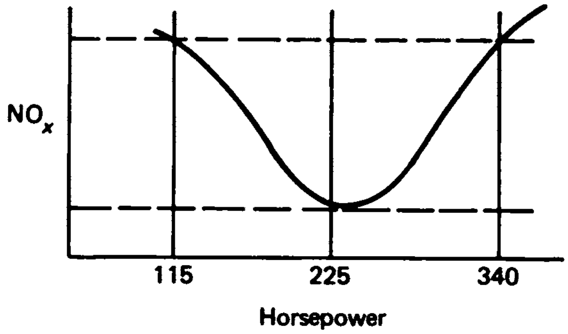
- New building costing $75 million with 12 to 18 months lead time
- New equipment costing $50 million with 12 months lead time

The equipment could be bought from Germany, Italy, and France. Manufacturing production methods would be equal to the U.S. systems, so the total minutes to make an engine would be equal to any U.S. production engine. An engine could be delivered from England at U.S. costs until the United States prepared for the production of light-duty Diesels.

The current facility is just starting production on two light-duty engines with superchargers:

- York Engine 4-cyl.-IDI-138CID-60 HP
- York Engine 6-cyl.-DI-207CID-90 HP

Turbochargers have been used to raise the horsepower of a 115-HP Diesel to 145 HP and, in special cases for marine racing environments, to 250 HP. The latter application involves intercoolers using fresh water as the coolant. A Monte Carlo racing engine was built to produce 340 HP. The effect of turbocharging on NO_x between 115 HP and 340 HP is illustrated



The coolant effect of the compressed incoming air reduces NO_x up to 225 HP, then the temperature effect differences are negligible and the NO_x rises.

Further NO_x reduction can be achieved with 5 to 7 percent EGR. These designs have not been tested on the Diesel light-duty engines at Ford.

A 1976 configuration could be developed but a complete R/D effort would have to be appropriated and scheduled. The events involve

- Revised light-duty design with turbo, EGR, and electronic fuel injection controls
- Build prototypes
- Obtain certifications for emissions
- Revise body designs
- Design tooling
- Obtain field experience
- Plan production

These events would probably require four years with high priorities. The injection pumps would be made by CAV - England and German Bosch.

The visit through the plant concentrated on 4- and 6-cylinder Diesel engine production. The manufacturing methods, equipment, tooling, and material handling system were equal to our best mass production system in the United States. Their employee problems were complicated by language and ethnic barriers. They have hired and trained employees from Africa, India, Italy, and Asia. The work pace was adequate but not comparable to the U.S. automobile companies.

APPENDIX IX

STATUS OF WANKEL ENGINE DEVELOPMENT AT GENERAL MOTORS

(July 19-20, 1972)

GENERAL MOTORS VISIT TO DISCUSS STATUS OF THE WANKEL ENGINE

Date:	July 19, General Motors Technical Center, Detroit July 20, General Motors - Wankel Prototype Mfg Willow Run
Attending:	M. Nelles, L. Lindgren, M. Ebner, and G. Clayton J. Nolan, CMVE
Hosts:	Edward Cole, President F. Bowditch, Executive Engineer E. Starkman, Emissions Director R. Templin, Wankel Project Manager

Mr. Cole, President of General Motors, devoted two hours to a comprehensive discussion of the General Motors efforts on the Wankel engine. He stressed the fact that they have not made the decision to go into production on the Wankel engine. They are working on various designs and they have set up a tool room facility at the Willow Run transmission plant for the development of manufacturing processes for each component and to build experimental engines for R/D testing.

Our Panel visited the facility at Willow Run to confirm the prior statements and to discuss the manufacturing problems with the design engineers and the manufacturing engineers. They have ordered tooling and equipment to study the various manufacturing processes. The manufacturing process development is GM's major effort at this stage. A firm design has not been specified by the R/D engineers. They have an engine in design that can be processed in production but it is not completely tested. The field testing is in process.

The cost estimates are being finalized for

1. Product costs (labor and material)
2. Tooling costs
3. Equipment costs
4. Facility costs

5. Quality costs
6. Warranty costs

They are using the Willow Run facility for the following reasons:

1. 1 million sq ft of floor space is available.
2. They have a good processing group at Willow Run because of their transmission production experience. (Transmission production requires many machining and quality requirements similar to the Wankel.)
3. They have project management team reporting directly to Mr. Cole.

Mr. Cole stated that they have selected the Wankel for investment in research and manufacturing development because of some inherent advantages:

1. The Wankel is shorter and lighter than equivalent engines so the front engine design can provide extra space for front end safety construction and for the 5 mph energy-absorption bumper.
2. The added space provides for emission control devices.
3. Even though the HC emissions are higher than other engines there is an NO_x emission advantage due to the inherent shape of the combustion chamber. In fact, the engine has a built-in EGR feature.
4. The new safety specifications require 5- to 7-in. additional length of car to absorb crash energy loads. The Wankel will provide 12 to 18 in. of space. Mr. Cole stated that the Wankel is the most compact package.
5. The Wankel has a cost advantage because of its low pounds per horsepower (1.0 to 1.5 lb per horsepower compared to 4 to 6 lb per horsepower for gasoline and Diesel engines).
6. The Wankel engine has no complex valve assemblies.

7. The rotary engine has a noise pollution advantage, although the noise problems are not fully resolved.

8. The oil consumption is higher than current engines. The lubrication is programmed into chambers, which is an advantage.

Some of the disadvantages at the current stages of development are:

1. High HC emissions output
2. Low mileage reliability (50,000- to 100,000-mile life potential not firm)
3. The emission devices will reduce the fuel consumption substantially.
4. The fuel consumption of the current design is higher than current gasoline engines. The GM engineers stated that the GM version's fuel consumption will be equal to current engines.
5. The Mazda dealers in the United States that also sell GM products have reported serious durability and maintenance problems.

The Wankel engine is a good design that can be manufactured on fully automated production lines--for machining components and engine assembly.

The engine design will evidently require a completely new frame and body design combined with a new drive system (possibly a front-end design).

Mr. Cole stated that a logical implementation plan for the introduction of Wankel might be as follows:

1. The pre-mass production models would be introduced into the Corvette so that a liaison with the customers can be established to test field performance in customer hands.
2. The 2-rotor Wankel would be introduced at the low end of the line competing against the 4-cylinder engine and will evidently replace it.

3. A larger or higher RPM version of the 2-rotor Wankel (1" in diameter might result in 40 percent more HP) could be used to compete against the 6-cylinder engine. The torque curve is flat at high RPM's. In fact at GM they say that they have run a Wankel up to 24,000 RPM.

4. The combined volume of the 4- to 6-cylinder engines is between 1.5 to 2 million engines/year. If the Wankel replaces this volume at GM, the engine would be at its least cost environment. GM produces 24,000 engines per day in 16 or 24 production plants. The optimum production is about 300,000 per year, so the Wankel production will be at full volume of 1,500,000/yr with GM. The Wankel least-cost volume will probably be between 450,000 to 600,000 per year.

5. The small V-8's (250 CID to 318 CID) might also find the larger Wankel version as a competitor especially if the 1976 emission control devices make the small V-8 a costly engine with poor fuel consumption and driveability.

6. The larger engines (V-8's 350 to 500 CID) are likely to be replaced with an improved V-8 using electronic control of ignition and emission systems. The 4-rotor Wankel is a more complex design with a long crankshaft and it will require a 2- to 4-year development program before it will compete with those V-8's.

Mr. Cole stated that a likely car configuration combined with a 2-rotor engine Wankel will be similar to a Mercedes-Benz 220 car.

The emission system for the Wankel will probably involve the following:

1. Electronic ignition controls
2. Thermal reactor
3. HC and NO_x catalytic converters
4. Fast choke designs for carburetors have made the carburetor feasible. A 40 ^{o}F plate temperature makes a liquid fuel act like a gaseous fuel.

5. New design carburetor
6. Electronic controls for emissions
    a. O_2 controls + catalyst 1975
    b. NO_x controls + catalyst 1976
7. Air pumps

The engines equipped with these emission devices have not been tested. The Wankel will probably be in some level of production by 1975 with some version of the above emission configuration.

The manufacturing facility for the Wankel was experimenting with the following critical equipment. (The whole facility equipment cost did not exceed $1 million.)

1. Trochoid Grinder - Vertical design made by Triordinate, New Jersey (estimated cost--$150,000).

2. Rotary Grinder with horizontal wheel for finished grinding of the end housing surfaces. The flatness and surface finish is critical (estimated cost--$75,000).

3. The Blanchard grinders were standard machines.

4. The turning equipment were standard W&S chucking machines.

5. The drilling machines were (and would be) standard (transfer line) drilling machines.

6. The milling machines were standard job shop machines.

7. The plating equipment was not visible.

8. The engineers were not keen about using metal spray equipment because of the surface preparation problems.

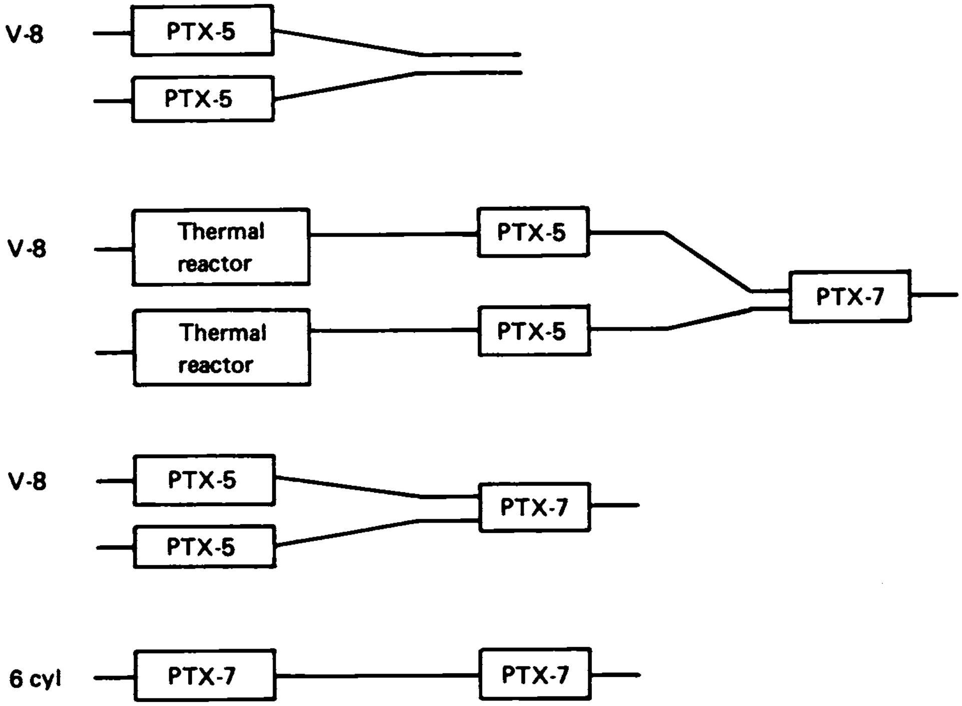
APPENDIX X

REPORTS OF PANEL REVISITS TO AMERICAN AUTOMOBILE COMPANIES (SUMMER 1972)

FORD MOTOR COMPANY VISIT

Date:	July 18, 1972, Ford Motor Co., Detroit, Mich.
Attending:	M. Nelles, M. Ebner, L. Lindgren, G. Clayton, J. Nolan
Hosts:	Bruce Simpson Jack Ninomiya Mr. Lutkehaus

Mr. Simpson reviewed the Ford Motor Co. test program called the Riverside Program. The configurations were illustrated as follows:



These converters were Engelhard with noble metal catalysts using .35 percent platinum.

The purposes of the tests are as follows:

1. To develop input-output data;
2. To isolate catalysts for evaluation;
3. To develop test-to-test data; and
4. To develop a calibration test car and the deterioration factors.

The group I cars show

HC - 2.2 with a spread of 1.31 to 3.80;
CO - 4.0 with a spread of 0.89 to 11.50; and
NO_x - 0.4 with a spread of .10 to .84.

The 1975 configuration status is as follows:

1. Carburetor - a new design to be made in the current facility
2. Engine block - new casting with minor T/L
3. Engine head - " " " " "
4. Engine manifold-" " " " "
5. Solid state ignition - new product made in a current facility
6. Proportional EGR
7. EGR control valves - vacuum controlled or throttle linkage
8. Control feedback - a mechanical subsystem
9. Air pump & air injection
10. Catalyst - Monolith
    Converter--Arvin
    Substrate--American Lava
    Coating Platinum--Engelhard

The 1976 configuration is as follows:

1. The NO_x system has no feedback control system
2. A major breakthrough on an NO_x catalyst is still a prime requirement
3. A 2nd generation catalytic converter system using Engelhard, Matthey-Bishop, American Lava substrate and possibly a Corning design
4. The Ford test configuration is using
    a. Leaner carburetion to reduce the CO
    b. More active catalyst to reduce the HC
    c. The driveability might be 3.0 where the acceptable factor is 5.0 on a 10.0 base

Mr. Lutkehaus related the following schedule for 1975 car plan:

1. The critical path items include the catalyst and the thermal carburetor
2. The new design carburetor is being implemented on the luxury cars
3. The variable venturi carburetor will not be used for 1975
4. The A/F fuel ratio controls can be accomplished
5. The converter will be 60 percent Engelhard and 40 percent to 2 or 3 vendors such as UOP, Corning, GM, and Matthey-Bishop
6. The substrates have been giving erratic results
7. The QC and QA problems with the design and application will become a major problem to Ford
8. The Air Pump - vendor is GM or a GM licensee
9. Electronic - breakerless ignition - Ford has capacity - the facility investment is made
10. Induction hardened ports are being phased into current designs
11. Body changes - tooling changes are being phased into the car body schedule

12. The converter location will be as close to the fire wall as possible, 6- to 8-in. from the exhaust manifold flange

13. Vacuum - not a problem for 1975

14. Cooling radiator--larger radiator added this year

15. EGR - will use a vacuum or mechanically operated valve

16. Temperature protection--the plan is to use overheat controls

17. Sensors design is not finalized

GENERAL MOTORS VISIT

Hosts: D. Milne, Executive Engineer
D. Davis, Environment Engineer
J. Wilson, representing Rochester
Mr. McCune

Dave Milne - Introductory statements

a. Production Planning
    1. Catalyst and converter is in the critical path
    2. Production tooling is not ordered yet
    3. Commitments are made for some materials and equipment
    4. Triple mode - emission control, latest configuration
    5. The 1975/76 converter system was the prior configuration
    6. Engineering vehicles are meeting standards but no production models are in test at this time
    7. Aug. 1974 deadline is a compressed schedule
    8. The production risks are great because of the lack of production experience.
    9. Losses in production volume are to be expected

Quality Control Procedures

a. <u>Functional testing</u>
    1. Air motor--motor is run by air pressure
    2. Engine dynamic balance

    3. Adjust timing--top dead center (peak press)
    4. Old pressure check

b. Compression pressure test
    1. Proper valve sealing
    2. Improper piston ring seals
    3. Idle control

c. Engine hot test--completely dressed engine
    1. Mechanical defects
    2. Power analysis
    3. Trans. Control spark
    4. Exhaust Gas Recirculation
    5. Timing

d. Leak tests--ultrasonic detector test

e. Intake manifold leak tests

f. Engine torque

g. Spark plug gap voltage drop

h. Engine compression ratio--whistle

i. Cam lobe contour checker--audit

j. Dynamometer reliability test audit (1- to 12-hr test)

k. Air injection reactor cylinder head

l. Air injection reactor system--final assembly

m. Trans. controlled spark--final assembly

n. Engine RPM--final assembly

Emission Tests

Engine assembly plant--audit complete engine
Idle test

Final Assembly Procedures

a. California production - 14 plants supply
    1. 2% cold start
    2. 25% California single hot cycle
    3. 75% idle test - HC/CO gross indicator

b. One division - 100% idle test

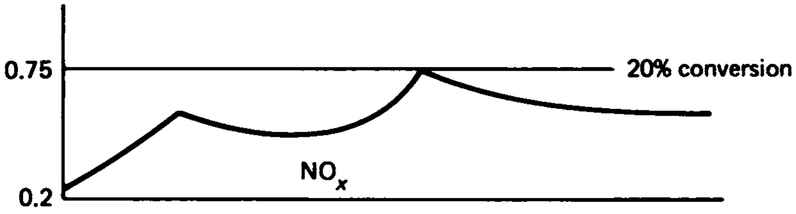
c. One division - 100% idle test on one car line

1975/76 Configuration

1. Dual catalytic system

    a. 2 NO_x reducing catalyst - monolith (preferred)
    b. HC/CO oxidizing
2. Carburetor--altitude compensation NO_x
3. EGR - 1.0 gm/mile--15% EGR (maximum)
    - with driveability 2.0

   (not proportional system) 1.0 gm
4. Quick heat manifold
5. Air pump
6. Electronic ignition - (higher energy ignition)



GMR Catalyst - GM research ruthenium is being tested.

Triple Mode - 1976 configuration dual catalyst

Exhaust manifold - Converters (2)

Quick heat manifold

MODE I Cylinder head cross over point so that fuel-air mixture for all 8 cylinders passes over preheat manifold

Manifold heat valve

Converter valve

Corning and American Lava Substrates (have ordered quantities of each)

Warm-up control

Reactor valve

MODE II Exhaust passes through converter

NO_x - Reducing in center section of catalyst -

with HC/CO oxidizing in the peripheral section monolith

MODE III Reactor Mode

Reactor valve opens and exhaust by-passes bed at high speeds and exhaust goes directly out the exhaust manifold. Then they might use EGR.

Advantages of Triple Mode

Quick light off

Higher temperature

Reduces contamination (high temp)

Reduces the full exhaust flow

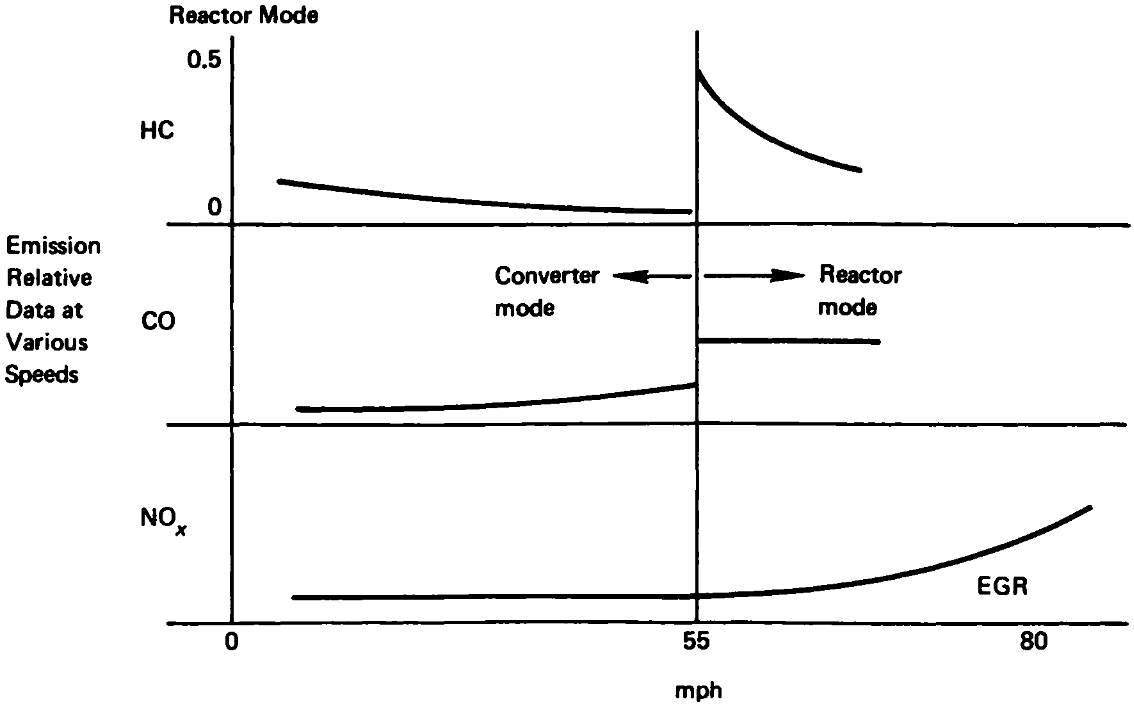
Bypassing the converter might improve driveability

Mode Switching

Startup mode--15 sec.

Coolant indicator needed

Manifold vacuum--switch source



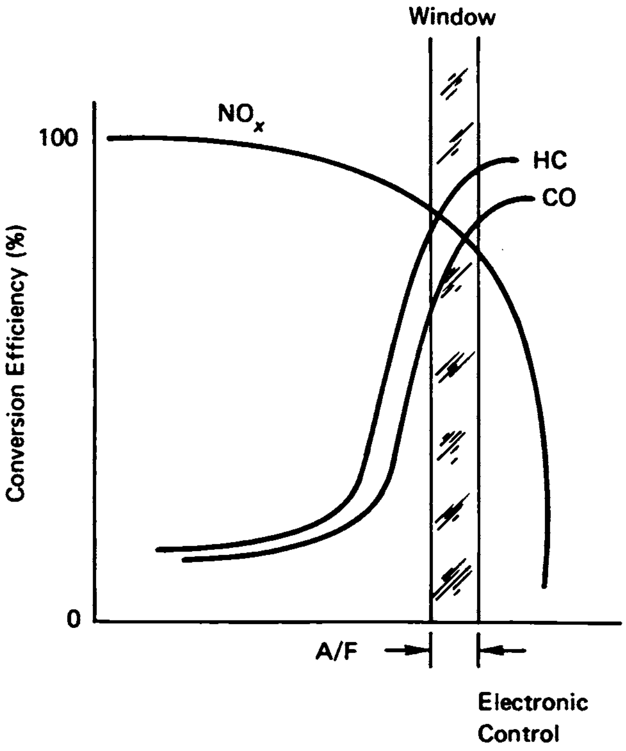
Temperature sensor in the catalyst bed is likely to improve catalyst life.

ELECTRONIC CONTROL
A/F Sensor

3-constituent catalyst

HC	0.16	
CO	2.3	8 tests
NO_x	0.27	2,500-lb car

Fuel Injection System



3-Constituent Emission System

Development in early stages

Noble metal requires precise A/F control

Base metal offers a little more freedom

Converter 120 cu in. - 60 cu in. (4½x4)

Tested one car in Colorado for altitude--favorable data were obtained

John Wilson - Rochester - Carburetors

Apache - 2 barrel - 3 subassembly

Air horn
Bowl
Throttle

Components - 247 separate parts 23 subassemblies for the 2 barrel

Manpower - 75 Engineers and Model shop personnel are used on this project

Lead Time Analysis

a. Design 1971 - 14 months
    - Drafting
    - Tolerance specifications
    - Costs estimating

b. Finalize design 1972

c. Design failure mode 1973

d. Model shop

e. Sand-cast carburetors

f. 1972 Prototype die cast molds ordered

g. March 1973 durability carburetors will be built and tested

h. Production parts in 1974

i. Run test May 1971 to 1974 (Road tests)

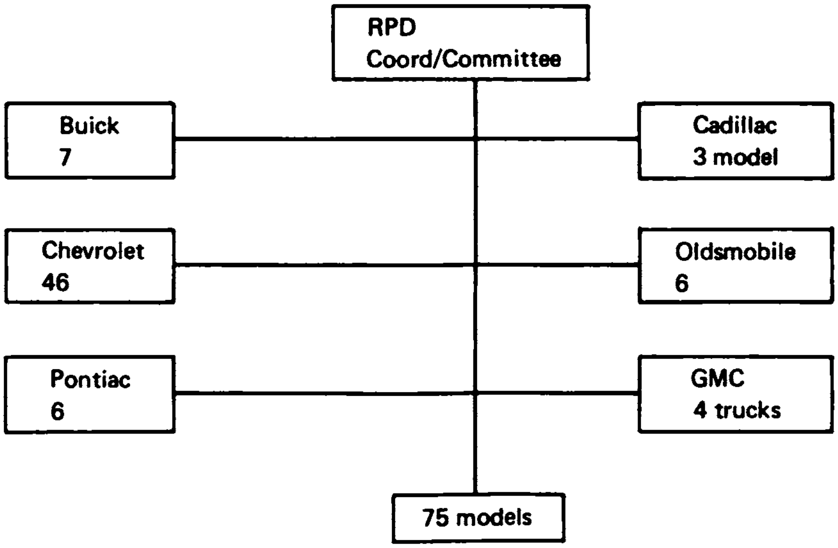
j. Final - altitude tests - Colorado

k. Production release late 1974

l. 8000/day by 1975 Apache 2 barrel

m. 1973 - start 1976 - 4 barrel for 30,000/day production

GENERAL MOTORS



MODEL CONFIGURATIONS

Apache - 6 models (85 - 4 barrel in test
2 barrel
95 samples under test)

New design carburetors

New die castings

New tooling

New equipment

New computer A/F test line

Significant components	Available
Air Horn (8000/day production)	1974
Float bowl	1974
throttle body	1974
choke	1974
Assembly and calibration	1973 - 1975
Screw machines	1973 - 1974
Purchased parts	1974

Tools, Dies and Equipment	Lead Time
Die cast molds	48 wks
In line machinery ($1,000,000)ea	58 wks
Assembly conveyors	52 wks
Subassembly duals	54 wks
Punch press	45 wks
Function test conveyors	64 wks

Status

1. Long lead time items are ordered
2. Calibration units are in design
3. Building - Nov. 1973 200,000 sq. ft.+
4. Phased production plan is planned to assure 1975 carburetor availability

Quick heat manifold system EFE

EFE (early fuel evaporation)

Purpose to vaporize the fuel as quick as possible during the first 2 minutes from starting -

principle is to use exhaust gas to preheat a stove or stove plates

Exhaust manifold heat control valve is used to transfer exhaust heat to stove plate. Time 10 sec at idle to achieve 270°.

Heat riser valve is controlling the exhaust gas flow.

Choke can be removed in 5 seconds

Manifold - design resulted in 62% reduction of EGR

Stove - expanded metal

STATUS - EFE system status

Hot plate - design - material

Heat flow - 8 cyl - 6 cyl

Gasket development - EFE plate

Heat Riser Valve

Intake manifold

Evaluation of EFE (Altitude performance)

ADVANTAGES OF EFE

a. Emission reduction

b. Has low mileage data

Schedule for EFE

Start components	2/17/72
Tooling	3/1/73
Production tooling	6/1/73
Start production	3/15/74
Full production	6/3/74

Converters

Hard dies are made - 1400 Total Quantity

Press line design

Engineering for Equipment

Floor space is available

Presses are available

Catalyst suppliers will be released very shortly
(Bead - Monolithic)

American Lava - has too many problems

GM Monolith - Ceramic

AUTOMOBILE MANUFACTURER
STATUS REPORT
CHRYSLER

July 19, 1972--1975/1976 Configuration and Manufacturing Status Review- Chrysler- Detroit, Michigan

Members Attending: M. Nelles, M. Ebner, L. Lindgren, and G. Clayton
J. Nolan, NAS

Chrysler Managers:

Mr. S. Terry - V.P. -Safety and Emissions
Mr. Sorensen - Emission Project Engineer
Mr. G. Lacy - Project Engineer
Mr. Arnold Hardie - V.P. - Purchasing
Mr. Engel - Engineer Chassis
Mr. Robert Steer - Power Train Engineer
Mr. Jack Woodrow - Exhaust Emission Engineer

Mr. Terry reviewed Chrysler's current status for 1975 and 1976 and summarized the status as follows:

1. The 1975 configuration is almost firm.
2. The catalyst is the critical path item.
3. The decision between pellet or monolith catalyst is dependent on final test data.
4. The 1976 configuration will probably be a dual catalyst.
5. The 1976 manufacturing plans are vague.
6. Chrysler is pursuing a noble metal catalyst with Johnson-Matthey and others.
7. The platinum negotiations are complicated as discussed later.
8. Chrysler is still working on a base metal catalyst but if Chrysler failed with a base metal catalyst then EPA would criticize the Chrysler position.
9. The 1973 cars have been certified so the general feeling at Chrysler is one of confidence that they can meet the requirements each year.

10. Many 1975 configuration changes are being incorporated into 73-74 models so that the changeover impact is gradual.

11. Chrysler is working on other engines on a limited scale. These engines are Wankel, stratified charge, and turbine. No R/D work is allocated on Diesels. Additional data:

    a. Wankel - Chrysler has no manufacturing plans for the Wankel. They have no foreign arrangements. In the past Chrysler concluded that the Wankel advantages did not warrant R/D investigation. Chrysler is reconsidering the Wankel now.

    b. Stratified-charge - Chrysler has participated with TACOM testing the 1976 MUTT Engine. Chrysler has no plans for producing a Stratified Charge engine.

    c. Diesel - Chrysler has considered the Diesel but because of noise and smoke problems they have not pursued the design. They realize that it can meet the 1975 standards but they feel that future legislation regulating noise and smoke will put the 76 Diesel out of contention.

    d. LPG - Fuel Engines - Chrysler has no production plans for LPG due to safety hazards.

12. CRC - Coordinating Research Council - A study by EPA A.D. Little- Cambridge has defined the problems related to odors and smoke as generated by a Diesel. This study has related some of the problems to fuel chemistry as it is generated in the combustion chamber of a Diesel.

13. The California Morse Std of 70 DB is going to make the Diesel design an impractical approach even though the emissions could be met.

The engineering and manufacturing groups reviewed the status of the designs and the manufacturing plans.

1. The carburetor developments are

    a. Vacuum-modulated enrichment

    b. Mechanical stepup control
    c. A/F control throughout the driving cycle
    d. The 318 CID engine will have solid fuel metering for 74 models with 4 BBL staged carburetors

2. The 1973 configuration is
    a. EGR System has pointed vacuum control and amplified vacuum venturi control
    b. OSAC Control
    c. Electric choke for cold driveability
    d. Revised air pump designs
    e. Hardened induction valve seats
3. Further developments are
    a. Electronic fuel control
    b. Electronic EGR controls (hand wire programs)
    c. Carburetor--variable venturi control
    d. Staged dual carburetor
    e. Electronic spark advance control
    f. Vendors related to these developments are Bendix, Bosch, and Carter
4. The 1975 Configuration Status is as follows:
    a. The catalyst data that are resolved
        1. Shape- oval vs. round section
        2. Volume- L/D
        3. Platinum content .2% Chrysler-Ford .35%
        4. Car design body resolved for A B C bodies
        5. By-pass requirement eliminated
        6. Double wall pipe eliminated
        7. Partial thermal reactor eliminated
    b. The unresolved problems for 1975 are
        1. Endurance level capability of system and catalyst
        2. Temperature level capability of catalyst

        3. Degree of control required for altitude compensation
        4. Need for a temperature probe
        5. Fuel and Oil poisoning
        6. Final protection requirements for converter container design
    c. A base metal pebble catalyst is not being considered

5. 1975/1976 Performance Status
    a. Low mileage performance to standards have been achieved
    b. High mileage durability and performance not known
    c. General field operation data and testing still are major concerns

Mr. Arnold Hardie, V.P., Purchasing, reviewed the current and future status of negotiations with vendors, catalyst manufacturers, and platinum vendors. He related the following data:

1. As of May 19, 1972, the final design specifications for a catalyst are not defined by Chrysler.

2. The noble metal companies are not in position to make an investment in equipment and product.

3. Chrysler is going down both design paths for catalysts (pebble and monolith designs) so two manufacturing facilities would be required.

4. Platinum requirements are negotiated with Johnson-Matthey-South Africa and J. Ahren - agents for Elmas Precision Metals-Russia.

5. Substrates are being made by American Lava. Corning has failed to deliver a satisfactory product to Chrysler.

6. Chrysler estimates using 700 oz/day @ $400/oz or $28,000/day for 7000 cars/day.

7. The converters being considered with vendors are the 180 cu in. and the 260 cu in. designs. The Engelhard-type converter (monolith) is planned for the 6-cylinder engines.

8. The air pumps (Saginaw) being considered are

   a. 19 cu in. now in use
   b. 26 cu in. being considered
   c. New design 30 cu in. now proposed because they have found that more air is needed as the catalyst deteriorates and also because the oxidation requirements increase for the 1976 configurations.

9. The 1976 NO_x requirements and status are
   a. Catalyst - location and size not defined
   b. Deterioration data not fully determined
   c. Control system for NO_x not developed

Appendixes to the Report on Manufacturability and Costs of Proposed Low-Emission Engine Systems
http://www.nap.edu/catalog.php?record_id=20393

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APPENDIX XI

COMPUTER SIMULATION OF HYPOTHETICAL AUTOMOTIVE IMPLEMENTATION PLAN

(August 21, 1972)

COMPUTER SIMULATION OF IMPACT ON RESOURCES OF PANEL'S PROJECTED 1976 IMPLEMENTATION PLAN

The broad mission of the Panel on Manufacturing and Producibility was to evaluate the technological feasibility of meeting the 1975-76 light-duty vehicle emission standards from the producibility point of view. This was to include not only a consideration of the technical possibility of building promising low-emission engines, but also an evaluation of the costs involved. In previous sections of this report, producibility and costs of several individual engine types were discussed. It is likely however that no single engine will prove suitable for all sizes and types of automobiles, but probably several new low-emission engine configurations will phase in to replace the different sizes of spark-ignition piston engines now offered. Clearly, different schedules of phasing in the various new engines and phasing out the conventional engines would result in different impacts on the resources required to build both the old and the new engines. Some of these schedules may be quite easily implemented, while others may be impossible because of the drastic requirements they would place on one or more resources. A production schedule of this latter type would be technologically infeasible.

A computerized simulation model was developed to deal with the complexities of the feasibility study. The simulation model is a computer-based system that can deal with the complexities of the production schedule of mass produced automobiles. The purpose of the model is to isolate the significant resources, namely, plants, production, transfer lines, foundries, materials, and manpower that would be impacted by the production schedule. The number of resources studied was 22, the number of body components was 50, and the number of engine components was 50. Because of the number of car types and configurations being considered in this study and the possible combinations of engines and bodies, the permutations became large. Thus a study at this level of detail is virtually impossible to do manually.

The model's function is to simulate a specific automotive production schedule and the industry-associated costs that would impact the related resources by time period. The model is capable of taking a production schedule by car configuration including quantity and the year required to explode these requirements by time period to the components and resources maintaining traceability back to the specific car configuration.

The Panel selected five engine types to be used in the model that will probably be used in motor vehicles of 1976. We then combined the engines with seven body types into seven configurations for each given engine type.

In the implementation plan we selected 26 car configurations because we made some assumptions that certain engines would not be installed in specific body types. Major components of the engine were selected that would have a corresponding significant resource associated with the manufacturing of that component. The same procedure was used in the selection of components that make up the body assemblies. This gave us 50 components for engines and roughly 50 components for body assemblies. These 100 components are then chained to about 22 significant or manufacturing resources.

The data base was established for each of the components for the engine and body assemblies and a data base was also selected for each of the resources. Then the logical structuring of each of these resources for each car configuration were chained together. This chaining is called a product structure.

The production schedule then used these data bases to create specific time phased requirements that are stored in memory, chained to the specific year required and the car configuration that will use the requirement. A production schedule was established to phase in the various configurations in the proper time frames. The schedule is based on a set of assemblies established by the Panel that were obtained during the visitations to the automotive industry in the United States and in Europe. No attempt was made to identify specific companies.

The output of the model is a display of the impact of the production schedule on the 21 major manufacturing resources that were established in the resource data base. These displays had to be analyzed for the various options that could be developed for each resource. Since each resource will be affected differently from this production schedule, the question is whether production lines that are currently available have to be scrapped and replaced by new production lines or whether a new facility has to be built and when. We then can evaluate what investments will be required and what resources will become excess and what their investments represent. We can also evaluate what added manpower will be required, transferred, or not required.

In summary, the model can be used for various alternative schedules and the data base can be modified to alter costs and lead times and structure. Any number of alternative schedules could be run and then analyzed for their resultant impacts and then compared for the significant changes of the impact on resources.

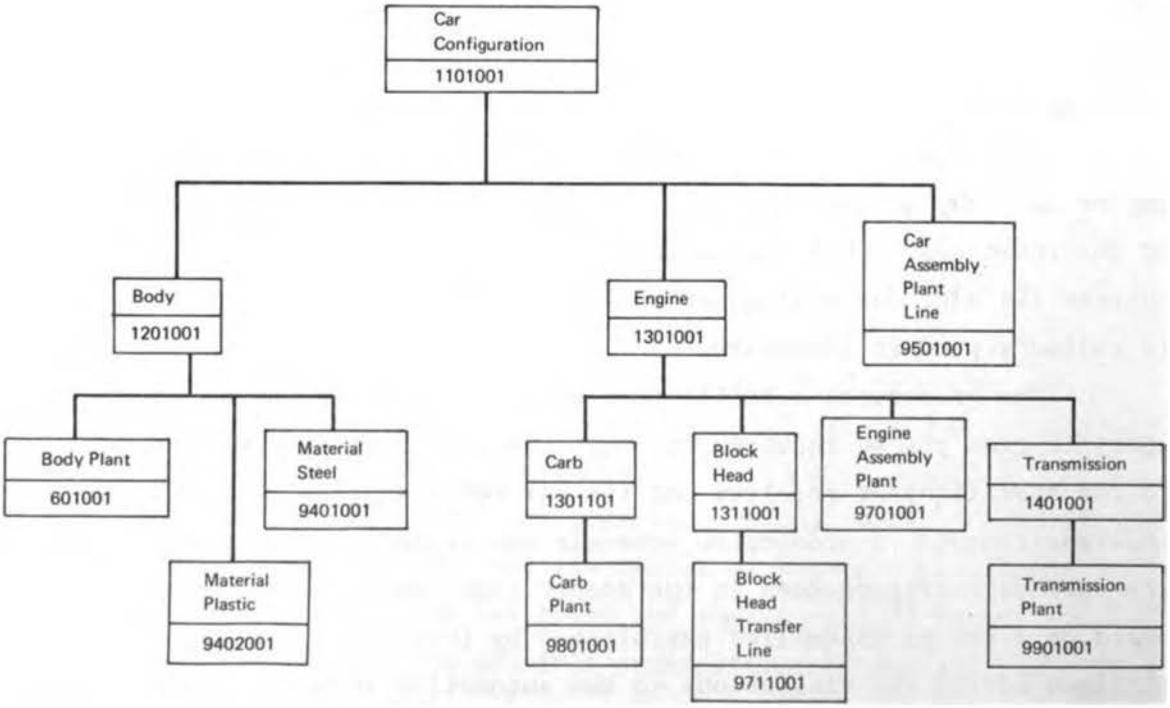

FIGURE XI-1 Parts explosion and associated resources as organized in the computer simulation.

SIMULATION OF PROJECTED IMPLEMENTATION PLAN

The implementation plan for this application used the following car configurations:

1975/1976	Spark-ignition internal-combustion engines
1978	Fuel-injection internal-combustion engines
	Light-duty Diesel internal-combustion engines
	1-, 2-, and 4-rotor Wankel internal-combustion engines
	4-cylinder stratified-charge fuel-injection internal-combustion engines

The volume mix will be based on the 1970 production data produced in the United States as follows:

CID	Car Configuration	Engine	Production/Year
153	Subcompact	4-cyl	100,000
170-200	Compact	6-cyl	400,000
225-250	Intermediate A	6-cyl	1,500,000
302-318	Intermediate B	8-cyl	2,000,000
340-360	Standard	8-cyl	3,000,000
383-402	Standard/Luxury	8-cyl	2,000,000
426-500	Luxury	8-cyl	1,000,000
			10,000,000

The product and resource data base and the structures were defined for each configuration using a significant retrieval number system. The data base included lead times, labor and material costs, and the sticker price value of end items and the major assemblies. No attempt was made to compute overhead, profit, or pricing markups. The sticker price includes the basic car prices and an average group of accessories, such as air conditioning, power brakes and steering, and average trim and interior accessories.

The Implementation Plan was developed from data used in the National Academy of Sciences report dated July 1, 1972, for the 1975/1976 car configurations. The Wankel and Diesel schedules are assumptions based on published data. The stratified-charge engine data are based on a production plan assumed for a 4-cylinder engine similar to the TACOM MUTT engine.

The resources (facilities and plants) were limited to those producing the major assemblies and components. A consolidated inventory of these major resources was used as follows:

Resource	Quantity	Production/Year Car Equivalent Units
Car assembly plants	43	250,000
Car assembly lines	44	250,000
Body assembly and stamping plants	28	360,000
Engine assembly lines	35	300,000
Engine block transfer lines	30	330,000
Foundry facilities	13	770,000
Foundry production lines	22	450,000
Carburetor plants	5	2,000,000
Ignition plants	6	1,700,000
Transmission plants	8	1,250,000
Steering manufacturing plants	4	2,500,000
Battery and alternator	4	2,500,000
Forging plants	4	2,500,000
Component manufacturing plants	60	170,000
Air pump manufacturing	1 (need 1)	5,500,000
Converter manufacturing	0 (need 4)	2,500,000
Catalyst manufacturing	0 (need 4)	2,500,000
Substrate manufacturing	0 (need 4)	2,500,000
Fuel injection pump plant	0 (need 2)	400,000
Turbocharger plant	0 (need 1)	400,000
Tools and dies	4	2,500,000

The vendors for supply parts for older models are not included in these resources. No allowance was made for spares and part production in this simulation. We were interested primarily in measuring the impact of an implementation plan of the various car configurations on the specific resources. Any expansion of the production plan due to growth forecasts or aftermarket forecasts would be a simple matter of expanding the product data base to include other vendor resources.

The alternative engines such as Turbine, Stirling, and Rankine configurations can be added using the same concepts of data base and structures.

TIME-PHASED RESOURCE INVENTORY MANAGEMENT

OVERVIEW

Objectives

The primary objectives of the system are to provide a high level of analysis and a reliable supply of data to various resource operations. The key design concept, which is expected to produce the desired results, is the response to time-phased resource requirements. It utilizes specific requirements which take the form of nonlinear interactive multi-variable relationships.

System Specifications

The system specifications may be summarized briefly as follows:

1. A complete data base of currently maintained information, such as:

    a. Planning for future capacity requirements in terms of men, machines, money, and materials.

    b. Comparison and evaluation of the actual performance against the forecast.

2. Netting the time-phased master production plan, which may be based on a forecast, as well as individual actual requirements against the resource inventory provides a longer planning horizon.

3. The status of any implementation plan can be determined more accurately since all action pertaining to each subelement is recorded in the files.

4. For forecast evaluation purposes, end-item and repair or spares demand are treated separately. The two are consolidated for economic analysis.

5. The system can develop unique end-item configurations from standard bills of material by incorporating add and delete capabilities in the processing of requirements. It is not necessary to alter the data base to do this.

COMPUTER FILES

The system uses three basic files: Item Master, Requirements/Replenishments, and Product Structure. File layouts are included at the end of this section. All are disk files.

1. Item Master

The Item Master File is a control sequential file organized under the Bill-of-Material Processor System. There is a record for each part for which a number has been assigned. The system cannot process a transaction unless there is an item number and that number has been entered in this file. The records contain standard data (description, cost, etc.) for each part as well as the on-hand balance at the prime storage location. In addition, it contains "chain linkages," which permit access to the Requirements/Replenishments and Product Structure files.

One of the unique features is the inclusion of two additonal record types in the Item Master File. One is a Control Anchor Record, which contains the start of address chains of records processed today. This "activity chain" is followed by the Order Action and Netting Program for extremely fast retrieval of those records that must be reviewed for order action. Secondly, a series of Order Anchor records are included that point to the first record for each order in the REQREP file. A continuing chain within that file permits rapid retrieval of all records associated with a particular order and determines the status of every item.

2. Requirements/Replenishments File (REQREP)

The REQREP File is a direct access file; records can be retrieved only by first accessing the Item Master or Order Master and using the "chain linkages" contained in these files. The REQREP File contains many different types of records, each serving a unique purpose.

a. Forecast Record (not a "sales forecast," but a master production plan based on backlog extended by a sales forecast)

There is one record for every four periods of the forecasted production plan. The period is variable (week, month, quarter), and there is no limit on the total number of records. It is possible to enter a two-year production plan by week by entering 26 cards with the dates 4 weeks apart. Actual requirements (customer orders) are summarized by period and entered on the forecast record, permitting comparison of actual to plan.

b. Customer Requirement (End Items)

An individual requirement record for each line item of a user order is created and maintained on the file. When resource requirement is completed on this plan, the "net" from inventory takes place. Requirement records show an "issued" status when the issue transaction is received and are deleted from the file when the order shipment takes place.

c. Customer Requirement (Repair)

Repair requirements are handled in much the same way as end-item requirements. They are assigned a different record type because they frequently receive priority in accordance with user policy.

d. Unplanned Requirement

This is any nonuser requirement--the part is required for internal use, such as an R&D project. It receives the lowest priority and is not netted against the forecasted plan.

e. Assembly Order, Resource Order, Purchase Order
These orders are replenishments that have been placed to satisfy requirements. A record is created automatically and is activated as a firm order upon the return of an order action card by Monitoring Control. The order is exploded (if necessary) to create requirement records at the next lower level, where the treatment is similar to User Requirements--End Item.

3. Product Structure File
The Product Structure File is also a direct access file, which requires the chain linkages in the Item Master to retrieve records. There is an individual record in the file for each assembly/component relationship that exists. This file provides the capability to "explode" requirements to lower levels and to print Bills of Material. Similarly, it permits "implosion" for where-used analysis and cost buildup. There are some limitations imposed on the system by the use of the master/chain-file-management technique.

a. Chain file records cannot be created until the associated master file records have been created.

b. Master file records cannot be deleted until all associated chain file records have been deleted.

IMPLEMENTATION PLAN

The Implementation Plan is based on the following set of assumptions:

1. The 1976 car configuration required to meet the 1970 Clean Air Act will be introduced in 1975 replacing the 1975 car configuration. The 1976 configuration will phase out because of the introduction of an improved V-8 fuel injection system.

2. The 4- and 6-cylinder configurations for spark ignition internal combustion engines will be replaced by 1- and 2-rotor Wankel Rotary engines.

3. The Diesel engines with 4- and 6-cylinder engines will be introduced for fleet car usage, because they have an improved fuel economy and a low maintenance and will not require a catalytic converter. This engine is assumed to have cost-effectivenss benefits for high mileage urban applications, such as cabs, vans, and pickup trucks used in the major cities where pollution of $HC/CO/NO_x$ is a major problem.

4. The Stratified-Charge engine configuration is introduced for the 4-cylinder engine to compare costs and to offer an alternative engine to the Diesel. The data base includes the various stratified-charge car configurations, but the Implementation Plan was limited to the 4-cylinder engine.

5. The improved fuel injection and computerized control system for the emission system was assumed for a 1978 V-8 engine. This is the V-8 that would replace the 1976 V-8 engines in 1977.

The Implementation Plan production schedules are based on assumptions using industry lead times and current status information on the various engines.

INVESTMENT ANALYSIS

Analyzing the output documents from the computer model illustrates the effect of the Implementation Plan on the body and stamping manufacturing facilities in the automotive industry.

The Implementation Plan for the 1976 car configuration created a demand on the subcompact body plant. The available plant covers the 1973-1974 production, but in 1975 we show an excess plant (investment \$99 million). The tools and dies for this plant are not usable for the new Wankel engine car, but the machinery, equipment, and building can be converted. The decision from this analysis indicates that this plant will be used for a new Wankel engine body. Similarly, the current facilities for the intermediate, standard, and luxury bodies can be converted by investing in new tools and dies for 1975-1976 production. The automobile industry can use the current tools and dies through 1975-1976 if the delivery of the new tools cannot be met by modifying temporarily the current bodies to fit the Wankel engines and drives.

The investment printouts are revised after the analysis of all the facilities has been made. Each facility is similarly analyzed. The computer programs cannot be designed to make the various manufacturing alternative decisions that are possible in the "real world." The programs can produce the proper data in the proper time frames, and then a realistic decision can be reached by managements and analysts.