Integrating R&D Efforts

A Report of The
National Petroleum Council

June 1988

NATIONAL PETROLEUM COUNCIL
1625 K Street, N.W., Washington, D.C. 20006 (202) 393-6100

June 8, 1988

The Honorable
John S. Herrington
Secretary of Energy
Washington, D.C. 20585

My dear Mr. Secretary:

On behalf of the members of the National Petroleum Council, I am pleased to transmit to you the enclosed report entitled Integrating R&D Efforts, as approved by the Council on June 8, 1988. This report was prepared in response to your request of July 2, 1987.

In the course of this study, the Council conducted a survey of U.S. petroleum and service companies to determine current and historical levels of oil and gas exploration and production research and development (upstream R&D). The results are reassuring; private-sector upstream R&D funding in 1988 will be more than $1 billion. Further, the survey shows a decline of only about 20 percent since the peak year of 1985 despite the far steeper decline in oil prices. The Council also reviewed current government-funded geoscience R&D programs that can be considered broadly related to oil and gas exploration and production. Expenditures on these programs will approach $500 million in 1988.

The industry survey supports two additional conclusions. First, industry is addressing all research areas identified as having high priority, and no areas of importance were identified that are not being covered by current efforts. Second, there appears to be some industry support for additional funding ($1-5 million) for increased cooperative R&D among industry, government, and academia.

Rather than recommend a major "all in one" petroleum research institute analogous to the Gas Research Institute, the Council recommends two complementary but more modest initiatives that will integrate R&D efforts and promote cooperation and coordination. These are: (1) the establishment of an industry forum to facilitate cooperative R&D projects; and (2) the selective increase of support for multidisciplinary university R&D efforts. Your new Office of Geoscience Research might coordinate requests for matching funds that might arise from operation of the proposed forum as well as requests from multidisciplinary university and other efforts.

The National Petroleum Council believes that the operation of a forum as proposed will provide industry advice on projects seeking matching government funds. Industry support of projects through financial contributions is the most important evaluation of the relevancy of the proposals.

The National Petroleum Council is pleased to be able to serve you and our nation. We sincerely hope that this study benefits you and the government in its effort to integrate its initiative in U.S. oil and gas research and will, ultimately, increase U.S. oil and gas recovery.

Respectfully submitted,

Edwin L. Cox

Edwin L. Cox
Chairman

Enclosure

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C. J. Silas, Chairman, Committee on Establishing a Petroleum Research Institute

NATIONAL PETROLEUM COUNCIL

Edwin L. Cox, *Chairman*
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U.S. DEPARTMENT OF ENERGY

John S. Herrington, *Secretary*

The National Petroleum Council is a federal advisory committee to the Secretary of Energy.

The sole purpose of the National Petroleum Council is to advise, inform, and make recommendations to the Secretary of Energy on any matter requested by the Secretary relating to petroleum or the petroleum industry.

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INTRODUCTION

In 1987, the United States consumed 16.5 million barrels of oil per day (MMB/D) but domestic supply was only 10.6 MMB/D. Various studies by the National Petroleum Council (NPC) and others have pointed out the growing level of U.S. dependence on foreign oil supplies. The Energy Information Administration's (EIA) 1988 base case forecast is for petroleum imports to rise from the 35 percent level of 1987 to 51 percent in 1995 and 55 percent in the year 2000.[1]

The increase in imports by the year 2000 is caused by the combination of an estimated 1.8 MMB/D increase in demand and a projected 2.2 MMB/D decrease in domestic supply. The EIA supply projection includes production from current booked reserves, improved recovery of oil in known fields, and new discoveries. Implicit in the EIA projections are the cumulative effects of extensive industry, academic, and government research and development (R&D) efforts. Without these efforts, future U.S. oil supplies would be less. Conversely, there is the prospect that increased and/or better-coordinated R&D efforts will slow the projected decline in U.S. supply and thus reduce import dependence.

The United States has over 300 billion barrels of oil in known reservoirs that is not currently being recovered under the present economic and technological conditions. The amount of this oil that will ultimately become economically recoverable will not change the implications of the long-range petroleum outlook. However, it is an attractive target and is the focus of extensive R&D activities.

By letter dated July 2, 1987, the Honorable John S. Herrington, Secretary of Energy, cited the need to "...provide an industry perspective relative to future integrated/coordinated research and development needs." In his letter, the Secretary requested the NPC to report on the "...first basic question of the advisability and feasibility of establishing a petroleum research institute [to address this need]." (See Appendix A for the complete text of the Secretary's letter.)

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[1] <u>Annual Energy Outlook 1987</u> (Washington, D.C.: Energy Information Administration, March 1988).

To assist in responding to the Secretary's request, the Council formed the Committee on Establishing a Petroleum Research Institute under the chairmanship of C. J. Silas, Chairman of the Board and Chief Executive Officer, Phillips Petroleum Company. The Honorable J. Allen Wampler, Assistant Secretary, Fossil Energy, U.S. Department of Energy, served as Government Cochairman of the Committee. The roster of the Committee is shown in Appendix B.

In developing its approach to the study, the Committee decided that it must first determine whether there are areas of oil recovery research that are not receiving adequate attention. The Committee was also concerned that the full extent of industry's internal R&D activities were not well known or understood. Accordingly, a survey was conducted of current and historical levels of exploration and production (upstream) research. The public accounting firm of Arthur Andersen & Co. was retained by the Council to collect the survey data. Arthur Andersen was instructed to hold all responses in strict confidence and to provide only aggregated data to the NPC. The aggregated results of the survey and a later addendum to the survey are discussed in Chapter Two and Appendices C and D.

This report contains the survey results and provides the Council's response to the Secretary's request.

SUMMARY AND RECOMMENDATIONS

SUMMARY

To aid in the assessment of the impact of additional R&D initiatives on domestic oil and gas supply and how best to leverage any additional funding, the NPC conducted a survey of its members. Detailed results are described in Chapter Two. In summary, the results lead to the conclusion that private-sector expenditures on upstream R&D in the United States will be on the order of $1 billion in 1988. In the course of this study, the NPC also reviewed available reports on public-sector research programs of relevance, e.g., earth sciences, satellite imagery, Arctic research, gravity and magnetics, and ocean sciences. Expenditures on these programs in fiscal year 1988 will approach $500 million. These programs are broadly related to petroleum geoscience because the fundamental knowledge they generate advances the general understanding of the geologic processes that govern oil and gas accumulation.

Upstream research spending of the oil and service companies that responded to the NPC survey grew steadily in the early 1980s and more than doubled in real terms between 1975 and 1985. When oil prices began to decline precipitously in late 1985, the 1986 spending plans of many companies turned from continued increase to sharp decrease. As prices continued to fall in early 1986, budgets were again cut and some major layoffs occurred. The cutbacks varied widely within the industry and it now appears that they were most severe in R&D activities outside of the industry's core business areas of oil and gas discovery and recovery. The cutbacks that occurred in the core areas tended to be the high cost, high risk areas such as chemical flooding and frontier exploration. R&D commitments stabilized in 1987 and 1988 at about 80 percent of the peak effort.

In 1988, the upstream research commitments of the oil and service companies responding to the survey total some $811 million and 6,500 man-years. Domestic upstream research is also being performed by private research laboratories and companies involved with chemical, software, and geophysical activities, as well as by other oil and service companies not included in the survey. It is estimated that including these firms would increase private-sector domestic upstream research to more than $1 billion from the $811 million reported by the survey respondents. Considerable research is also conducted internationally and much of this work becomes available for use in domestic operations. Total activity levels, therefore, are significantly higher than those reported in the survey.

The NPC survey also sought opinions on 78 specific areas of research in geoscience and enhanced recovery. These topics were identified in previous NPC, National Research Council, and Energy Research Advisory Board reports as being of potential importance in future oil recovery. The respondents were asked to provide an assessment of the priority of the research area and whether it was being actively pursued. The results indicate that the industry is focusing effort on those topics considered to be of medium to high priority. Even most of the areas that the industry, in aggregate, rated as low priority are being worked on by some companies. Furthermore, the respondents did not identify significant additional areas where major new initiatives would be required. There was, however, an expression of support for a modest program of cooperative research in the broadly based area of geoscience, with a strong preference for it to be industry led and controlled. The actual level of support by the industry will be dependent on the specific projects that are proposed.

From the survey responses, industry has a relatively equal distribution of funding between Exploration activity (29 percent), Reservoir Characterization and Enhanced Oil Recovery (EOR) (34 percent), and Other Production R&D activity (37 percent). Because of the highly competitive nature of exploration for new reservoirs, it was not considered likely that industry would involve itself in much cooperative research in this area. However, since improved recovery through better reservoir characterization and EOR mostly applies to properties already under production, cooperative research is potentially more acceptable. Some topics, of course, are sufficiently general in nature to apply to both exploration and development. Other Production R&D covers a broad spectrum of activities, much of which is already approached cooperatively by industry, e.g., drilling, environmental, and offshore research. Thus, the main thrust of this report focuses on improved reservoir characterization and EOR aimed at increasing recovery from already discovered reservoirs.

With the large quantity of oil currently considered as unrecoverable in the domestic reservoirs (estimated to be over 300 billion barrels), and restricted opportunities to explore in many of the frontier areas, it has become increasingly important to the nation and to the industry to improve recovery from the known resources. Improved capabilities in reservoir characterization leading to additional drilling opportunities could have a significant impact, although this has not been quantified. Previous studies by the NPC, though, have identified the range of production rates likely to result from the application of enhanced recovery technology. While this is dependent on factors such as crude oil price, government regulation, and the rate of development of technology, the general conclusion is that domestic EOR production might reach 1 MMB/D by the year 2000, compared to today's production rate of 0.6 MMB/D. Although this will only partially offset the requirement for oil imports, nevertheless it is important to both the nation and the industry.

Results from the present study indicate that industry may well be in a position to increase cooperative research on some specific projects, especially with a focused drive to facilitate such efforts. It is not expected, though, that cooperative joint research would increase dramatically over the current level in view of the large and continuing industry efforts now being pursued. While recognizing that cooperative research efforts will potentially be of benefit, individual companies are faced with balancing this against the stewardship concern of being dependent on outside entities for research important to full development of a company's resource base. Companies with major research programs are not likely to cease such programs to enter joint projects, nor are they likely to continue such programs and simultaneously support broad-based cooperative research programs in areas important to a company's overall future. Because of the importance attached to research directed toward increased oil recovery, individual companies voluntarily participating in joint projects will usually want to exercise substantial control over the scope of the individual projects. Any mechanism established to increase cooperative research should make provisions for reasonable control by industry participants.

RECOMMENDATIONS

In response to the Secretary's request for the NPC to report on the "...basic question of the advisability and feasibility of establishing a petroleum research institute," and based on the findings of this study, the NPC does not recommend establishment of a national petroleum research institute modeled after the Gas Research Institute as described in his July 2, 1987, letter. However, the NPC recommends two related but different areas for increased cooperation between industry, academia, and government that would effectively enhance the future integrated and coordinated R&D efforts of this nation in increasing the recovery of oil and gas from already discovered reservoirs. These are:

- <u>An industry forum should be established to facilitate additional industry support for cooperative projects aimed at improving ultimate oil recovery</u>. The forum would serve as a vehicle for proposed projects to be presented to interested parties with participation to be on a voluntary basis.

- <u>Support for multidisciplinary research in universities should be encouraged with modest funding increases in selected areas</u>. This is in recognition of the desirability of integrating efforts across the disciplines that contribute to resource definition and improved hydrocarbon recovery, i.e., geology, geophysics, engineering, and related sciences.

The proposed industry forum and the multidisciplinary research projects are seen as complementary efforts. It is anticipated that synergy would develop between the two activities, with the forum providing a vehicle for universities to seek industry funding for multidisciplinary projects and industry having improved access to the existing research organizations in academia.

Although it is probable that a focused increase in cooperative research will result in increased oil production, it must be recognized that the resultant sustaining contribution to U.S. domestic oil production will be far from sufficient, in and of itself, to resolve the future energy problems of the nation. Any increase in research funding is not a substitute for other policy options that could also significantly improve oil and gas production, such as opening government lands to exploration and eliminating disincentives in the tax laws.

DISCUSSION

Industry Forum

The proposed industry forum would be designed to facilitate participation in cooperative research projects. This forum, or clearinghouse, would contribute to the national petroleum research effort by serving as a vehicle for proposed cooperative research projects to be presented to interested members, and by providing industry with a mechanism to stimulate research proposals in areas that could be addressed by cooperative research. Participation in each research project would be on a voluntary basis; however, it is anticipated that the forum would increase the current level of cooperative research by enabling project sponsors to obtain funding more readily and by stimulating additional proposals. A similar forum, conducted by the Lease Planning and Research Committee of the Alaska Oil and Gas Association has been effective in facilitating research related to petroleum operations in the Arctic during the past 10 years. More recently, the Drilling Engineering Association established such a forum to sponsor cooperative research in the area of drilling. Some 25 companies are members of the U.S. chapter, with a European chapter formed in 1987. From 1983 through 1987, 49 projects were formally proposed to the membership with some 30 projects supported at a total cost of over $6 million.

The specific operating principles and procedures of an industry forum should be developed after its establishment. It is anticipated, however, that the forum would generally operate as follows:

- Meetings would be held periodically at locations most appropriate to the membership for the purpose of discussing proposed cooperative research projects with interested members of the forum.

- Project sponsors would submit proposals to forum members for consideration. The terms and conditions of participation would be arranged between the project sponsor and potential participants. The forum might provide a standard agreement for use if the sponsor chooses.

- Proposals could be submitted by any qualified entity, with qualifications to be determined by the members. It is expected that forum members, academic institutions, consulting organizations, contractors, and independent research laboratories would submit proposals.

- Participants would elect to join projects on an individual basis. A project would be considered funded when the participation level met the project sponsor's minimum requirement. The interest expressed by industry in funding various proposals could serve as one measure of industry's evaluation of priority and importance of the research objectives of the proposal.

- The decision to seek additional funding from the Department of Energy (DOE) or other entities would be made by the project sponsor in conjunction with the participants. The forum would only maintain information and records regarding total funding and status of projects.

Research projects that industry would elect to fund on a cooperative basis would most likely be focused in areas that do not offer a strong competitive advantage to participants, with highly proprietary activities continuing to be pursued individually by the member companies. As discussed in Chapter One, the nature of the oil industry is such that, in time, most of the technology is shared throughout the industry. While it is anticipated that the forum would attract mostly applied research projects, any project sponsor that wished to solicit funding for a more fundamental research project should be encouraged to do so. Administration of the forum would be most effectively handled as an adjunct to an existing industry organization such as the NPC. The forum would require a director, possibly full-time, responsible for organizing and conducting the functions of the forum. The parent organization could provide secretarial and administrative services and funding of the administrative expenses. It is likely that an industry steering committee would be desirable to provide input and direction to the forum.

Multidisciplinary Research

Although the above described forum would contribute beneficially to the challenge of improving overall oil recovery, a gap would still exist between the more applied forum-sponsored activity and the traditional support for research of a more fundamental nature. In particular, there has been a growing trend in the academic community to establish multidisciplinary programs that integrate geology, geophysics, engineering, and related sciences in order to obtain an improved definition of the hydrocarbon resource and maximize its recovery. This emphasis builds on the experience of industry and other research organizations, which has demonstrated the effectiveness of a multidisciplinary approach to improving oil recovery, both in research and in field applications. The trend in academia has resulted in a number of recent research programs and proposals; e.g., the Stanford Center for Reservoir Forecasting, where industry supports coordinated research between the Departments of Geology, Geophysics, and Petroleum Engineering; cooperative research of a similar nature at the University of Texas and Colorado School of Mines; and the recently formed Geoscience Institute for Oil and Gas Recovery Research, which has the goal of coordinating multidisciplinary research between several different universities and state organizations.

Industry presently supports petroleum-related disciplines at universities through grants, fellowships, and selected research involvement. These university programs, that in turn support the petroleum industry, have been severely affected by the industry's downturn and will probably require additional support to ensure their future viability. The proposed forum and multidisciplinary efforts discussed would assist universities in their ability to provide an adequate future supply of technologists for industry.

While considerable funding may be available within individual areas of geoscience, the recent emphasis on integrated activities is largely outside the purview of the traditional funding sources. Although industry provides some support to these multidisciplinary efforts, they would potentially benefit from a greater focusing of the effort and additional funding by government and industry of a limited nature. Some of the principles that should be considered are as follows:

- Multidisciplinary research should be encouraged to most effectively leverage advances in the areas of geology, geophysics, engineering, and related sciences.
- Research should emphasize development of methodologies to improve the ability to characterize complex reservoirs in the subsurface.
- Encouragement should be given to long range research in high potential areas that have a reasonable chance of success, as well as to projects that would be useful to industry in the short term.
- Industry input should be solicited to assist in developing and prioritizing areas of important research.
- To obtain maximum participation by industry, the activities proposed for industry funding should be project-oriented rather than programmatic, with industry having the freedom to voluntarily participate in the direction of individual projects.

Presumably the application of methods and processes developed through this initiative could be commercialized through cooperative joint industry projects funded through the industry forum. The forum could also be used to solicit industry support for projects that would be proposed for matching DOE funds. In this fashion, synergy would be encouraged between the industry-led forum and the multidisciplinary research effort that would probably mostly reside in academic institutions.

CHAPTER ONE

OIL AND GAS RESEARCH AND TECHNOLOGY BACKGROUND

INDUSTRY RESEARCH

The domestic oil and gas industry consists of many private companies, ranging from a number of large integrated firms to thousands of small independent oil producers. In addition, the petroleum industry is paralleled by a large and diverse group of companies that provide vital support services to the petroleum companies in such areas as geophysics, drilling and well services, well surveying, computer hardware and software, process design, and construction. Although relatively few of the thousands of private petroleum companies actually carry out significant research, most of the larger oil and gas companies and many companies in related support services for decades have maintained large, broad-based oil and gas research programs, in some cases for 50 or more years.

Petroleum companies perform research because of the significant incentives to acquire and effectively develop resources and because of the potential edge to be gained in this highly competitive business, especially with respect to resource acquisition, the lifeblood of a resource company. Research performed by the support industries has been a major contributing factor to industry's steady technological progress. As might be expected, industry and support-company laboratories focus most, but not all, efforts on applied research and development. As discussed later, universities and private research institutions, typically with partial financial support from industry and government, provide a significant share of the more basic research needed by the petroleum industry. In addition to technology developed within the United States, domestic petroleum companies have access to the results of substantial research conducted in other countries.

UNIVERSITY AND GOVERNMENT-FUNDED RESEARCH

The active research programs of the petroleum industry and the support companies are augmented by substantial research efforts in universities and private institutions. It is beyond the scope of this study to analyze this research effort in detail or to accurately determine the level of funding. However, a brief description of this effort is provided below.

DOE funds a petroleum research program within the fossil energy budget. The funding level in fiscal 1988 is nearly $20 million, but budget levels for the program may increase as DOE provides matching funds for other programs. A much larger effort in the area of geoscience (geology, geophysics, and related sciences necessary to an integrated petroleum exploration and development effort) is funded by a number of agencies, as summarized in Table 1 and detailed in Appendix E.

The fundamental knowledge generated by this research effort advances the general understanding of the geologic processes that govern oil and gas accumulation. For example, data generated by the National Science Foundation's Ocean Drilling Program contributes to our understanding of tectonics and basin evolution. Deep seismic data gathering aids in defining the basement and determining the broad structural characteristics of basins. Knowledge of heat flow in the earth contributes to our ability to predict petroleum source potential. While these efforts primarily benefit exploration at the regional or trend level, they also enhance our ability to accurately define fields and reservoirs. Without a definitive study, one cannot estimate the total research funding that directly or indirectly benefits the petroleum research effort, nor can one be certain that all the pertinent activities are listed. It is clear, however, that funds on the order of $500 million per year are spent by the government on research broadly related to petroleum geoscience.

The university effort in geoscience and oil and gas recovery research is not limited to the government-funded programs included in Table 1. Additional projects are funded by private industry and other sources that address petroleum research needs.[1] The fundamental research conducted by the universities provides important support to the applied research conducted by the petroleum industry.

TECHNOLOGY TRANSFER

The result of this diverse and sustained activity has been steady, continuing technological progress in all areas important to the economic development of the nation's petroleum resources. Government and academic research is widely published and is available to the public. Additionally, while proprietary technology and the incentives to develop and acquire such technology remain important in the petroleum industry, the industry has traditionally supported a high degree of technology interchange, and petroleum technology has spread rapidly throughout the industry.

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[1] It is estimated by M. Milling, Texas Bureau of Economic Geology, that approximately $26 million was spent at universities in 1987 on oil and gas research programs.

TABLE 1

GOVERNMENT-FUNDED GEOSCIENCE PROGRAMS
BROADLY RELATED TO UPSTREAM RESEARCH
(Detailed program budgets are provided in Appendix C)

Agency	1988 Funding (Millions of Dollars) Total	Geoscience Program *	Activities
Department of Energy	142	~100§	Geothermal, Hot Dry Rock, Thermal Regions, Atmospheric Geosciences, etc.
National Science Foundation, Directorate of Geoscience	291	196	Earth Sciences, Ocean Sciences, and Arctic Research Program
U.S. Geological Survey	446	176	Geological and Mineral Resource
National Oceanic and Atmospheric Administration	1,216	40	Research in areas related to paleoclimate, world topography, and gravity
National Aeronautics and Space Administration	3,294	¶	Support to satellite imagery efforts
Office of Naval Research	9,500	4**	Projects in areas of oceanic circulation, world bathymetry, sediment velocity, and gravity and magnetics

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*Approximate funding level for activities directly or indirectly applied to petroleum geoscience.

§Geoscience projects, FY 1985 listing, DOE/ER-0277, reported in Geoscience Research for Energy Security (Washington, D.C.: Energy Research Advisory Board, February 1987).

¶Research activities related to petroleum industry are significant; however, allocation of expenditures related to geoscience is not possible without a more detailed investigation.

**Unclassified basic research in the $6.5 million Marine Geology and Geophysics Program only.

Several large and effective professional societies that relate principally to oil and gas contribute to technology interchange within the petroleum industry. These societies, which are listed in Table 2, have over 100,000 members and provide forums for dissemination of new technology in geoscience and petroleum engineering. In 1987, over 1,800 technical papers were presented and/or published at national, regional, and local meetings, workshops, and courses. In addition to these, numerous other professional societies and trade associations provide for exchange of research and technical information of importance to oil and gas. The petroleum industry has a long history of support for these organizations and their technology transfer efforts.

In addition, there are several other mechanisms that contribute to the wide dissemination of technology within the petroleum industry. Very few domestic oil fields are fully owned and controlled by a single company; rather it is common for many companies (large and small) to own interests in a single field. In order to carry out certain operations, such as enhanced recovery processes, these diverse ownership interests are typically merged into a single-unit operation under which all owners benefit by application of the latest and most effective technology.

In recent years, members of the petroleum industry, in various combinations, have conducted hundreds of joint research programs designed to develop research results of common interest. Groups such as the Drilling Engineering Association and the

TABLE 2

MAJOR PROFESSIONAL SOCIETIES RELATING TO PETROLEUM INDUSTRY

Society	Approximate Membership	Papers Presented in 1987
Society of Petroleum Engineers	51,000	1,000
American Association of Petroleum Geologists	39,000	800
Geological Society of America	16,000	
Society of Exploration Paleontologists & Mineralogists	7,000	
Society of Exploration Geophysicists	18,000	
Society of Professional Well Log Analysts	4,000	~ 80

Alaska Oil and Gas Association have helped to facilitate these cooperative programs. Recently, joint research within and without the petroleum industry has been encouraged by the National Cooperative Research Act of 1984. These joint programs have augmented the research programs of individual companies and have been an additional vehicle for the dissemination of useful technology.

The support companies are another conduit for the flow of technology within the petroleum industry. Many of industry's developments have been licensed for application throughout industry. Thus, for a number of technologies, all petroleum companies can benefit at a fraction of the cost associated with independent development. Of course, these support companies also carry out their own research and make their technological developments available to all at competitive prices.

The petroleum industry has access to a large body of professional consultants in every phase of the business. Many of these consultants were trained in industry and are available to provide a substantial body of state-of-the-art technology to those needing assistance.

IMPROVED RECOVERY TECHNOLOGY

Current oil production technology will leave a substantial portion of the oil in the reservoir at the end of the field life. It has been estimated that over 300 billion barrels of oil will remain in already discovered fields after conventional production operations are completed. It is recognized that only a small fraction of this potential is likely to be produced with improved oil recovery technology. This still represents a significant incentive for improved recovery; that is, the recovery of additional oil from already discovered fields by applying existing or new technology. Improved recovery is expected to come from two primary sources: enhanced oil recovery and unswept, mobile oil recovery. However, it is recognized that other new technology, such as horizontal drilling, may contribute to improved recovery. For purposes of this report, the following definitions are used:

- Improved recovery -- recovery of oil from already discovered fields that will not be recovered by conventional producing operations

- Enhanced oil recovery -- the incremental ultimate oil that can be economically recovered from a petroleum reservoir over oil that can be economically recovered by conventional primary and secondary methods

- Unswept, mobile oil recovery -- recovery of mobile oil that is bypassed or otherwise not produced by existing wells. To recover this oil, the accumulations must be defined and additional wells drilled.

The EOR target provides an incentive for research on EOR processes, while the unswept, mobile oil target primarily motivates research on reservoir characterization. This latter category requires an accurate reservoir description to define potential well locations where bypassed oil can be captured. An accurate reservoir description is also essential to the design of EOR projects.

The oil and gas research that has been conducted within the petroleum industry, as well as that conducted within university and government programs, has provided significant advances in both EOR and reservoir description technology. The EOR methods that have shown significant promise are classified in three general categories: thermal recovery, miscible flooding, and chemical flooding. EOR processes have resulted in over 300 field applications that currently produce 0.64 million barrels of oil per day. This represents 8 percent of current U.S. crude oil production. These three processes are briefly described below.

Thermal recovery processes involve the introduction of heat into a petroleum reservoir, usually by the injection of steam or the propagation of a combustion zone through a reservoir. Examples of such processes include steam drive, cyclic steam injection, and in-situ combustion.

Although related patents were issued as early as the 1920s, the development of in-situ combustion and steam injection processes began primarily during the 1950s. This initial development was closely followed by field projects, which were started mainly in the late 1950s and early 1960s. As shown in Table 3, the number of thermal recovery field projects in the United States more than doubled in the 15 years between 1971 and 1986. Likewise, as shown in Table 4, thermal recovery oil production has increased steadily. Thermal recovery is the most commercially advanced EOR process, accounting for 73 percent of the current U.S. EOR production. Approximately three-quarters of the current projects are being conducted on a field-wide basis.

Miscible flooding involves the injection into a petroleum reservoir of a material that is miscible,[2] or can become miscible, with the oil in the reservoir. The primary material considered for miscible flooding is carbon dioxide. However, nitrogen and hydrocarbon gases are also considered for specific projects. Industry practice includes a few projects in which gas injection enhances oil recovery by lowering viscosity or swelling the oil even though miscibility is not achieved. Pressure maintenance by gas injection is not included within the miscible flooding category.

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[2]Miscible means the solution of the injected gas in the reservoir oil in a single phase, characterized by the absence of interfaces between the fluids.

TABLE 3

NUMBER OF ACTIVE EOR PROJECTS

EOR Process	1971	1974	1976	1978	1980	1982	1984	1986	1988
Thermal	91	83	106	115	150	139	151	201	152
Miscible*	-	-	-	-	34	50	84	104	90
Chemical	19	18	28	46	42	85	138	206	124
Total	-	-	-	-	226	274	373	512	366

*Includes projects that achieve enhanced recovery due to swelling or viscosity reduction in addition to miscible fluid displacement. Does not include pressure maintenance by gas injection.

Source: Oil & Gas Journal, April 18, 1988, p. 47.

TABLE 4

U.S. EOR PRODUCTION
(Barrels Per Day)

EOR Process	1980	1982	1984	1986	1988
Thermal	255,610	298,624	364,560	479,669	464,905
Miscible*	74,807	71,915	83,011	108,216	150,047
Chemical	2,404	4,409	13,398	16,901	22,501
Total	332,821	374,948	460,969	604,786	637,453

*Includes projects that achieve enhanced recovery due to swelling or viscosity reduction in addition to miscible fluid displacement. Does not include pressure maintenance by gas injection.

Source: Oil & Gas Journal, April 18, 1988, p. 46.

The development and field testing of miscible recovery processes has continued since the early 1950s. Early focus of this work was on hydrocarbon solvents. The use of carbon dioxide for enhanced oil recovery began in the early 1970s. Since this time, the oil production from miscible gas projects has increased continuously, as shown in Table 4. Currently there are 90 miscible projects being conducted in the United States, accounting for 23 percent of the total current EOR production. More than half of these projects are being conducted on a field-wide basis. However, there are several small field pilots being conducted and, as indicated in Chapter Two, a significant amount of research is continuing on miscible processes.

Chemical flooding involves the injection of water with added chemicals into a petroleum reservoir. The major chemical flooding processes include surfactant[3] and polymer flooding.[4] Alkaline flooding[5] is also a chemical flooding process, although it is not as widely considered as the other chemical processes.

Research on surfactant-based recovery methods was initiated by several companies over 30 years ago. Polymer flooding research began somewhat later. This continuous research effort has resulted in an increasing number of field projects within the United States, as shown in Table 3. Although there are 124 ongoing chemical EOR projects in the United States, these projects account for only 4 percent of the current EOR production, mainly because the incremental oil production from polymer projects is typically low. In addition, most of the ongoing surfactant flooding projects are small field pilots, which is indicative of the stage of application for this EOR process.

RESERVOIR DESCRIPTION TECHNOLOGY

In order to maximize the economical recovery of oil from a field, or reservoir, it is necessary to accurately describe the reservoir. That is to define the areal and vertical extent, the presence of flow barriers, the continuity of individual reservoir formations, the amount of oil in place, and the fluid flow properties of the reservoir. Reservoir description technology that has been developed by industry and others includes 3-D seismic

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[3]Surfactants are chemicals that reduce the interfacial tension between the injected water and the reservoir oil to permit additional oil recovery.

[4]Polymers are large molecules that are added in injection water to increase viscosity and oil displacement.

[5]Alkaline materials react with components of certain crude oils to create surfactants in situ and reduce interfacial tension.

surveys, inter-wellbore measurements, individual well surveys -- both seismic and logs, geological mapping techniques, concepts of reservoir deposition and diagenesis, well testing, and core analysis. Industry and others have maintained very active research programs in this area. Several of the technical areas are reasonably mature, but emerging technologies are also important. Many geologic, geophysical, and engineering disciplines are involved in reservoir description; experience has shown that interdisciplinary studies are most effective in developing the best possible description of a reservoir.

There is no practical method of determining how much the improvements in reservoir description technology have increased U.S. oil production. It is clear, however, that the technology available today to define reservoir characteristics is far superior to what was available 20 years ago. Many of the U.S. oil fields were developed without use of the latest reservoir description technology. Due to inaccuracies in defining the reservoirs and in locating development wells, depletion of these reservoirs may result in areas or zones where oil is not effectively displaced to producing wells, leaving unswept, mobile oil. It is anticipated that application of state-of-the-art reservoir description technology, particularly in studies that effectively integrate geoscience and engineering, will increase recovery from many existing fields. Further research in reservoir characterization could increase the potential for additional recovery of unswept, mobile oil.

CHAPTER TWO

PRIVATE-SECTOR R&D -- NPC RESEARCH SURVEY

INTRODUCTION

The previous chapter noted some of the R&D expenditures of government and academia. This chapter describes the extent of U.S. petroleum industry research as found in a survey of petroleum research and development activities.

The NPC Oil and Gas Research and Development Survey was designed to provide information on the following questions:

- What is the level of industry spending on oil and gas research and development, and how has this varied with time?
- What is the level of manpower committed to this effort?
- How is the effort subdivided amongst the major research areas of enhanced oil recovery, reservoir characterization, other production research, and exploration research?
- What is the importance of these areas of research, in the view of companies responding to the survey?
- What is the current industry assessment of the importance of the specific research topics identified in earlier reports by the Energy Research Advisory Board, the National Research Council, and the NPC, in the view of those companies actively pursuing research in those areas?
- Are there areas of research that, in the view of the respondents, are not adequately addressed by current industry, government, and/or academic research programs?

Recognizing that the NPC membership contains a large and varied group of companies involved in oil recovery research, it was concluded that their responses would be representative of the industry as a whole. Accordingly, all industry members of the Council were invited to participate in the survey.

After the survey results were aggregated and reviewed, an addendum to the survey was sent to the industry members of the

Council. The addendum sought to quantify the industry's interest in possible new cooperative research activities that might be leveraged with federal funds. Opinions were also sought on the structure of an organization to coordinate such activities.

The public accounting firm of Arthur Andersen & Co. was retained to receive and aggregate the completed surveys under the agreement that no identifiable individual respondent data be revealed. A total of 63 companies participated in the survey, with 38 companies providing data on their research programs. These 38 companies accounted for 3.1 billion barrels, or about half, of U.S. oil-equivalent oil and gas production in 1986, and are believed to conduct about three-quarters of the U.S. private-sector R&D in oil recovery.

Appendix C contains a copy of the blank survey forms and Appendix D contains aggregations as provided by Arthur Andersen & Co. Appendix D also lists the companies that participated in the survey.

OVERALL SPENDING AND MANPOWER COMMITMENT

The composite results of the survey show estimated 1988 spending on oil and gas research and development by the 38 respondents to be $811 million, involving approximately 6,500 man-years of effort. It is important to realize that the responding companies make up only a portion of the total upstream research and development effort in the United States. Substantial additional upstream research is being performed by oil and service companies not included in the survey, as well as chemical, software, and geophysical companies. Total U.S. private-sector activity levels, therefore, are significantly higher than the levels reported in this survey. Considerable private-sector research is also conducted internationally, and much of this work becomes available for use in domestic operations.

Figure 1 plots research spending in 1988 dollars (bars) and the total manpower (line) represented by the 38 companies that provided research activity data. Figure 2 compares these respondent's research expenditures with oil prices. The historical trends show a close relationship between total spending levels and manpower commitments. Spending trends also show general increases and decreases that broadly follow oil price movements, as might have been anticipated, but do not reflect the severity of the drop in prices since 1981. Table 5 shows percentage changes in R&D spending and manpower for the respondents, compared to oil price changes over the same time periods. The first year for which the survey provided data was 1975, and 1985 was the last year before the major oil price decrease of 1986.

From 1975 to 1985, respondent's spending on oil and gas research more than doubled in real terms. During this period, crude oil prices grew by 59 percent in real terms. Since 1985,

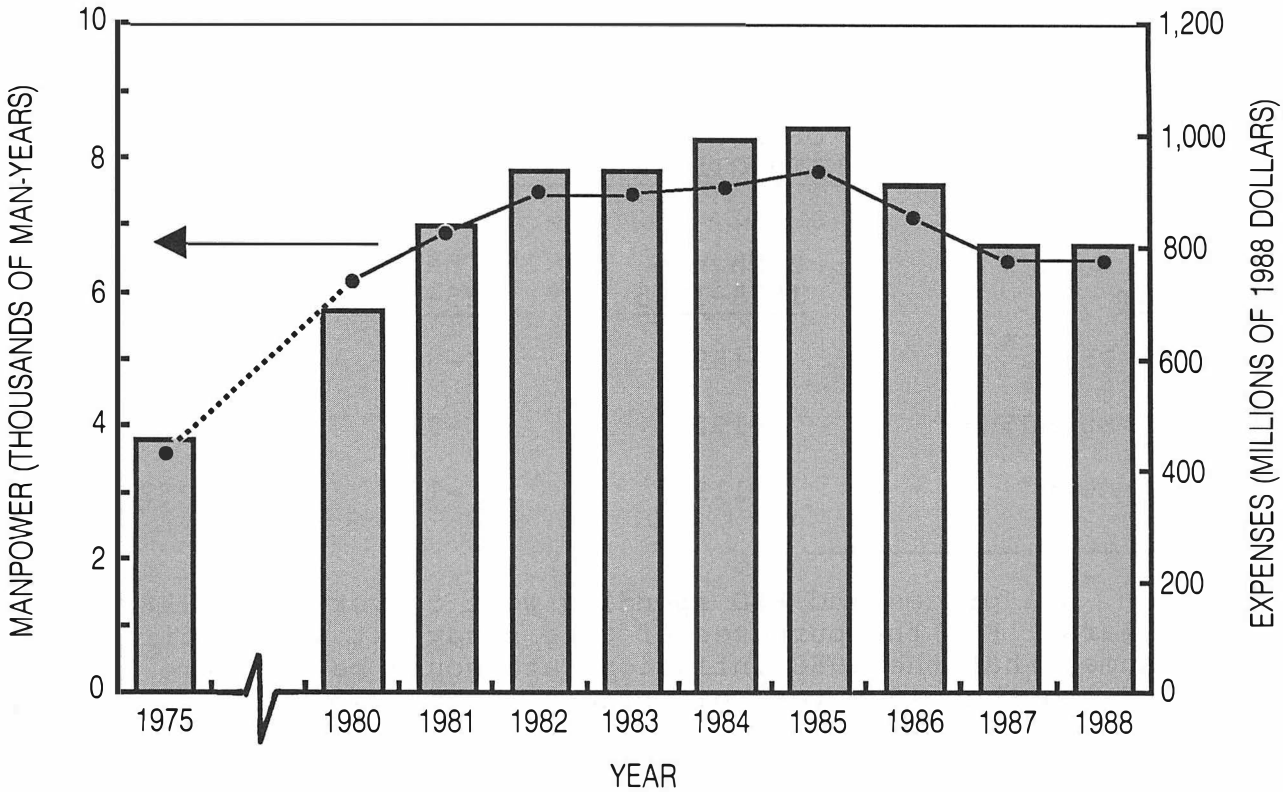

Figure 1. Research Expenditures and Manpower Commitment.

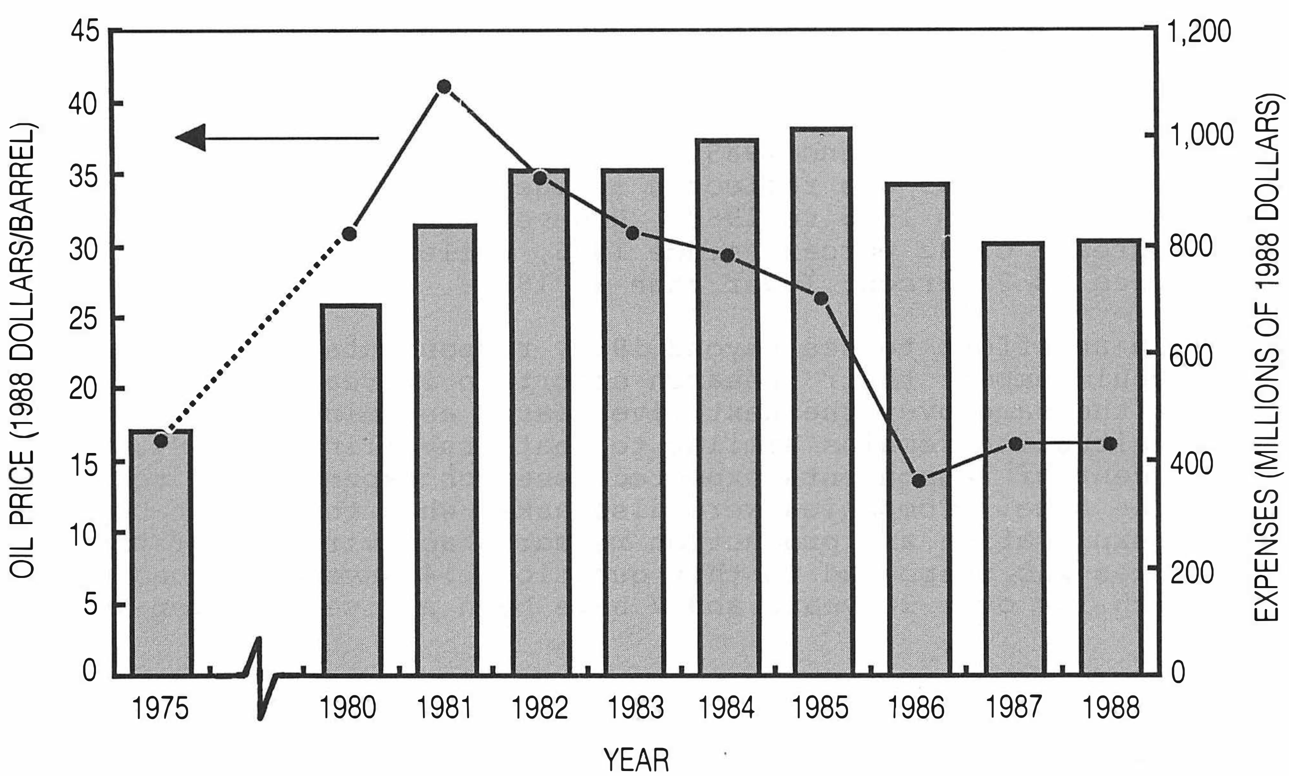

Figure 2. Research Expenditures and Oil Price.

TABLE 5

COMPARISON OF SURVEY RESPONDENTS' R&D ACTIVITY WITH OIL PRICE - 1975-1988

Item	% Change 1975-1985	% Change 1985-1988	% Change 1975-1988
Oil Price*	+59	-39	-2
R&D Spending*	+122	-21	+77
Manpower	+119	-17	+82

*Oil prices and R&D spending were converted to 1988 dollars. For the purposes of this study, it was arbitrarily assumed that the 1988 inflation rate would be the same as in 1987 and that 1988 real oil prices would also be the same as in 1987.

oil prices have fallen 39 percent but research expenditures are off only 21 percent. Over the entire 1975-1988 time period, the research expenditures of the respondents are 77 percent above 1975 in real terms, while real crude oil prices fell 2 percent over this period.

The total R&D manpower of these respondents also more than doubled between 1975 and 1985. The cutbacks and restructurings that followed 1985 are reflected in the 17 percent reduction in R&D manpower from 1985 to 1988. However, there has been an overall increase of 82 percent since 1975, while the real term crude oil price is 2 percent lower than in 1975.

In an effort to see beyond 1988, respondents were asked if they would expect their research effort to increase, decrease, or remain the same over the next five years, assuming that the oil price situation remains similar to that prevailing in 1987. Over 70 percent of respondents expected research expenditures to remain the same. Companies were also asked when they first began their exploration and production research activities. Of the 23 companies who responded to this question, 14 have been conducting research for over 30 years and 7 have been active for over 50 years.

Based on the sample of the industry represented in the survey, it can be concluded that there is a large and well-sustained industry research effort that is more than half again as large as it was in 1975. Indications are that this effort will continue at the current levels into the future.

TRENDS IN R&D EMPHASIS

In Part II of the survey, respondents were asked to divide their R&D activities into six specific categories: three EOR processes -- Chemical, Miscible Gas, and Thermal -- as well as Reservoir Characterization, Other Production R&D, and Exploration. Appendix C contains definitions of the categories and Appendix D contains the aggregated year-to-year totals and 1988 details of the full group of 38 companies. Not all companies provided detailed breakdowns by category, however. Table 6 below compares only the responses of those who provided complete data.

Year-to-year changes in expenditure levels can be significantly distorted by the initiation or completion of major field

TABLE 6

CHANGES IN R&D MANPOWER COMMITMENT - 1975-1988*

Area of Research	% Change 1975-1985	% Change 1985-1988	% Change 1975-1988
EOR - Chemical	+65	-49	-16
EOR - Miscible Gas	+256	+6	+276
EOR - Thermal	+169	-32	+83
Reservoir Characterization	+226	-20	+159
Other Production R&D	+87	-8	+71
Exploration	+92	-24	+46
TOTAL R&D	+105	-17	+70
MEMO: Total Man-Years Included Above	2,945	6,031	5,014
Total Man-Years of All Respondents	3,571	7,818	6,489
Percentage Change of All Respondents	+119	-17	+82

*Based on only those respondents for which comparable year-to-year data were provided.

tests; manpower allocations tend to more accurately reflect the trends in emphasis given the various areas. Trends in manpower commitments are shown by major research area in Table 6 for those respondents who provided comparable year-to-year data.

Over the three time frames, in three categories -- EOR - Thermal, Other Production R&D, and Exploration -- changes in manpower are similar to the changes for total manpower. The other areas show significant differences:

- The research effort in chemical flooding has actually decreased 16 percent since 1975, whereas all other areas show increases. Chemical flooding also shows the largest average percentage decrease since 1985. This indicates that there has been a shift in emphasis away from chemical EOR. The trend may be continuing since these respondents indicated a 7 percent decrease from 1987 to 1988. The overall trend of the respondent's chemical research effort has been significantly affected by the completion of major long-term projects as well as by the oil price decline.

- Manpower commitment to miscible flooding research is over 3.5 times the 1975 level, and actually increased 6 percent from 1985 to 1988 when all other areas show a decrease.

- The manpower commitment to reservoir characterization research more than tripled from 1975 to 1985. Despite a decline since 1985 in line with other areas, industry emphasis in this area remains high relative to historical levels. This area of research helps identify unswept, mobile oil and aids in the proper design of recovery processes.

RELATIVE IMPORTANCE OF MAJOR RESEARCH AREAS

In Parts III and IV of the survey, respondents were asked to indicate the importance to their company of various activities in six major areas of research. Three areas relate to exploration and reservoir characterization, while the other three relate to enhanced oil recovery. Companies were asked to indicate whether they regarded the technology area as "Very Important", "Somewhat Useful," or as having "No Significant Impact" on their operations. (See Parts III and IV of Appendices C and D for the survey questions and responses, respectively.)

The responses to these questions are summarized in Table 7. Results are expressed in terms of the percentage of companies voting a certain way, as well as in terms of the percentage of domestic oil production and the percentage of R&D dollars of the companies included in the survey. Note that the percentage of production is based on the total production reported by the

TABLE 7

IMPORTANCE OF TECHNOLOGY AREAS TO RESPONDENTS*
(Percentages)

Area	Companies			Production			R&D Dollars		
	H	M	L	H	M	L	H	M	L
Geology	71	16	13	83	17	0	85	10	5
Geochemistry	39	32	29	75	23	2	91	4	5
Geophysics	73	10	16	93	7	0	87	1	11
Thermal Recovery	35	10	56	71	3	25	57	30	13
Miscible Flooding	50	29	21	88	11	1	86	9	5
Chemical Flooding	16	55	29	16	74	11	6	77	16

*H = Very Important; M = Somewhat Useful; L = No Significant Impact. Percentages may not add to 100 due to rounding.

survey respondents rather than a percentage of total domestic production, and that the percentage of R&D spending is based on total spending by all respondents and not on the amount spent by the respondents on that particular research area.

The following observations can be made from the results shown in Table 7:

- All areas except chemical flooding are rated very important by the respondent companies that spend the majority of the research dollars and that have most of the production. In other words, the companies supporting research think that all areas except chemical flooding are very important.

- Geology and geophysics are also rated as very important by a majority of the companies. These ratings do not change significantly when reported as either a percentage of production or R&D dollars.

- Geochemistry, miscible flooding, and thermal recovery are not rated by a majority of the companies as very important, but these areas are viewed as very important by those companies representing a majority of the production and R&D dollars.

- Few companies view chemical flooding as being "Very Important." This assessment is also reflected on the basis of production and research expenses. Chemical flooding is rated as "Somewhat Useful" according to all three criteria, indicating a fairly uniform opinion among survey respondents.

DETAILED RESEARCH TOPICS

Several reports have been issued in recent years that address issues relevant to oil and gas exploration research. Three reports were used in preparing the survey.[1] Each of these identified a series of detailed research topics as of potentially high importance to improving future oil supplies. These topics were used in developing the detailed tables for each of the six general research areas addressed in the survey: geology, geochemistry, geophysics, thermal recovery, miscible flooding, and chemical flooding. (See Appendix C, Parts III and IV.) For instance, under the heading of geology, a list of 11 specific topics was identified.

Only survey respondents who were active in the general research area were asked to indicate the priority that they placed on each detailed topic and to indicate whether they were actively involved in research in each topic area. Priority was based on "the need for additional research to develop adequate technology" and/or "the importance of the technology to economic application" of the EOR process. In Appendix D, responses to these detailed questions are tabulated according to the percentage of respondents answering the question in each of the six combinations of Priority (High/Medium/Low) and Activity (Yes/No).

For purposes of summarization, each topic was assigned an overall priority ranking as follows:

- High priority if 50 percent or more of the respondents identified it as high priority
- Low priority if 50 percent or more of the respondents identified it as low priority
- Medium priority if neither of the above criteria were satisfied.

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[1]<u>Geoscience Research for Energy Security</u> (Washington, D.C.: Energy Research Advisory Board, February 1987); <u>Future Directions in Advanced Exploratory Research Related to Oil, Gas, Shale, & Tar Sand Resources</u> (Washington, D.C.: National Research Council, 1987); <u>Enhanced Oil Recovery</u> (Washington, D.C.: National Petroleum Council, June 1984).

Using the above definitions, Table 8 shows the number of detailed topics that were rated high, medium, and low priority by those companies active in the general research area.

TABLE 8

OVERALL PRIORITY RANKING OF DETAILED RESEARCH TOPICS

Research Area	Number of Research Topics					
	High	Med.	Low	Total	Active By 4+ Co.'s	Active By 10+ Co.'s
Geology	5	6	0	11	11	10
Geochemistry	3	2	0	5	5	5
Geophysics	9	8	1	18	18	15
Subtotal	17	16	1	34	34	30
Thermal EOR	0	6	4	10	8	0
Miscible EOR	4	3	3	10	9	5
Chemical EOR	4	11	9	24	20	3
Subtotal	8	20	16	44	37	8
TOTAL	25	36	17	78	71	38

Under geologic research, for example, 5 of the 11 research topics received an overall priority ranking of high, 6 medium, and none low. All 11 of these topics are being pursued by at least 4 of the companies, and 10 of the topics are being researched by at least 10 companies.

With respect to geology, geochemistry, and geophysics, the respondents were asked to comment on 34 specific areas of research. As shown in Table 8, all but one of these were considered to have medium to high priority. Of these 34 topics, all but 4 are being pursued by at least 10 companies. From this information, it appears that the respondents agree with the importance of the geoscience research topics previously identified and that they have ongoing, active research programs in the majority of the areas. Only one of these research topics is considered to be low priority.

Looking at thermal recovery, 10 previously identified research topics were selected for assessment. None of these were assessed to have a high priority; 6 were medium and 4 were low priority. Eight topics are being actively pursued by at least 4 companies but none by as many as 10 companies. Two of the topics -- downhole steam generation and fluidized bed combustion -- were considered low priority topics and no active research programs were reported. It should be pointed out, however, that research in these areas is being conducted at non-petroleum-industry laboratories. Although the thermal recovery research topics listed were not judged to be of overall high priority by the respondents, there are active research programs in most areas of this technology. This reflects, in part, the fact that thermal EOR is the most mature EOR process and much research has been successfully completed and applied in the field.

Of 10 miscible recovery topics, 7 are considered to have medium to high priority. Nine of these topics are being actively pursued in 4 or more companies, with 5 topics active in 10 or more companies.

Topics related to chemical processes are generally assigned a lower priority, with only 15 of the 24 identified topics receiving a medium or high priority. The level of interest and effort appears to be closely related to this assessment. The lower priority probably reflects the long history of research with limited commercial success, and the realization that high economic risk and difficult technical problems are associated with this research area. Even so, there are only 4 topics that do not have an active research program by at least 4 companies. Only 3 topics are active in 10 or more companies.

The list of EOR topics were identified as important research areas in the 1984 NPC report, in which many of the respondent companies participated. Responses in this survey indicated only 8 of the 44 topics are currently high priority. While a number of factors have influenced this change, two are prominent: (1) the downturn in oil prices that occurred after the 1984 EOR report was written, and (2) research projects that were completed between 1984 and 1988. It is to be expected that four years of research progress, including both successful and unsuccessful projects, would alter the priority of future research in an area.

RESPONDENTS' CONCEPT OF RESEARCH TOPICS NOT CURRENTLY COVERED

Respondents were asked an open-ended question: "What R&D related activities do you consider important to future oil and gas recovery technology that you do not believe are being covered by current industry, government, and/or academic efforts?" Respondents were also reminded of this question after rating each of the detailed research topics. The responses are given verbatim in Appendix D. Of the 38 companies in the survey, only 22 commented on this question. Of these 22, two indicated no additional effort was needed, three indicated no major deficiencies, but suggested areas of special importance, and the remainder submitted a variety of suggestions. No single topic was mentioned more than five times, and only a few were mentioned more than twice.

The most frequently mentioned topic was foams for gas mobility control. However, the responses to questions on specific research topics indicate that 76 percent of companies working on miscible flooding are working on mobility control. It may be that respondents listing this as an area not currently being covered are unaware of the significant activity now underway.

A second area mentioned several times was horizontal wells. This is currently attracting widespread interest and is the subject of a cooperative research project that has a record number of industry participants.

An item that was mentioned four times was the integration of geology, geophysics, and engineering. While this is not necessarily a research topic, it does reflect industry's growing recognition of the importance of interdisciplinary approaches to oil recovery problems.

Finally, numerous single items, spanning a wide variety of areas, were suggested by the respondents. The area of Reservoir Characterization received 14 suggestions, which is indicative of its importance to oil recovery.

SURVEY ADDENDUM

The Council concluded from the initial survey that the U.S. petroleum industry was committing a large amount of resources to R&D in its core business lines of oil and gas discovery and recovery. Further, the Council concluded that all of the research topics identified as high and medium priority were being actively pursued.

The question then arose as to whether there were areas that might be pursued more aggressively in a cooperative and/or leveraged environment. To get a broader feel for the potential in this area, the Council presented its membership with the R&D Activity Survey Addendum. The addendum sought to quantify the potential industry support for cooperative, leveraged R&D and to identify those structural elements that were thought to be most important for the success of such an effort.

Fifty-seven responses were received from companies that span the continuum from large integrated majors to small independents. In aggregate, the responses could be characterized as mixed, but there was some significant interest expressed in cooperative research. The first question set forth the general premise of the addendum:

> Assuming that there will be proposed projects of importance to your operations and that your participation would be voluntary, would you contribute money to such a cooperative research program if the money were matched by DOE?

To this question, 32 respondents said "yes" and 25 said "no." Of the 30 "yes" respondents who indicated the funding level they would consider, 19 were in the "$10,000 to $100,000" range. The others were fairly evenly split between "less than $10,000" and "$100,000 to $500,000," as shown in Figure 3. No respondent indicated a willingness to contribute over $500,000 annually. In aggregate, the survey found that the potential funding for such projects might initially be in the range of $1-5 million per year. While this is not a significant incremental amount of funding when compared to the ongoing industry effort, it is enough to allow the Council to conclude that the concept has potential. This outlook is shared by 80 percent of the contributing respondents.

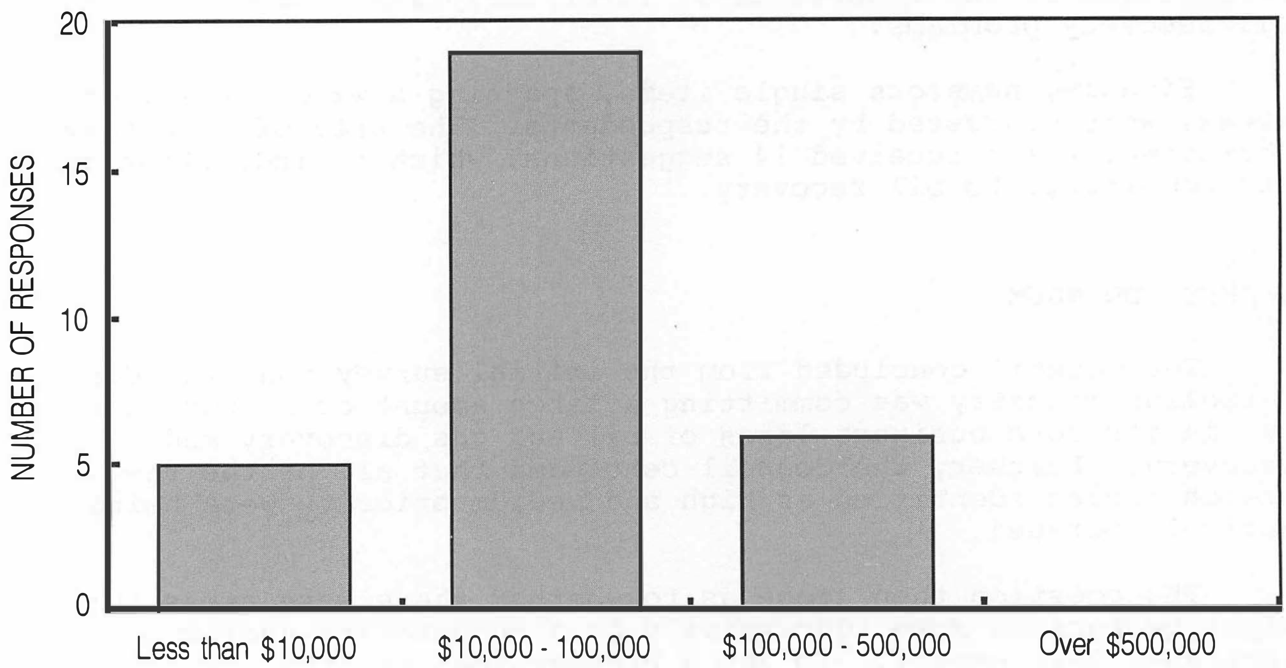

Figure 3. Distribution of Possible Funding Levels by Respondents.

In considering the structure for such a cooperative effort, a majority of the respondents selected an industry committee with voluntary participation and matching government funds. Close behind, however, were those who felt the organization should be non-industry led. Only one respondent was in favor of a permanently staffed national petroleum research institute. On the issue of the leadership and control of the organization, the respondents followed a similar trend, with 69 percent in favor of industry and 31 percent in favor of university. While no respondent suggested that DOE lead or control the activity, there was agreement that DOE should be involved.

Finally, the addendum asked if respondents had "the technical staff necessary to provide advice to a cooperative research effort and to apply the results to your operations?" The response was 56 percent "yes," 38 percent "no." However, when looking at only those respondents who would consider contributing financially, 23 of 32, or 72 percent, said "yes."

From the addendum, the Council concludes that a fair number of companies would be interested in and capable of participating meaningfully in a cooperative research program. The respondents indicate that the program should be industry-led, voluntary, include the participation of industry, academia, and government, and have government matching funds available. Finally, the focus of the projects should be the broad geosciences, not just limited to EOR.

CHAPTER THREE

IMPACT OF RESEARCH ON OIL RECOVERY

This chapter addresses the impact on the nation's energy supply of R&D to increase the recovery of oil. A comparison is made of the expected oil production from the use of EOR methods to the expected increase in the net imports of oil. Policy options in addition to the promotion of an increase in R&D are also noted, which, if adopted, would also have a significant impact on the nation's energy supply.

IMPACT OF CURRENT EOR RESEARCH

The contribution that enhanced oil recovery is expected to make to the future oil production rate was the topic of the 1984 NPC report entitled Enhanced Oil Recovery. As reported in that study, the implementation of then-current (1984) EOR technology in the United States would contribute an oil production rate of 1.2 MMB/D by the year 2000. This projection was premised on a constant oil price of $30 in 1983 dollars. With the subsequent downturn in oil prices, this projection is not likely to be realized.

In 1986, Lewin and Associates, Inc., evaluated the impact of the lower oil prices on the findings of the 1984 NPC report. They evaluated EOR production for the two oil price trends shown in Table 9. EOR production in the United States in the year 2000 was projected to be 0.49 MMB/D for the lower crude oil price outlook. This level is down from the reported current EOR production of 0.64 MMB/D.[1] The decline in the number of active EOR projects between 1986 and 1988 may indicate that the rate of implementation of the technology decreased. For the higher price trend, EOR production in the year 2000 was projected to be 1.11 MMB/D, an estimate that is consistent with the earlier NPC study.

Projections of the impact of continued EOR research efforts on the oil producing rate were also included in the 1984 NPC study. For an oil price of $30 per barrel in 1983 dollars, the advancements in EOR technology resulting from the continuing research were expected to contribute an additional 0.8 MMB/D in the year 2000. The estimate of the contribution of improved

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[1] Oil & Gas Journal, April 18, 1988.

TABLE 9

EFFECT OF OIL PRICE ON OIL PRODUCTION RATE FROM EOR

	1990	1995	2000
Upper Price Trend ($/bbl)*	22	28	36
NPC Survey (MB/D)	605	710	848
Lewin and Associates (MB/D)§	660	880	1,110
Lower Price Trend($/bbl)*	14	17	21
NPC Survey (MB/D)	465	394	382
Lewin and Associates (MB/D)§	470	460	490

*Refiner acquisition cost of crude oil in 1986 dollars per barrel.

§Based on the methodology developed in the 1984 NPC study, Enhanced Oil Recovery, with updated projections made by Lewin and Associates, Inc.

NOTE: This table compiled from 1987 NPC study, Factors Affecting U.S. Oil & Gas Outlook.

technology has not been updated to reflect the lower oil prices, but one would expect a reduction in the additional contribution.

IMPACT OF RESEARCH ON RESERVOIR CHARACTERIZATION

A research area closely related to EOR is reservoir characterization. In recent years there has been considerable interest from industry, government, and academia in obtaining better reservoir descriptions to improve the application of EOR methods. The same reservoir characterization techniques are also being used to add production and reserves through selective drilling to recover unswept, mobile oil, and to develop extensions of existing fields. The industry's interest in reservoir characterization is evident by the survey results, which show a substantial ongoing effort in R&D (about 1,650 man-years and about $210 million in expenditures in 1988) to continue to improve the technology. In addition to these R&D efforts, there is considerable activity in applying current reservoir characterization technology.

Although there is much research activity in reservoir characterization, information is not available to establish the impact it will have on increasing oil recovery. With the industry effort in research and applications in this area and the lack of identification of unaddressed concerns, it appears that most of the benefit from this technology will be realized by current efforts.

IMPACT OF ADDITIONAL RESEARCH

The industry efforts, as noted in the survey results, are addressing the recognized, needed improvements in oil recovery reported in previous studies by the NPC, the National Research Council, and the Energy Research Advisory Board. The survey asked the participants to indicate priority for topics in geology and geophysics related to reservoir characterization and topics on EOR processes. Specifically, the results show that the industry is currently working on all topics that were perceived to be of high or medium priority.

For an additional research effort on oil recovery to result in a substantial increase in oil production, it will need to address opportunities for technology advancement (or research needs) not being covered by current research. Survey respondents were asked to identify such areas; however, no specific research needs were identified that appear to represent a substantial opportunity for new technology. Although the possibility of a major breakthrough in oil recovery research cannot be ruled out, the long, sustained effort in research in this area certainly decreases the likelihood of it occurring.

EXPECTED NET INCREASE IN OIL IMPORTS

The net imports of oil are expected to increase as a result of the combined effects of the increase in demand and decrease in the forecast oil supply. This expectation has increased since the oil price decline. The 1987 NPC report entitled <u>Factors Affecting U.S. Oil & Gas Outlook</u> addressed this question. The results of a survey conducted as a part of that study showed that net imports were expected to increase by the year 2000 from the 1985 level of 4.2 MMB/D to 9.1 MMB/D for the upper oil price scenario and 13.6 MMB/D for the lower oil price scenario. The Energy Information Administration report, <u>Annual Energy Outlook 1987</u> [DOE/EIA-0383(87)], forecast net imports to be 10 MMB/D by the year 2000. Past research efforts are contributing to current oil production, and the ongoing efforts in oil recovery may contribute more to future oil production. However, with such a large expected increase in the net imports of oil, the benefits from research to improve oil recovery are far short of offsetting such a trend.

OTHER POLICY OPTIONS

There are other policy options that potentially would have a significantly greater impact on increasing domestic oil production in the next decade. Some of the most important options are to provide greater access to federal lands and to improve lease terms; to remove tax disincentives (e.g., Windfall Profits Tax) and to use positive incentives to maintain existing production and stimulate exploration and production; and to decontrol gas prices through repeal of the Natural Gas Policy Act.

Both DOE and the oil industry have separately identified a number of these issues. While there is not always agreement about the priority, there is agreement that collectively their adoption would have the greatest probability of increasing the domestic U.S. oil production. Additional policy options are addressed in Factors Affecting U.S. Oil & Gas Outlook.

One example of federal government action contributing to an increased oil supply has been the leasing of the Outer Continental Shelf in both offshore California and in deep water in the Gulf of Mexico. This action has resulted in the discovery of oil reservoirs, and development projects are progressing. A second example was the phased decontrol of oil prices, partially offset by the "Windfall Profits Tax," starting in 1979. "New" oil and certain EOR projects received the higher oil prices first, followed by "old" oil being allowed to gradually rise to the world prices. The combination of higher oil prices and the targeted investments in new drilling and EOR projects resulted in record level rotary rig activity and an increase in total domestic oil production. The resultant incremental production in the lower 48 states was more than sufficient to offset the historical decline normally associated with reservoir depletion. In fact, the incremental production over the normal decline may have contributed an additional 1.5 to 2.0 MMB/D to U.S. production. Thus the U.S. oil industry has shown the ability to increase the domestic oil supply if given effective incentives and access to federal lands.

Appendices

APPENDIX A

THE SECRETARY OF ENERGY
WASHINGTON, D.C.

July 2, 1987

Mr. Edwin L. Cox
Chairman
National Petroleum Council
1625 K Street, NW
Washington, DC 20006

Dear Mr. Cox:

In December 1985, the Energy Research Advisory Board was requested to undertake a review of this Nation's energy related geoscience research needs and the status of the Department's geoscience research and development needs. The final report was delivered in February 1987. Your organization delivered a report at the same time entitled "Factors Affecting U.S. Oil and Gas Outlook." One of the options to reduce this Nation's energy vulnerability was to promote research and development to increase the recovery of oil and gas already discovered, much of which cannot be produced economically with current technology and to develop longer range technologies. There is a definite need to integrate these two efforts and provide an industry perspective relative to future integrated/coordinated research and development needs.

Accordingly, I am requesting the National Petroleum Council to undertake an urgent study relative to the implementation and execution of a national petroleum research effort. Specifically, the study should address the feasibility and mechanisms for establishment of a national, not-for-profit, petroleum research institute analogous to the Gas Research Institute, participation of the entire oil and gas industry, appropriate funding level(s), internal and external department organizational structures and interfaces, prioritization of research and development needs, geographic location(s), incorporation of existing Federal and non-Federal expertise and data bases and detailed plan for implementation and execution. I have noted that the National Petroleum Council was originally established to advise me on any matter relating to the petroleum and gas industry. It is well qualified and has excellent expertise and representation to perform this timely and critical assignment.

Because of the urgent need to integrate our initiatives in U.S. oil and gas research, I would like an interim report on the first, basic question of the advisability and feasibility of establishing a petroleum research institute. For the purpose of this study, I designate J. Allen Wampler, Assistant Secretary for Fossil Energy to represent me and to provide the necessary coordination between the Department of Energy and the National Petroleum Council.

Yours truly,

John S. Herrington

John S. Herrington

DESCRIPTION OF THE NATIONAL PETROLEUM COUNCIL

In May 1946, the President stated that he had been impressed by the contribution made through government/industry cooperation to the success of the World War II petroleum program. He felt that this close relationship should be continued and suggested that the Secretary of the Interior establish an industry organization to provide advice on oil and gas matters. Pursuant to this request, Interior Secretary J. A. Krug established the National Petroleum Council on June 18, 1946. In October 1977, the Department of Energy was established and the Council's functions were transferred to the new department.

The sole purpose of the NPC is to advise, inform, and make recommendations to the Secretary of Energy on any matter, requested by him, relating to petroleum or the petroleum industry. Matters that the Secretary would like to have considered by the Council are submitted as a request in the form of a letter outlining the nature and scope of the study. The Council reserves the right to decide whether it will consider any matter referred to it.

Examples of recent major studies undertaken by the NPC at the request of the Secretary include:

- Refinery Flexibility (1980)
- Unconventional Gas Sources (1980)
- Emergency Preparedness for Interruption of Petroleum Imports into the United States (1981)
- U.S. Arctic Oil & Gas (1981)
- Environmental Conservation -- The Oil and Gas Industries (1982)
- Third World Petroleum Development: A Statement of Principles (1982)
- Petroleum Inventories and Storage Capacity (1983, 1984)
- Enhanced Oil Recovery (1984)
- The Strategic Petroleum Reserve (1984)
- U.S. Petroleum Refining (1986)
- Factors Affecting U.S. Oil & Gas Outlook (1987).

The NPC does not concern itself with trade practices, nor does it engage in any of the usual trade association activities. The Council is subject to the provisions of the Federal Advisory Committee Act of 1972.

Members of the National Petroleum Council are appointed by the Secretary of Energy and represent all segments of petroleum interests. The NPC is headed by a Chairman and a Vice Chairman, who are elected by the Council. The Council is supported entirely by voluntary contributions from its members.

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Code Number*__________

NATIONAL PETROLEUM COUNCIL
OIL AND GAS
RESEARCH AND DEVELOPMENT
SURVEY

COVER PAGE

Reporting Company ________________________________

Address ________________________________

____

____

Employee of Reporting Company to be Contacted if Questions Arise ________________________________

Telephone Number ________________________________

Date ________________________________

Please Return Form to Mr. Michael F. O'Donnell
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711 Louisiana, Suite 1300
Houston, Texas 77002

Telephone Number (713) 237-2323

*This entry, and other NPC Code spaces on subsequent pages, will be entered by the accounting firm for data tabulation purposes.

DEFINITIONS

Research: Planned search or critical investigation aimed at discovery of new knowledge with the hope that such knowledge will be useful in developing a new product or service, or a new process or technique, or in bringing about a significant improvement to an existing product or process.

Development: The translation of research findings or other knowledge into a plan or design for a new product or process, or for a significant improvement to an existing product or process intended for sale or use. It includes the conceptual formulation, design and testing of design alternatives, construction of prototypes, and operation of pilot plants. It does not include routine or periodic alterations to existing products, production lines, manufacturing processes, and other ongoing operations, and it does not include market research or testing activities.

The following examples are **NOT** research and development activities:

Engineering follow-through in an early phase of commercial production

Quality control testing during commercial production

Trouble shooting in connection with breakdowns in commercial production

Ongoing efforts to refine or otherwise improve an existing product

Adapting an existing capability to a particular customer's need as part of an ongoing commercial activity

Design and construction engineering related to construction, rearrangement or start-up of facilities, unless such facilities are pilot plants or are used solely for a particular research and development project.

Expenditures: Research and development costs include a reasonable allocation of indirect costs. However, general and administrative costs that are not clearly related to research and development activities should not be included.

Manpower: Technical manpower (scientists, engineers, direct technical support, and first line supervision) employed in your research effort. Only those employed in full-time research should be included. Do not include field support personnel.

NOTE: The above definitions of research and development and examples of non-qualifying activities were taken with minor modifications from the Financial Accounting Standards Board statement of accounting standards for research and development costs.

EOR - Chemical Flooding: Injection of water with added chemicals into a petroleum reservoir. Three chemical processes are considered: surfactant flooding, polymer flooding, and alkaline flooding.

EOR - Miscible Flooding: Injection into a petroleum reservoir of a material that is miscible, or can become miscible, with the oil in the reservoir. Carbon dioxide is the primary material considered. Nitrogen and hydrocarbon gases are considered for specific projects.

EOR - Thermal Recovery: Injection of steam into a petroleum reservoir, or propagation of a combustion zone through a reservoir by air or oxygen-enriched air injection. Steam drive, cyclic steam injection, and in situ combustion are thermal recovery processes.

Reservoir Characterization: Definition of the reservoir configuration and its fluid flow properties. Includes well logging, core analysis, well testing, and tracer methods. Also includes post-discovery geological or geophysical work related primarily to reservoir description, such as clastic and carbonate facies distribution, reservoir diagenesis, fault and fracture characterization, geologic modeling, and seismic definition of reservoir properties and structural features.

Other Production Research and Development: Areas of research and development related to oil and gas production not included in the categories noted above. Areas include drilling, well completions, materials, production facilities, gas recovery and processing, tight and other unconventional gas recovery, reservoir simulation, offshore and Arctic operations, and environmental protection.

Exploration: Areas of research and development related to exploration not included in the reservoir characterization category. Areas include geophysical data acquisition and processing, seismic data interpretation, seismic modeling, DHI analysis, basin evolution, petroleum geochemistry, migration, structural geology, trap and seal, sequence stratigraphy, etc.

Total Research and Development: The total research and development effort related to oil and gas exploration and production. The sum of the categories listed above should equal total research and development.

Code Number__________

PART I
General Questions

1. What was your corporate revenue from oil and gas production in 1986?

$__________Million

2. What was your oil and gas production in 1986?

a) Domestic __________Million BOE

b) International __________Million BOE

3. Assuming that the oil price situation for the next five years remains similar to that prevailing in 1987, do you expect your research and development spending for oil and gas to: *(Check One)*

a) Increase? __________

b) Decrease? __________

c) Remain the Same? __________

4. Does your organization conduct or support exploration and production research activities?

a) Yes __________

b) No __________

NOTE: If yes, please indicate approximately in what year your company began exploration and production research (_______) and also complete manpower and expense details in Part II.

5. What R&D related activities do you consider important to future oil and gas recovery technology that you do not believe are being covered by current industry, government, and/or academic efforts? *(NOTE: All answers to this question will be transmitted--without identifying the author in any way--to the NPC Committee on Establishing a Petroleum Research Institute and will be public. Please attach additional sheets if necessary.)*

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Code Number__________

PART II

Oil and Gas Research and Development Activity Levels, 1975 - 1988

Table II-1 Research and Development Expenditures in Millions of Dollars

	1975	1980	1981	1982	1983	1984	1985	1986	1987	1988
EOR - Chemical										
EOR - Miscible Gas										
EOR - Thermal										
Reservoir Characterization										
Other Production Research and Development										
Exploration										
TOTAL, Research and Development										

Table II-2 Research and Development Activity Levels in Man-Years

	1975	1980	1981	1982	1983	1984	1985	1986	1987	1988
EOR - Chemical										
EOR - Miscible Gas										
EOR - Thermal										
Reservoir Characterization										
Other Production Research and Development										
Exploration										
TOTAL, Research and Development										

NOTE: Definitions of terms used are attached.

Code Number__________

PART III

Assessment of Current Geoscience Research

The 1987 reports by ERAB and NRC* identified additional research needs in the three major geoscience areas listed below. For each area, please indicate the nature of your research program by answering the following questions.

GEOLOGY

1. Indicate the importance of geology technology to your company: *(Check One)*

   a) Very Important ______

   b) Somewhat Useful ______

   c) No Significant Impact ______

2. Is your company conducting geologic research?

   No_____ Yes_____ *(If yes, please complete Table III-1).*

GEOCHEMISTRY

3. Indicate the importance of geochemistry technology to your company: *(Check One)*

   a) Very Important ______

   b) Somewhat Useful ______

   c) No Significant Impact ______

4. Is your company conducting geochemical research?

   No_____ Yes_____ *(If yes, please complete Table III-2).*

GEOPHYSICS

5. Indicate the importance of geophysics technology to your company: *(Check One)*

   a) Very Important ______

   b) Somewhat Useful ______

   c) No Significant Impact ______

6. Is your company conducting geophysical research?

   No_____ Yes_____ *(If yes, please complete Table III-3).*

*Energy Research Advisory Board, *Geoscience Research for Energy Security,* February 1987; National Research Council, *Future Directions in Advanced Exploratory Research Related to Oil, Gas, Shale, & Tar Sand Resources,* 1987.

Code Number________

TABLE III-1

GEOLOGIC RESEARCH

Research Area	Priority* (H/M/L)	Active Program (Y/N)
1. Clastic and Carbonate Facies Distribution		
a) Sequence analysis	________	________
b) Geostatistical analysis	________	________
c) Development of modern and ancient analogs	________	________
2. Fault and Fracture Characterization		
a) As major conduits for migration of petroleum	________	________
b) In relationship to conventional reservoir properties (permeability and porosity) for controlling fluid flow	________	________
c) Mathematical models integrating fracture networks with reservoir properties	________	________
3. Reservoir Studies		
a) Thermal and hydrodynamic history of basins	________	________
b) Relationship between geologic variables and fluid flow	________	________
c) Relationship between primary porosity and permeability to secondary patterns of diagenesis and fracturing	________	________
d) Rock physics and chemistry	________	________
4. Complex Structure Analysis		
a) Development of new geologic techniques	________	________
5. Other**		

*Priority should be based on the need for additional research to develop adequate technology.
**If you feel other areas should receive high priority, please include them in your answer to question 5 in Part I.

Code Number_________

TABLE III-2

GEOCHEMICAL RESEARCH

Research Area	Priority* (H/M/L)	Active Program (Y/N)
1. Reservoir Studies		
a) Geochemical studies related to compositional changes of rocks through time	________	________
b) Chemical reactions related to fluid-rock or fluid-rock interfaces	________	________
2. Petroleum Geochemistry		
a) Correlation of oil and gas	________	________
b) Recognition of source rock	________	________
c) Prediction of hydrocarbon accumulations	________	________
3. Other**		

*Priority should be based on the need for additional research to develop adequate technology.
**If you feel other areas should receive high priority, please include them in your answer to question 5 in Part I.

Code Number__________

TABLE III-3

GEOPHYSICAL RESEARCH

Research Area	Priority* (H/M/L)	Active Program (Y/N)
1. Seismic Identification of Reservoir Properties and Structural Features		
a) 3-D techniques	______	______
b) Vertical seismic profiles	______	______
c) S-waves	______	______
d) Seismic tomography	______	______
e) Seismic modeling	______	______
f) Fracture identification	______	______
g) Seismic determination of lithology	______	______
h) Seismic determination of fluid content	______	______
2. Development of Geologic Modeling Techniques		
a) Computer/physical 2-D modeling	______	______
b) Computer/physical 3-D modeling	______	______
c) Integration of geologic, geophysical, and geochemical data	______	______
3. Well Logging		
a) Logging tool development	______	______
b) Techniques for identification of reservoir properties	______	______
c) Techniques to examine behind well casing	______	______
d) Deep investigation techniques	______	______
e) Measurement while drilling (MWD)	______	______
4. Seismic Data Quality (Enhanced Resolution)		
a) Improved data gathering tools and techniques	______	______
b) Data processing	______	______
5. Other**		

*Priority should be based on the need for additional research to develop adequate technology.
**If you feel other areas should receive high priority, please include them in your answer to question 5 in Part I.

Code Number__________

PART IV

Assessment of Current EOR Research

The 1984 NPC EOR study* identified additional research needs in the three major EOR areas listed below. For each area, please indicate the nature of your research program by answering the following questions.

THERMAL RECOVERY

1. Indicate the importance of thermal recovery technology to your company: *(Check One)*

   a) Very Important ______

   b) Somewhat Useful ______

   c) No Significant Impact ______

2. Is your company conducting research on thermal recovery?

   No_____ Yes_____ *(If yes, please complete Table IV-1).*

MISCIBLE FLOODING

3. Indicate the importance of miscible flooding technology to your company: *(Check One)*

   a) Very Important ______

   b) Somewhat Useful ______

   c) No Significant Impact ______

4. Is your company conducting research on miscible flooding?

   No_____ Yes_____ *(If yes, please complete Table IV-2).*

CHEMICAL FLOODING

5. Indicate the importance of chemical flooding technology to your company: *(Check One)*

   a) Very Important ______

   b) Somewhat Useful ______

   c) No Significant Impact ______

6. Is your company conducting research on chemical flooding?

   No_____ Yes_____ *(If yes, please complete Table IV-3).*

*National Petroleum Council, *Enhanced Oil Recovery,* June 1984.

Code Number__________

TABLE IV-1

THERMAL RECOVERY TECHNOLOGY

Research Area	Priority* (H/M/L)	Active Program (Y/N)
1. Injectant Systems		
a) Downhole steam generation	________	________
b) Cogeneration	________	________
c) In situ combustion with oxygen-enriched air	________	________
2. Process Mechanisms		
a) Mobility control	________	________
b) Noncondensible gas injection with steam	________	________
c) Light oil steamflooding	________	________
d) Hydraulic fracturing (improved understanding of geomechanical effects)	________	________
3. Project Design and Analysis		
a) Post-steam waterflooding	________	________
b) Wellbore heat loss	________	________
c) Fluidized bed combustion	________	________
4. Other**		

*Priority should be based on the importance of the technology to economic application of thermal recovery and to the need for additional research at this time to develop adequate technology.

**If you feel other areas should receive high priority, please include them in your answer to question 5 in Part I.

Code Number__________

TABLE IV-2

MISCIBLE FLOODING TECHNOLOGY

Research Area	Priority* (H/M/L)	Active Program (Y/N)
1. Injectant Systems		
a) CO_2 production technology	________	________
2. Process Mechanisms		
a) Mobility control	________	________
b) Miscible nitrogen flooding	________	________
c) Immiscible CO_2 flooding	________	________
d) Fluid-rock interactions (wettability, water blocking, etc.)	________	________
3. Process Design and Analysis		
a) Minimum miscibility pressure prediction methods	________	________
b) Phase behavior characterization	________	________
c) Process simulation capabilities for field-scale application	________	________
d) Produced CO_2 processing facilities	________	________
e) WAG process optimization	________	________
4. Other**		

*Priority should be based on the importance of the technology to economic application of miscible flooding and to the need for additional research at this time to develop adequate technology.

**If you feel other areas should receive high priority, please include them in your answer to question 5 in Part I.

Code Number__________

TABLE IV-3

CHEMICAL FLOODING TECHNOLOGY

Research Area	Priority* (H/M/L)	Active Program (Y/N)
1. Injectant Systems		
a) Temperature-insenstive surfactants	________	________
b) Salinity-insensitive surfactants	________	________
c) Surfactants for high-temperature, high-salinity reservoirs	________	________
d) Surfactants for low-temperature, high-salinity reservoirs	________	________
e) Surfactants for high-temperature, low-salinity reservoirs	________	________
f) Lower-cost surfactants	________	________
g) More-effective surfactants	________	________
h) Surfactants for use in carbonate reservoirs	________	________
i) Thermally-stable polymers	________	________
j) Lower-cost polymers	________	________
k) More-effective polymers	________	________
l) Polymers for lower-permeability formations	________	________
m) Thermal stabilizers for polymers	________	________
n) Polymers having improved injectivity characteristics	________	________
2. Process Mechanisms		
a) Reduced surfactant adsorption	________	________
b) Improved understanding of flow mechanisms	________	________
c) Understanding of polymer thermal degradation mechanisms	________	________
d) Effects of microorganisms/biocides on polymer stability	________	________
e) Polymer propagation and retention	________	________
f) Factors affecting injectivity	________	________
g) Improved polymer cross-linking treatments	________	________
h) Improved alkaline flooding processes	________	________
3. Project Design and Analysis		
a) Design of project pattern size/type and facilities	________	________
b) Vertical distribution of fluids	________	________
4. Other**		

*Priority should be based on the importance of the technology to economic application of chemical flooding and to the need for additional research at this time to develop adequate technology.

**If you feel other areas should receive high priority, please include them in your answer to question 5 in Part I.

Code Number*__________

ADDENDUM

NATIONAL PETROLEUM COUNCIL
OIL AND GAS
RESEARCH AND DEVELOPMENT
SURVEY

COVER PAGE

Reporting Company ______________________________

Address ______________________________

____

____

Employee of Reporting Company to be Contacted if Questions Arise ______________________________

Telephone Number ______________________________

Date ______________________________

Please Return Form to
Mr. Michael F. O'Donnell
Arthur Andersen & Co.
711 Louisiana Street
Suite 1300
Houston, Texas 77002

Telephone Number (713) 237-2323

*This entry, and other NPC Code spaces on subsequent pages, will be entered by the accounting firm for Data Tabulation purposes.

Code Number __________

NPC RESEARCH ADDENDUM SURVEY

1. Assuming that there will be proposed projects of importance to your operations and that your participation would be voluntary, would you contribute money to such a cooperative research program if the money were matched by the DOE?

   ______ Yes ______ No

   If yes, what level of annual contribution would you anticipate?

   ______ Less than $10,000

   ______ $10,000 to $100,000

   ______ $100,000 to $500,000

   ______ Over $500,000

2. Would these be funds additional to your current spending on research and development?

   ______ Yes ______ No

3. If a cooperative research institute were established, which of the following structures would be most effective (check one):

   ______ a. A permanently staffed national petroleum research institute?

   ______ b. An industry committee that would facilitate the formulation, financing and contracting of individual cooperative research projects proposed by various industry or academia organizations with partial government funding when appropriate?

   ______ c. A non-industry-led group (e.g., university consortium) that would facilitate the formulation, financing and contracting of individual cooperative research projects with both industry and government providing advice and financing?

   ______ d. Other structure (please describe)?

   ____

   ____

   ____

   ____

   ____

   ____

   ____

   ____

Code Number ________

4. What features do you want to see in a consortium research institute?

	Yes	No
EOR Institute Only	_____	_____
Broad Based Geoscience Institute	_____	_____
No Institute	_____	_____
Industry Led/Controlled	_____	_____
Univeristy Led/Controlled	_____	_____
DOE Led/Controlled	_____	_____
University Participation (without control)	_____	_____
DOE Matching Funds Only (money without control)	_____	_____

Other Essential Features ____

____

____

5. Do you have the technical staff necesary to provide advice to a cooperative research effort and to apply the results to your operations?

______ Yes ______ No

6. Do you believe that a new cooperative effort on enchanced oil recovery research (oil recovery processes and related geoscience) is likely to have a positive and significant impact on the domestic oil and gas supply outlook?

______ Yes ______ No

APPENDIX D

AGGREGATIONS OF RESPONSES

TO THE

NATIONAL PETROLEUM COUNCIL

OIL AND GAS RESEARCH AND DEVELOPMENT SURVEY

The data contained in this Appendix are the aggregations of the survey responses as provided by Arthur Andersen & Co. Individual survey responses were held in strict confidence by Arthur Andersen, and no identifiable individual response data were released to the NPC.

CONTENTS

PART I

GENERAL QUESTIONS

National Petroleum Council

Aggregate Survey Results of 38 Respondents

1. What was your corporate revenue from oil and gas production in 1986?

   $59,198.78 Million

2. What was your oil and gas production in 1986?

   a) Domestic 3,056.29 Million BOE

   b) International 1,692.23 Million BOE

3. Assuming that the oil price situation for the next five years remains similar to that prevailing in 1987, do you expect your research and development spending for oil and gas to:

4. Does your organization conduct or support exploration and production research activities?

	Increase	Decrease	Same
Yes	13.16%	10.53%	42.11%
No	2.63%	2.63%	28.95%

NOTE: If yes, please indicate approximately in what year your company began exploration and production research:

1907	1939	1960
1920	1941	1966 (2)
1924	1945	1975
1927	1947	1978
1929	1950	1980 (2)
1935	1952	1981
1936	1956	1982

5. What R&D related activities do you consider important to future oil and gas recovery technology that you do not believe are being covered by current industry, government, and/or academic efforts?

COMPANY A:

Important aspects of recovery technology are being addressed by one or more of the above segments.

COMPANY B:

All aspects relating to technical matters are being adequately covered.

We consider CO_2 Foam as an important R&D need.

COMPANY C:

Research on feasibility of mining or otherwise extracting oil from sandstone reservoirs near surface (down to 200'). It could be perhaps approached similarly to shale oil.

COMPANY D:

Development of cost-effective chemicals (surfactants and polymers) for use in high-temperature (more than 160°F) EOR applications.

COMPANY E:

1) Completion methods for horizontal wellbores.
2) Direct measurement of hydraulic fracture geometry.
3) Improved methods of reservoir characterization between wellbores.
4) Improved methods of predicting rock/surfactant chemical reaction.
5) Improved acid retardation for high temperature, carbonate rocks.

COMPANY F:

1) More funds need to be utilized in oil recovery methods. This activity needs to be channeled through joint projects with universities and industry.
2) Quantitative measurement of fluid flowing behind wellbore casing (horizontal and vertical flow).
3) Quantitative three phase (oil, water, gas) measurement of flow within the reservoir and borehole.
4) We consider down hole elemental analysis of the formation and borehole fluids an important R&D need.

We consider monitoring of thermal recovery operations using well logging techniques (multiphase flow within reservoir and behind wellbore casing) as an important R&D need.

Seal and material designs for injection and production.

We consider monitoring of CO_2 flood operations using well logging techniques (multiphase flow within the reservoir and behind wellbore casing) as an important R&D need.

Monitoring of chemical flood operations using well logging technology:

1. flow within reservoir and behind wellbore casing and
2. down hole elemental

COMPANY G:

There are no major gaps in the kind of research being undertaken. There may well be areas of research that would benefit from increased emphasis in industrial and university laboratories (as opposed to a National Research Institute). An example would be improved reservoir description through probabilistic methods. However, such research will be largely irrelevant in adding recoverable oil reserves in North America until such time as public policy measures insure a sound economic basis for improved recovery projects.

a) We consider the effect of reservoir pressure and producing well bottomhole pressure on miscible flooding oil recovery as an important R&D need.

b) We consider reservoir condition relative permeabilities including hysteresus as an important R&D need.

COMPANY H:

1) Novel methods of hydrocarbon exploration deletion.
2) Horizontal drilling technology.
3) Remote seismic techniques.
4) Fracture orientation detection.

We consider recognition of hydrocarbon paleo-emplacement and/or pass through as an important R&D need.

We consider computerized A/I recognition of paleo-depositional environments from log curves (including dipmeter) as an important R&D need.

Company H current focus is on heat conservation, alternative heat sources, and optimization of steam injection after response.

COMPANY I:

We consider performance of cross-linked polymers in carbonate reservoirs as an important R&D need.

COMPANY J:

Adequate government support is needed through financial assistance at the university level and through tax incentives for promoting additional corporate research. Liquid loading in hydraulically fractured tight gas reservoirs needs R&D attention.

COMPANY K:

1) Greater emphasis on the integration of geologic and reservoir engineering concepts on EOR application.
2) A greater emphasis on efficient energy utilization in the application of EOR technology, particularly in thermal EOR, with the goal of reducing costs.
3) Development of EOR technology for offshore locations.
4) Development of CO_2 resources from various fuels (e.g., coal, natural gas) for increased availability in prime application areas.

Integration of geologic concepts with reservoir engineering concepts for reservoir characterization <u>and</u> numerical simulation.

1) Continued development of the oxygen-enriched in-situ combustion process
2) Development of the wet oxidation boiler for producing steam from brackish waters

COMPANY L:

Deep-water floating production and storage systems. R&D in this area is particularly urgent as exploration is now in progress at water depths in excess of 3,000 feet.

Deep-water production equipment, including risers, subsea wellheads, subsea blowout preventers, and remote actuation control systems, must be developed. The Brazilians have pioneered development of some deep-water systems, but much additional work is needed.

Solids control systems need improvement. The recent increase in the number of deep, high-pressure wells in the Gulf of Mexico and other areas has resulted in a substantial increase in the cost per well for drilling mud and exotic lost circulation materials. Greatly improved solids control systems are needed to reduce drilling fluids costs, reduce drilling time, and reduce the risk of hole loss.

Deep, high-pressure wells with heavy casing tools are placing new demands on individual drilling rig components, particularly the traveling assemblies, wire rope, rotary drive systems, and mud pumps. In many areas, the demands placed on the equipment are reaching the physical limits set by API as standards for manufacturers.

In order to meet the increased demands placed on rig components, more rigorous manufacturing standards are needed. In addition, component certification is necessary in order to trace the history of specific components through the manufacturing sequence from raw material to finished product. European standards may be studied to provide guidelines.

It should be noted that R&D on drilling and production techniques and tools, instruments, equipment, and components has virtually stopped as most oil field service and supply companies experienced massive financial losses over the past 3 to 5 years.

The resumption of meaningful R&D will not be possible until economic conditions improve substantially and the service and supply companies return to profitable operation.

COMPANY M:

The items listed below are probably all receiving current attention, but should receive more:

1) More emphasis on computer-assisted expert systems to better manage, manipulate, interpolate, and extrapolate data;
2) More emphasis on methods of relating and connecting the different attributes of multidimensional data (i.e., engineering, geology, geophysics, petrophysics, etc.) in a common data base (framework);
3) Wettability alteration for the enhanced mobilization of oil; and
4) Formulate highly structured (compositionally high strength) foams for mobility control and gas shut-off.

COMPANY N:

Laboratory & field tests of EOR processes
Reservoir characterization methods
Horizontal drilling technology
Gels for permeability modification
Foams for mobility control
Low tension polymer flooding
Reservoir characterization

COMPANY O:

Integrated approach to reservoir characterization & description (multidisciplinary approach, comprising geologists, geophysicists, reservoir engineers and statisticians/mathematicians)

COMPANY P:

Oil and gas recovery research is strongly tied to current predicted future oil prices. More consideration should be given to available domestic oil supply and sources of future domestic oil supplies. Chemical oil recovery research has decreased drastically in the past 2-3 years. The industry and government efforts have decreased below what is needed for critical mass to maintain this activity which will be an important future technology for crude oil recovery in the United States. Recovery of oil from shale and liquefaction of coal will also be important for future U.S. oil supplies. Government and industry research in this area is almost nonexistent. There are still isolated groups in academics working in these two areas, but in general they are struggling to obtain sufficient funds to carry on this work that may be critical for future supplies of hydrocarbons in the U.S.

We consider means for improving volumetric sweep conformance as an important R&D need.

We consider mathematical description of hydrocarbon phase behavior in the presence of steam as an important R&D need.

COMPANY Q:

R&D related activities important to future oil and gas recovery technology that is not being considered by current programs.

<u>Enhanced Oil Recovery</u>
- Wellbore heat loss control
- Downhole generation of heat
- Cost effective downhole safety systems for wellbore control in gas injection systems
- Downhole corrosion control systems
- Injection profile control for steam or miscible gas

<u>Wireline Services</u>
- Open Hole
  - Deep investigating instrumentation for fracture detection, porosity and direct permeability measurements
- Cased Hole
  - Deep investigating instrumentation for through-pipe applications
  - Cased hole resistivity measurements

<u>Seismic Services</u>
- Investigate the contribution of seismic technology in monitoring enhanced recovery operations. Such work is conducted in Canada under Aostra funding for heavy oil miscible/immiscible floods and WAG projects. Wider acceptance of this technology in the United States may be contingent upon the initiation of a high profile demonstration project conducted with federal funding.

COMPANY R:

Research related to oil and gas recovery is now conducted by oil companies, government laboratories, universities, and by cooperative research projects. All these efforts combine to cover the industry's needs.

No new research organizations are needed.

COMPANY S:

Remote sensing.
Surface geochemistry.

COMPANY T:

We consider very little or nothing is not covered by current industry, government, or academic effort. By this, we do not mean that all is solved, but a start has been made on all significant avenues that we are aware of. Reservoir sweep is one of the major questions which needs further advancement in the immediate future.

COMPANY U:

1. Fundamental understanding of two and three phase flow in porous media, including the effects of capillary number, wettability, rock pore structure, etc.
2. Proper scaling from laboratory results to field results, including the effects of heterogeneities at all length scales.
3. Optimum tests and data for reservoir description and how optimum varies with recovery method.
4. Research on efficient, state-of-the-art numerical methods for faster, more accurate simulations.
5. Gas foams.
6. Determining more about the chemical composition of hydrocarbons.
7. Determining more and correlating properties of hydrocarbons (such as PVT and thermodynamic properties).
8. Determining more about the chemical and/or physical composition of naturally occuring rocks and soils (including reservoir rock).
9. Correcting of properties (such as mechanical and thermodynamic) of natural rocks and soils.
10. Development of borehole-to-borehole tomographic measurement techniques for detailed reservoir delineation for guiding development and monitoring production. (This could include seismic, electrical, and other technologies.)
11. Foam flow mechanisms for steamflooding applications.
12. Development of in-situ core measurement techniques for determining local porosity, saturation, and phase concentrations all the way to pore level discrimination.

COMPANY V:

EOR is a R&D related activity considered important.

PART II

OIL AND GAS RESEARCH AND DEVELOPMENT ACTIVITY LEVELS, 1975-1988

TABLE II-1 Aggregate Research and Development Expenditures in Millions of Dollars*

	Companies Providing Complete Data										All Companies, 1988
	1975	1980	1981	1982	1983	1984	1985	1986	1987	1988	
EOR - Chemical	10.88	16.71	24.88	43.31	37.78	66.06	49.85	40.39	27.78	25.10	25.50
EOR - Miscible Gas	3.26	11.40	16.76	17.44	20.42	31.15	29.03	28.09	25.34	25.91	26.01
EOR - Thermal	9.59	13.75	24.72	38.73	30.42	25.12	21.52	14.60	13.48	14.25	14.55
Reservoir Characterization	17.83	44.51	61.11	71.84	78.82	89.05	99.25	90.57	83.55	87.23	209.43
Other Production Research and Development	77.93	158.00	194.57	226.12	228.11	247.29	259.24	222.87	230.06	251.72	299.12
Exploration	55.04	139.10	191.96	209.77	219.73	227.09	245.29	197.07	201.48	205.38	236.48
TOTAL R&D	174.53	383.47	514.00	607.21	615.28	685.76	704.18	593.59	581.69	609.59	N/A
TOTAL for All Companies	209.73	484.87	649.20	772.41	796.08	881.96	932.38	852.99	780.49	N/A	811.09

*Not all 38 companies were able to provide data for all of the past years or to break their activities into the six categories. In order to make consistent comparison between years and categories, only complete responses are aggregated in the body of the table. All 38 respondents are included in the perimeter totals.

TABLE II-2 Aggregate Research and Development Activity Levels in Man-Years*

	Companies Providing Complete Data										All Com-
	1975	1980	1981	1982	1983	1984	1985	1986	1987	1988	panies, 1988
EOR - Chemical	169.90	185.26	208.90	250.40	249.10	271.20	280.80	233.50	153.85	142.80	146.80
EOR - Miscible Gas	45.80	103.50	100.80	113.80	129.20	169.70	162.90	163.30	160.20	172.30	174.00
EOR - Thermal	54.90	102.50	120.50	150.20	143.80	144.10	147.80	113.20	101.20	100.60	101.70
Reservoir Characterization	285.90	510.20	627.70	761.30	820.70	882.10	931.20	891.20	754.10	741.20	1642.30
Other Production Research and Development	1469.20	2447.20	2582.30	2728.00	2609.10	2501.30	2741.10	2456.30	2417.70	2519.40	2868.60
Exploration	918.80	1548.20	1785.70	1892.70	1817.10	1774.00	1766.70	1405.80	1381.40	1338.00	1555.20
TOTAL R&D	2944.50	4896.86	5425.90	5896.40	5769.00	5742.40	6030.50	5263.30	4968.45	5014.30	N/A
TOTAL for All Companies	3570.90	6153.66	6888.30	7489.90	7459.50	7580.30	7817.60	7122.40	6463.35	N/A	6488.60

*Not all 38 companies were able to provide data for all of the past years or to break their activities into the six cagetories. In order to make consistent comparison between years and categories, only complete responses are aggregated in the body of the table. All 38 respondents are included in the perimeter totals.

PART III

ASSESSMENT OF CURRENT GEOSCIENCE RESEARCH

NUMBER OF RESPONDENTS: 38

	Number of Companies		Domestic Production		Research Dollars	
	Yes	No	Yes	No	Yes	No
AREA: GEOLOGY						
Very Important	42%	29%	74%	9%	85%	0%
Somewhat Useful	8%	8%	8%	9%	8%	2%
No Significant Impact	0%	13%	0%	0%	0%	5%
AREA: GEOCHEMISTRY						
Very Important	39%	0%	75%	0%	91%	0%
Somewhat Useful	11%	21%	8%	15%	2%	2%
No Significant Impact	0%	29%	0%	2%	0%	5%
AREA: GEOPHYSICS						
Very Important	47%	26%	85%	8%	87%	0%
Somewhat Useful	5%	5%	7%	0%	1%	0%
No Significant Impact	3%	13%	0%	0%	6%	5%

III-1 GEOLOGY

1. Clastic and Carbonate Facies

1.a Sequence analysis:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	58%	21%	5%
No	5%	5%	5%

1.b Geostatistical analysis:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	26%	26%	11%
No	0%	5%	32%

1.c Development of modern and ancient analogs:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	42%	26%	5%
No	5%	11%	11%

2. Fault and Fracture Characterization

2.a As major conduits for migration of petroleum:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	42%	21%	0%
No	0%	11%	26%

III-1 GEOLOGY (continued)

2.b In relationship to conventional reservoir properties (permeability and porosity) for controlling fluid flow:

	Percent of Respondents Priority		
Active Program	High	Medium	Low
Yes	47%	21%	5%
No	5%	11%	11%

2.c Mathematical models integrating fracture networks with reservoir properties:

	Percent of Respondents Priority		
Active Program	High	Medium	Low
Yes	26%	21%	5%
No	5%	26%	16%

3. Reservoir Studies

3.a Thermal and hydrodynamic history of basins:

	Percent of Respondents Priority		
Active Program	High	Medium	Low
Yes	53%	11%	5%
No	5%	16%	11%

3.b Relationship between geologic variables and fluid flow:

	Percent of Respondents Priority		
Active Program	High	Medium	Low
Yes	42%	21%	0%
No	11%	11%	16%

III-1 GEOLOGY (continued)

3.c Relationship between primary porosity and permeability to secondary patterns of diagenesis and fracturing:

Active Program	Percent of Respondents Priority: High	Medium	Low
Yes	63%	16%	0%
No	5%	16%	0%

3.d Rock physics and chemistry:

Active Program	Percent of Respondents Priority: High	Medium	Low
Yes	21%	32%	5%
No	5%	26%	11%

4. Complex Structure Analysis

4.a Development of new geologic techniques:

Active Program	Percent of Respondents Priority: High	Medium	Low
Yes	47%	11%	5%
No	0%	26%	11%

III-2 GEOCHEMISTRY

1. Reservoir Studies

1.a Geochemical studies related to compositional changes of rocks through time:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	42%	16%	16%
No	0%	21%	5%

1.b Chemical reactions related to fluid-rock or fluid-rock interfaces:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	32%	37%	0%
No	11%	11%	11%

2. Petroleum Geochemistry

2.a Correlation of oil and gas:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	53%	26%	0%
No	5%	11%	5%

2.b Recognition of source rock:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	58%	16%	5%
No	11%	5%	5%

III-2 GEOCHEMISTRY (continued)

2.c Prediction of hydrocarbon accumulations:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	63%	5%	0%
No	26%	0%	5%

III-3 GEOPHYSICS

1. Seismic Identification of Reservoir Properties and Structural Features

1.a 3-D techniques:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	48%	14%	10%
No	5%	10%	14%

1.b Vertical seismic profiles:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	29%	19%	14%
No	5%	19%	14%

1.c S-waves:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	24%	29%	10%
No	5%	10%	24%

III-3 GEOPHYSICS (continued)

1.d Seismic tomography:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	38%	14%	10%
No	0%	10%	29%

1.e Seismic modeling:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	33%	38%	10%
No	0%	10%	10%

1.f Fracture identification:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	33%	29%	5%
No	5%	10%	19%

1.g Seismic determination of lithology:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	57%	14%	10%
No	5%	5%	10%

III-3 GEOPHYSICS (continued)

1.h Seismic determination of fluid content:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	57%	14%	5%
No	0%	10%	14%

2. Development of Geologic Modeling Techniques

2.a Computer/physical 2-D modeling:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	52%	14%	5%
No	5%	0%	24%

2.b Computer/physical 3-D modeling:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	48%	24%	5%
No	5%	10%	10%

2.c Integration of geologic, geophysical, and geochemical data:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	67%	14%	14%
No	5%	0%	0%

III-3 GEOPHYSICS (continued)

3. Well Logging

3.a Logging tool development:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	14%	19%	19%
No	10%	5%	33%

3.b Techniques for identification of reservoir properties:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	62%	10%	5%
No	14%	5%	5%

3.c Techniques to examine behind well casing:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	29%	14%	0%
No	10%	33%	14%

3.d Deep investigation techniques:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	24%	19%	0%
No	0%	43%	14%

III-3 GEOPHYSICS (continued)

3.e Measurement while drilling (MWD):

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	5%	19%	14%
No	19%	19%	24%

4. Seismic Data Quality (Enhanced Resolution)

4.a Improved data gathering tools and techniques:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	52%	14%	14%
No	5%	10%	5%

4.b Data processing

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	57%	19%	14%
No	0%	5%	5%

PART IV

ASSESSMENT OF CURRENT EOR RESEARCH

NUMBER OF RESPONDENTS: 38

	Number of Companies		Domestic Production		Research Dollars	
	Yes	No	Yes	No	Yes	No
AREA: THERMAL RECOVERY						
Very Important	32%	3%	69%	2%	57%	0%
Somewhat Useful	5%	5%	3%	0%	7%	23%
No Significant Impact	3%	53%	10%	15%	4%	9%
AREA: MISCIBLE FLOODING						
Very Important	34%	16%	84%	4%	57%	29%
Somewhat Useful	8%	21%	4%	7%	8%	1%
No Significant Impact	0%	21%	0%	1%	0%	5%
AREA: CHEMICAL FLOODING						
Very Important	13%	3%	15%	1%	6%	0%
Somewhat Useful	26%	29%	65%	9%	53%	24%
No Significant Impact	3%	26%	7%	4%	5%	11%

IV-1 THERMAL RECOVERY

1. Injectant Systems

1.a Downhole steam generation:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	0%	0%	0%
No	7%	7%	87%

1.b Cogeneration:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	13%	27%	0%
No	13%	13%	33%

1.c In situ combustion with oxygen-enriched air:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	0%	40%	0%
No	7%	7%	47%

2. Process Mechanisms

2.a Mobility control:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	20%	40%	0%
No	13%	13%	13%

IV-1 THERMAL RECOVERY (continued)

2.b Noncondensible gas injection with steam:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	7%	7%	13%
No	7%	13%	53%

2.c Light oil steamflooding:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	7%	20%	0%
No	0%	13%	60%

2.d Hydraulic fracturing (improved understanding of geochemical effects)

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	27%	20%	0%
No	7%	0%	47%

3. Project Design and Analysis

3.a Post-steam waterflooding:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	7%	13%	7%
No	7%	27%	40%

IV-1 THERMAL RECOVERY (continued)

3.b Wellbore heat loss:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	20%	27%	7%
No	13%	13%	20%

3.c Fluidized bed combustion:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	0%	0%	0%
No	7%	0%	93%

IV-2 MISCIBLE FLOODING

1. Injectant Systems

1.a CO_2 production technology:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	13%	6%	0%
No	6%	25%	50%

2. Process Mechanisms

2.a Mobility control:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	63%	13%	0%
No	0%	19%	6%

IV-2 MISCIBLE FLOODING (continued)

2.b Miscible nitrogen flooding:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	0%	25%	6%
No	0%	6%	63%

2.c Immiscible CO_2 flooding:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	19%	19%	6%
No	6%	6%	44%

2.d Fluid-rock interactions (wettability water blocking, etc.)

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	44%	19%	0%
No	0%	19%	19%

3. Process Design and Analysis

3.a Minimum miscibility pressure prediction methods:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	19%	38%	0%
No	0%	6%	38%

IV-2 MISCIBLE FLOODING (continued)

3.b Phase behavior characterization:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	50%	13%	0%
No	0%	13%	25%

3.c Process simulation capability for field-scale application:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	63%	6%	0%
No	6%	19%	6%

3.d Produced CO_2 processing facilities:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	13%	19%	0%
No	13%	31%	25%

3.e WAG process optimization:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	63%	6%	13%
No	0%	13%	6%

IV-3 CHEMICAL FLOODING

1. Injectant Systems

1.a Temperature-insensitive surfactants:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	19%	13%	0%
No	6%	13%	50%

1.b Salinity-insensitive surfactants:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	25%	6%	0%
No	13%	19%	38%

1.c Surfactants for high-temperature, high-salinity reservoirs:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	25%	6%	0%
No	6%	13%	50%

1.d Surfactants for low-temperature, high-salinity reservoirs:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	13%	13%	6%
No	6%	19%	44%

IV-3 CHEMICAL FLOODING (continued)

1.e Surfactants for high-temperature, low-salinity reservoirs:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	25%	0%	0%
No	0%	19%	56%

1.f Lower-cost surfactants:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	44%	6%	0%
No	6%	6%	38%

1.g More-effective surfactants:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	44%	6%	0%
No	13%	6%	31%

1.h Surfactants for use in carbonate reservoirs:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	19%	6%	0%
No	13%	13%	50%

IV-3 CHEMICAL FLOODING (continued)

1.i Thermally-stable polymers:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	25%	13%	0%
No	19%	19%	25%

1.j Lower-cost polymers:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	25%	0%	0%
No	6%	44%	25%

1.k More-effective polymers:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	38%	6%	0%
No	13%	25%	19%

1.1 Polymers for lower-permeability formations:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	0%	19%	0%
No	6%	19%	56%

IV-3 CHEMICAL FLOODING (continued)

1.m Thermal stabilizers for polymers:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	6%	6%	0%
No	0%	31%	56%

1.n Polymers having improved injectivity characteristics:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	19%	0%	6%
No	6%	31%	38%

2. Process Mechanisms

2.a Reduced surfactant adsorption:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	44%	13%	0%
No	13%	6%	25%

2.b Improved understanding of flow mechanisms:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	44%	19%	0%
No	0%	19%	19%

IV-3 CHEMICAL FLOODING (continued)

2.c Understanding of polymer thermal degradation mechanisms:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	19%	13%	0%
No	0%	25%	44%

2.d Effects of microorganims/biocides on polymer stability:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	13%	13%	0%
No	25%	19%	31%

2.e Polymer propagation and retention:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	44%	19%	0%
No	0%	31%	6%

2.f Factors affecting injectivity:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	25	19%	6%
No	13%	19%	19%

IV-3 CHEMICAL FLOODING (continued)

2.g Improved polymer cross-linking treatments:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	38%	25%	0%
No	6%	0%	31%

2.h Improved alkaline flooding processes:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	13%	0%	6%
No	0%	13%	69%

3. Project Design and Analysis

3.a Design of project pattern size/type and facilities:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	6%	13%	0%
No	6%	25%	50%

3.b Vertical distribution of fluids:

Active Program	Percent of Respondents Priority High	Medium	Low
Yes	25%	19%	0%
No	13%	19%	25%

NPC RESEARCH SURVEY ADDENDUM

(ALL RESPONDENTS)

1. Would you contribute money to a cooperative research program if the money were matched by DOE:

    Yes 32
    No 25

    Level of contribution:

Less than $10,000	5
$10,000 to $100,000	19
$100,000 to $500,000	6
Over $500,000	0

2. Funds would be in addition to current spending on research and development:

    Yes 38
    No 10

    Number of respondents with no R&D activity: 23

3. Most effective cooperative research institute structure:

    Permanently staffed national petroleum research institute: 1
    An industry committee with voluntary participation and matching government funds: 24
    A non-industry-led group: 19
    Other structure: 11

4. A new cooperative effort is likely to have a positive impact on the domestic oil and gas supply outlook:

    Yes 37
    No 16

    For yes respondents, the most effective features would be:

    a. Focus of research

EOR only	14
Broad-based geoscience	23

b. Type of Control

Industry led/controlled	24
University led/controlled	11
DOE led/controlled	0

c. Type of participation

Industry	33
University	32
DOE	32

5. Do you have the technical staff necessary to provide advice and apply the results to operations:

Yes 32
No 22

(RESPONDENTS WHO ANSWERED <u>YES</u> TO QUESTION 1)

NOTE: The following results include only those responses for the respondents who answered Yes to question 1.

2. Funds would be in addition to current spending on research and development:

Yes 27
No 5

Number of respondents with no R&D activity: 23

3. Most effective cooperative research institute structure:

Permanently staffed national petroleum research institute: 0
An industry committee with voluntary participation and matching government funds: 16
A non-industry-led group: 11

4. A new cooperative effort is likely to have a positive impact on the domestic oil and gas supply outlook:

Yes 25
No 6

For yes respondents, the most effective features would be:

a. Focus of research

EOR only	7
Broad-based geoscience	18

b. Type of Control

Industry led/controlled	17
University led/controlled	6
DOE led/controlled	0

c. Type of participation

Industry	24
University	23
DOE	24

5. Do you have the technical staff necessary to provide advice and apply the results to operations:

Yes	23
No	8

NATIONAL PETROLEUM COUNCIL
OIL AND GAS
RESEARCH AND DEVELOPMENT
SURVEY
ADDENDUM

The following are other cooperative research institute structures listed by survey respondents:*

COMPANY A:
A non-industry-led group with industry to have more influence than just advisory.

COMPANY B:
A combination of an industry committee and a non-industry-led group with an industry committee to provide more than "advice." Industry should direct the projects to be researched, with a University consortium carrying out the task.

COMPANY C:
It is our view that oil recovery research is being handled efficiently in the private sector. A new DOE-sponsored Petroleum Research Institute would be redundant, and not cost-effective.

COMPANY D:
(In regards to a non-industry-led group) The successful consortia such as Stanford's Geophysical Consortium have really been led by participants and the work done by the University.

COMPANY E:
Would recommend that, if DOE was interested in stimulating/leveraging research, it be done through a tax relief mechanism.

COMPANY F:
Joint research projects developed under an industry committee could be contracted to universities, private research institutes, one of the participating companies, or other organizations, depending on selection of the best-qualified R&D organization for the particular job. Participation by individual companies would be voluntary and on a project-by-project basis, and individual projects would be subject to direction by the participating companies.

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*The letter designations are random and do not relate to the designations in the answer to question 5 in Part I.

COMPANY G:

A combination of an industry committee and a non-industry-led group with industry leading the group.

COMPANY H:

An internal committee of DOE, composed of existing employees, could allocate DOE funds to committed joint industry research effotrs that have five or more industry and/or academic participants. DOE funds should not exceed 20% of total project cash contributions of other participants.

COMPANY I:

Utilize a non-industry-led group without government matching funds.

COMPANY J:

A national institute with a lean staff charged only to manage and direct research efforts. This group would report to an industry-oriented board of directors. The actual research work would be done by universities, private companies, consulting companies, and the like.

COMPANY K:

An industry committee is essentially an expansion of the Task Force concept but including matching funds from DOE. Conceptually, Company K does not believe that support by the DOE in any form of monetary support is appropriate.

COMPANY L:

An Institute with industry control, university involvement, and government matching funds. The institute would be funded as a whole and not on a project basis. A permanent core staff is desired with rotation possible from university and industry.

COMPANY M:

Some of our oil state universities have capable research scientists who could do a good job with industry advice and leadership plus additional funding.

COMPANY N:

A non-industry-led group -- Industry should have strong review authority over the selection of projects and evaluation of research proposals and results.

The following are other desired features of a cooperative research institute listed by survey respondents:

COMPANY O

Industry to have more than passive advisory role.

COMPANY P:

Although the focus should be broad based, Company P believes EOR has the most to offer.

COMPANY Q:

Participation by not-for-profit research institutes related to geosciences.

COMPANY R:

Major involvement of a wide range of scientific and engineering disciplines.

COMPANY S:

Industry should have strong review authority over the selection of research proposals and results.

Other general comments provided by respondents:

COMPANY T:

If any program is initiated, it should definitely be industry led, industry controlled, and industry participation. Any other control would not be effective nor would it be cooperative. Without industry the program would fail. Therefore, it should not be placed in a university consortium.

COMPANY U:

Would contribute to a cooperative research program as long as not controlled or unduly influenced by DOE.

COMPANY V:

Believe that the technology is available to increase oil and gas recovery but that unstable oil and gas prices do not allow its implementation.

COMPANY W:

Contributions would be on a voluntary, project-by-project basis and the scope of each project would be subject to company direction.

COMPANY X:

Cooperative effort would not have a positive impact on supply outlook in the sense of a major impact on domestic supplies, but cooperative research on a project-by-project basis with voluntary participation and industry direction is worthwhile, is currently supported, and will continue to be supported as a supplement to company programs.

COMPANY Y:

A national energy policy, integrated with nations of world which produce needs to include consideration of above (questions 4 and 5). Otherwise, let majors pursue on a competitive basis, as of present.

COMPANY Z:

Industry must play a dominant role in project selection, stewardship, and field testing. Otherwise, the value to us would be very low. Different organizational options such as a university consortium could be successful if this condition is met.

Focus of research -- broad-based geoscience excluding exploration research.

Any type of control can work but industry control is essential.

COMPANY AA:

Focus on integrated reservoir description (integrated interdisciplinary approach to reservoir description and characterization by geoscientists and engineers).

COMPANY AB:

We believe we have the staff that can offer suggestions for research and can utilize new and improved ideas, after they have been developed.

COMPANY AC:

Industry contributions could be through increased association dues (e.g., the NPC), which would be passed on, thereby assuring more widespread participation. Under any mechanism, however, access to the R&D should be restricted to only those who have contributed.

COMPANY AD:

I simply do not believe in some sort of an Energy Research Institute. It will turn into an expensive albatross.

NATIONAL PETROLEUM COUNCIL

COMPANIES RESPONDING
TO THE
NPC OIL AND GAS
RESEARCH AND DEVELOPMENT
SURVEY AND ADDENDUM

American Petrofina, Incorporated

Amoco Corporation

* Apache Corporation

Ashland Oil, Inc.

Atlantic Richfield Company

Baker Hughes Incorporated

* Bass Brothers Enterprises, Inc.

BP America Inc.

Burlington Northern Inc.

* Bruce Calder, Inc.

Cameron Iron Works, Inc.

* Captiva Corporation

* Chandler & Associates, Inc.

* Chevron Corporation

Conoco Inc.

* Cox Oil & Gas, Inc.

* Dalwood Corporation

* DeltaUS Corporation

Dresser Industries, Inc.

* Enron Corp.

Ethyl Corporation

Exxon Corporation

* Forest Oil Corporation

* Michel T. Halbouty Energy Co.

Halliburton Company

* Hamilton Oil Corporation

* Roy M. Huffington, Inc.

Jones Company

Keplinger Holdings, Ltd.

§ Kerr-McGee Corporation

The Louisiana Land and Exploration Company

* McFarland Energy, Inc.

* Maguire Oil Company

* Maxus Energy Corporation

§ Mesa Limited Partnership

Mitchell Energy and Development Corporation

Mobil Corporation

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* Responded to Addendum only.
§ Responded to initial Survey only.

Murphy Oil Corporation

§ Noble Affiliates, Inc.

§ Occidental Petroleum Corporation

Panhandle Eastern Corporation

* Panhandle Producing Company

* Parker Drilling Company

§ Pennzoil Company

Phillips Petroleum Company

* Pitts Energy Group

Pruet Drilling Company

Schlumberger Limited

Shell Oil Company

* Sonat Inc.

§ Sun Company, Inc.

Tenneco Inc.

Tesoro Petroleum Corporation

Texaco Inc.

Texas Eastern Corporation

* Transco Energy Company

Union Pacific Resources Company

Union Texas Petroleum Corporation

Unocal Corporation

USX Corporation

* Ward Petroleum Corporation

* M. H. Whittier Corporation

* The Williams Companies, Inc.

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* Responded to Addendum only.
§ Responded to initial Survey only.

APPENDIX E

GOVERNMENT-FUNDED PROGRAMS
RELATED TO
PETROLEUM GEOSCIENCE

TABLE 1. NSF: Directorate for Geosciences (GEO)

	Millions of Dollars			
	FY 1987 Actual	FY 1988 Current	FY 1989 Proposed[a]	Change, %[b]
Atmospheric Sciences	**93.5**	**96.3**	**104.3**	**8.2**
Atmospheric Sciences Projects (total)	48.0	48.8	52.7	8.1
Aeronomy	6.2	6.0	6.8	13.5
Atmospheric chemistry	6.1	8.7	10.0	14.9
Climate dynamics	8.6	8.8	9.1	3.9
Experimental meteorology	5.0	5.0	6.1	22.0
Global Atmospheric Research Program (GARP)	4.1	3.0	0.0	−100.0
Magnetospheric physics	–	4.8[c]	5.2	8.4
Meteorology	8.6	9.1	11.6	27.6
Solar-terrestrial research	6.9	3.5	4.0	14.3
National Center for Atmospheric Research (total)	41.3	42.8	46.1	7.8
Climate and Global Dynamics	3.5	3.4	3.6	5.8
Atmospheric Chemistry	3.1	3.1	3.4	9.7
High-Altitude Observatory	3.1	3.3	3.3	2.1
Advanced Study Programs	0.7	0.9	0.9	2.2
Meso- and Microscale Meteorology	2.7	2.7	3.0	11.1
Scientific Computing	12.3	12.2	12.5	2.1
Atmospheric Technology	7.0	7.5	9.5	26.7
University Corporation for Atmospheric Research[d]	1.8	0.9	0.9	2.4
Other[c]	8.0	8.8	9.0	1.8
Upper Atmospheric Facilities	4.2	4.8	5.4	12.9
Earth Sciences	**49.9**	**51.3**	**59.3**	**15.6**
Earth sciences project support (total)	34.3	35.4	38.5	8.8
Stratigraphy and paleontology	3.9	3.9	4.2	7.7
Surficial processes	3.4	3.6	4.1	13.9
Crustal structure and tectonics	3.9	4.0	4.3	7.5
Seismology	4.5	4.6	5.0	8.7
Experimental and theoretical geophysics	4.9	5.0	5.5	10.0
Petrogenesis and mineral resources	4.1	4.2	4.6	9.5
Volcanology and mantle geochemistry	3.7	3.8	4.2	10.5
Experimental and theoretical geochemistry	5.9	6.0	6.6	10.0
Instrumentation and facilities	5.0	5.4	6.0	12.3
Continental lithosphere	10.5	10.5	14.8	40.1
Ocean Sciences	**133.7**	**135.4**	**146.5**	**8.2**
Ocean Sciences Research Support (total)	66.6	67.4	73.1	8.4
Physical oceanography	22.5	22.8	24.0	5.0
Chemical oceanography	13.4	13.7	15.0	9.5
Marine geology and geophysics	16.2	16.2	16.5	1.9
Biological oceanography	14.4	14.8	17.6	19.3
Oceanographic Centers and Facilities	37.2	37.3	41.3	10.9
Ocean Drilling Program[e]	30.0	30.7	32.1	4.6
Arctic Research Program	**8.1**	**8.3**	**10.8**	**29.9**
Arctic research projects	7.6	7.9	10.3	31.5
Arctic Research Commission	0.5	0.5	0.5	4.2[d]
Total GEO	**285.2**	**291.3**	**320.9**	**10.1**

Numbers may not total because of rounding. Source: National Science Foundation.

[a]From the FY 1989 budget submitted to Congress by President Reagan.

[b]Change from FY 1988 current to FY 1989 proposed. Percentages are calculated directly from original figures supplied by NSF, before rounding.

[c]Includes administrative and support services and physical plant operation and maintenance.

[d]Contractor Management budget for NSF's support of the University Corporation for Atmospheric Research.

[e]These figures equal the total cost of the program less foreign funding and inputs from other U.S. agencies. Foreign contributions to ODP are expected to be $15.0 million in FY 1988 and $15.5 million in 1989.

TABLE 2. NASA Research and Development Program Budget

	Budget Authority, millions of dollars			
	FY 1987	FY 1988	FY 1989 Proposed[a]	Change %[b]
Space Station	**420.0**	**392.3**	**967.4**	**146.6**
Space Transportation Capability Development	**495.5**	**609.8**	**631.1**	**3.4**
Space Science and Applications	**1547.6**	**1575.8**	**1859.6**	**18.0**
Physics and Astronomy (total)	554.0	610.8	791.6	29.6
Hubble Space Telescope	96.0	93.1	102.2	9.8
Gamma Ray Observatory	50.5	53.4	41.9	−21.5
Global Geospace Science	0.0	20.0	101.4	407.0
Advanced X-Ray Astrophysics Facility	0.0	0.0	27.0	100.0
Shuttle/Spacelab payload mission management and integration	72.8	54.2	61.5	13.5
Payload and instrument development	—	43.7	77.1	76.4
Space Station integrated planning and attached payloads	15.5	18.9	8.0	−57.7
Explorer development	55.7	67.9	82.1	20.9
Mission operations and data analysis	131.0	132.0	156.2	18.3
Research and analysis	53.4	82.9	89.1	7.5
Suborbital program	79.1	44.7	45.1	0.9
Life Sciences (total)	71.8	69.5	101.7	46.3
Planetary exploration (total)	359.2	329.2	404.0	22.7
Galileo	71.2	51.9	61.3	18.1
Ulysses	10.3	7.8	10.3	32.0
Magellan	97.3	73.0	33.9	−53.6
Mars Observer	35.8	53.9	102.2	89.6
Mission operations and data analysis	75.1	74.7	112.7	50.9
Research and analysis	69.5	67.9	83.6	23.1
Space Applications (total)	**562.6**	**566.3**	**562.3**	**−0.7**
Solid earth observations	72.4	74.3	82.1	10.5
Environmental observations	318.3	313.5	368.3	17.5
Other[c]	171.9	178.5	111.9	−37.3
Commercial Programs	**40.9**	**73.7**	**57.9**	**−21.4**
Aeronautical Research and Technology	**374.0**	**334.8**	**414.2**	**23.7**
Transatmospheric Research and Technology	**45.0**	**52.5**	**84.4**	**60.8**
Space Research and Technology	**206.0**	**223.6**	**390.9**	**74.8**
Safety, Reliability, and Quality Assurance	**12.0**	**14.1**	**22.4**	**58.9**
Tracking and Advanced Data Systems	**17.1**	**17.9**	**18.8**	**5.0**
Total R&D	**3153.7**	**3294.5**	**4446.7**	**35.0**

Numbers may not total because of rounding. Source: National Aeronautics and Space Administration.
[a]From the FY 1988 budget proposed by President Reagan.
[b]Change from FY 1988 to FY 1989 proposed.
[c]Includes Materials Processing, Space Communication, and Information Systems.

TABLE 3. NOAA Budget for Operations, Research, and Facilities (ORF)

	Millions of Dollars			
	FY 1987 Actual	FY 1988 Approp.	FY 1989 Proposed	Change, %[a]
National Ocean Service	**114.9**	**116.7**	**71.4**	**−38.8**
Mapping, charting, and geodesy	42.0	43.0	44.2	2.8
Observation and assessment	30.4	30.3	19.7	−35.0
Ocean and coastal management	42.5	43.4	7.5	−82.7
National Marine Fisheries Service	**165.8**	**162.0**	**96.8**	**−40.2**
Oceanic and Atmospheric Research	**147.9**	**141.3**	**98.1**	**−30.6**
Climate and air quality research	37.7	36.1	48.4	34.1
Interannual and seasonal climate	10.6	10.3	7.4	−28.1
Long-term climate and air quality	25.0	23.8	24.9	4.6
Climate and Global Change	0.0	0.0	15.0[b]	100.0
National Climate Program	2.1	2.3	1.1	−52.1
Atmospheric programs	45.5	40.8	38.6	−5.8
Weather research	40.9	36.4	33.9	−6.8
Solar-terrestrial services and research	4.6	4.4	4.6	4.5
Ocean and Great Lakes programs	64.7	64.3	11.2	−82.7
Marine research	13.7	14.5	11.2	−22.7
Sea Grant	40.3	38.2	0.0	−100.0
Undersea research program	10.6	11.6	0.0	−100.0
National Weather Service	**333.2**	**332.0**	**333.4**	**0.4**
National Environmental Satellite, Data, and Information Services	**289.2**	**300.5**	**408.8**	**36.0**
Satellite observing systems	267.7	279.1	386.2	38.4
Polar orbiting system	30.9	75.0	130.4	73.8
Geostationary system	136.7	128.1	172.1	34.3
NOAA-Port[c]	0.0	3.5	0.0	−100.0
Landsat commercialization	27.5	0.0	34.1	100.0
Environmental observing services	72.6	72.5	49.6	−31.5
Environmental data management system	21.5	21.4	22.5	5.2
Program Support	**122.2**	**127.3**	**124.7**	**2.8**
Total, ORF Program Requirements	**1173.1**	**1206.3**	**1133.2**	**−6.1**

Numbers may not total because of rounding. Source: National Oceanic and Atmospheric Administration.
[a]Change from FY 1988 appropriation to FY 1989 proposed.
[b]$3 million of this request to be used for restoration of funds to the TOGA program.
[c]NOAA-Port is a proposed data transfer facility.

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TABLE 4. U.S. Geological Survey Budget

	Millions of Dollars			
	FY 1987 Actual	FY 1988 Base[a]	FY 1989 Proposed[b]	Change, %[c]
Geologic and Mineral Resource Surveys and Mapping	**169.0**	**176.2**	**167.8**	**−4.8**
Geologic hazards surveys	48.3	48.6	45.6	−6.2
Geologic framework and processes	24.5	27.0	23.3	−13.9
Offshore geologic surveys	24.8	25.2	28.2	11.9
Mineral resource surveys	45.1	46.6	46.3	−0.8
Energy geologic surveys	26.3	28.7	24.5	−14.8
Water Resources Investigations	**141.2**	**147.7**	**133.3**	**−9.7**
NWRRIS,[d] Federal Program	74.9	78.1	72.1	−7.6
NWRRIS, Federal-State Cooperative Program	55.2	58.8	55.9	−4.4
State Research Institutes and Federal Grants Program	11.1	10.8	5.3	−51.2
National Mapping, Geography, and Surveys	**88.5**	**90.2**	**90.0**	**−0.1**
Primary Mapping and Revision	34.4	35.6	35.6	0.0
Digital Cartography	13.8	14.0	13.3	−5.4
Small, Intermediate, and Special Mapping	14.2	13.4	12.5	−6.5
Advanced Cartographic Systems	12.2	13.2	17.7	34.0
Earth Resources Observation Systems (EROS)	9.0	8.6	7.1	−17.4
Cartographic and Geographic Information	3.5	3.8	3.8	0.0
Side-Looking Airborne Radar (SLAR)	1.5	1.5	0.0	−100.0
Facilities	**15.1**	**17.4**	**17.4**	**0.0**
General Administration	**17.1**	**14.4**	**16.4**	**13.8**
Total	**430.9**	**445.9**	**425.0**	**−4.7**

Numbers may not total because of rounding. Source: U.S. Geological Survey.

[a]FY 1989 base is calculated by making adjustments to 1987 appropriation, mostly for pay increase effective January 1, 1987, and for new retirement system.

[b]Taken from the FY 1988 budget proposed by the Reagan Administration.

[c]Change from FY 1989 base to FY 1989 proposed. Percentages are calculated directly from original figures supplied by USGS, before rounding.

[d]National Water Resources Research and Information Systems.

TABLE 5

EXPENDITURES RELATED TO GEOSCIENCE PROGRAMS

	FY 85 Expenditures (amounts in M$)
ALL DOE GEOSCIENCES	
Solid Earth Sciences	88
Atmospheric Geosciences	25
Ocean Geosciences	13
Space and Solar Terrestrial Geosciences	1
Hydrological Geosciences	15
Total	142*

SUBDIVISION OF SOLID EARTH BUDGET ($88M)	All Funding	Geosciences
Geothermal, Hot Dry Rock, and Thermal Regimes	36	36
Tar Sands, Oil Shale, Coal	20	-
Petroleum Geosciences	9	7
Underground Coal Gasification	10	-
Unconventional Gas	12	2
Gas to Liquids	1	-
Total	88§	45¶

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*Geosciences as defined in DOE (1986) Geoscience Projects, FY 1985.

§Budget in geoscience-related energy supply areas.

¶Approximate amount actually for solid earth sciences.

Source: Geoscience Projects, FY 1985 Listing, DOE/ER-0277.