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Geoscience Research For Energy Security

February, 1987

**A Report of the
Energy Research Advisory Board
to the
United States Department of Energy
Washington, DC 20585**

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Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585
(202) 252-8933

February 11, 1987

The Honorable John S. Herrington
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Dear Mr. Secretary:

Enclosed is the report by the Energy Research Advisory Board (ERAB), "Geoscience Research for Energy Security," prepared in response to your letter of December 1985 which requested a review of the nation's energy-related geoscience short and long term research needs, and the status of, and opportunities for changes in, DOE R&D programs.

In the view of the Board, the primary energy needs of the United States will continue to be met with oil, gas, coal, and nuclear resources for at least the next several decades. In 1985 the ERAB, in its report ("Guideline for DOE Long-Term Civilian Research and Development") stated that a primary national objective should be to: Reduce U.S. Long-Term Dependence on Foreign Oil. You observed in your December 1985 letter to ERAB that: "For the DOE programs to be effective, they must focus on the highest priority topics relevant to our mission." This report focuses on the nations geoscience needs and recommends DOE activities to mitigate major problems that effect energy security.

The report recommends new or redirected DOE geoscience research initiatives for oil and gas, coal, nuclear resources, structures and processes in the earth's crust, geothermal resources, oil shale, and waste disposal.

In light of the current and near-term National energy requirements, federal budget constraints, and the diminished R&D efforts from the domestic energy industry, the Board recommends that DOE:

- o Assign highest geoscience research emphasis to shorter-term, energy priorities of the nation; particularly advanced oil and gas exploration and production technologies;
- o Establish in DOE an Office of Geoscience Research to develop and administer a strategic plan for geoscience research activities;
- o Establish oil and gas research centers within each of the six major oil and gas provinces of the United States to conduct and coordinate interdisciplinary problem-oriented research;
- o Increase oil and gas research funding by an initial annual increment of \$50 million, primarily to support the regional research centers.

The Honorable John S. Herrington
February 11, 1987
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While the Board recognizes that implementation of these recommendations would require a restructuring of the Department's programs and budget priorities, the Board nevertheless feels that the growing dependence of the Nation on imported oil is sufficiently serious to warrant the recommendations made.

Sincerely

A handwritten signature in dark ink, appearing to read "John H. Schoettler". The signature is fluid and cursive, with a large initial "J" and a stylized "S".

John H. Schoettler
Chairman
Energy Research Advisory Board

Enclosure

ROBERT J. WEIMER
GOLDEN, COLORADO

February 9, 1987

Mr. John H. Schoettler, Chairman
Energy Research Advisory Board
Forrestal Building
Washington, D.C. 20585

Dear John:

I am pleased to submit to you the report "Geoscience Research for Energy Security" prepared by ERAB. The report reviews geoscience research needs and recommends activities by the Department of Energy (DOE) to mitigate major problems that affect energy security. Geoscience research is prioritized to meet both the short and long-term energy needs of the nation. A policy change is recommended to expand and emphasize short- and intermediate-term oil and gas research, which has been significantly reduced or eliminated by industry. However, this change should not diminish the strength of the long-term basic research programs within DOE which must be maintained.

I express my gratitude to members of the Solid Earth Science Panel, to ERAB members and staff who contributed to this study.

Sincerely,

A handwritten signature in cursive script, reading "Robert J. Weimer", with a long horizontal flourish extending to the right.

Robert J. Weimer, Chairman
Solid Earth Science Panel

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EXECUTIVE SUMMARY

OVERVIEW

Geoscience involves the geological materials, structure, and history of the earth, and the physical, chemical and biological processes that formed or now affect these materials.

Geoscience is of fundamental importance to the Department of Energy (DOE) because most of the nation's energy supplies are extracted from the earth. In addition, many waste materials derived from the extraction, production, and utilization of energy are subsequently returned to the earth.

In December 1985 the Secretary of Energy, John S. Herrington, requested that the Energy Research Advisory Board (ERAB) undertake a review of the nation's energy-related geoscience research needs and the status of DOE geoscience research and development (R&D) programs. In January 1986, ERAB created the Solid Earth Sciences Panel (SESP), which examined the following topics as identified by the Secretary of Energy:

- the future energy-related geoscience needs of the nation
- existing DOE geoscience research and development areas relative to the identified national requirements and within the context of related programs being carried out by other government agencies, universities, and industry
- opportunities for change and prioritization in existing DOE geoscience programs and organizational structure, and
- new geoscience research and development (R&D) initiatives.

The primary energy needs of the United States will continue to be met with oil, gas, coal, and nuclear resources for at least the next few decades. However, the ongoing rapid erosion of the nation's energy supply infrastructure threatens the future availability of these domestic resources, and hence, the energy security, international competitiveness, and standard of living of the United States. The low price of foreign petroleum has severely weakened the domestic oil and gas industry, and both coal and nuclear energy face significant economic and environmental restrictions.

The United States is meeting its energy needs with an ever increasing dependence on imported oil. Another national fuels crisis could be caused by such dependence on imported oil, future market manipulations by foreign nations, international conflicts involving petroleum-producing nations, the ongoing and rapid disassembly of the domestic petroleum

industry, and the severe stagnation of the domestic energy supply infrastructure.

GEOSCIENCE RESEARCH PRIORITIES

Geoscience research and technology development must play a critical role in solving the country's energy problems by providing the foundation for more cost-effective and environmentally sound energy resource exploration, characterization, recovery, and waste management. Geoscience research currently conducted by the Department of Energy is quite limited by its relatively low priority and funding levels within the department. Furthermore, the focus of geoscience research within DOE is on long-term, high-risk energy supply options and basic, discipline-oriented research. The shorter term applied geoscientific research and technology development has been largely conducted by industry. However, with the depressed economic conditions in the U.S. energy industry, research and technology development has been significantly reduced for the more conventional fuels. This reduction has left a large unfilled need in applied and basic research which necessitates a change in the federal research role.

In light of the current and near-term national energy requirements, federal budget constraints, and the diminished contributions from the domestic energy industry, the ERAB recommends that DOE re-focus research funding, in order of priority, as follows:

- oil
- gas
- coal
- nuclear
- basic research on structure and processes of the Earth's crust
- geothermal
- oil shale.

Oil and gas are given top priority because of their overall dominant role in energy usage and because the major energy problem facing the nation in the intermediate future is a shortage of domestic liquid hydrocarbon fuels, which threatens the nation's energy security and international competitiveness. (*Guidelines for DOE Long-Term Civilian Research and Development*, 1985, Vol. 1). No other domestic energy supply can meet the demand for liquid hydrocarbon fuels at the rate needed in the event of a disruption in the supply of imported oil.

Coal is third on the list because geoscience research offers opportunities to increase efficiency in future utilization of coal in electric power generation, liquid fuel conversion (liquefaction), gasification, and deep in-situ coal extraction. Furthermore, the domestic coal industry is currently limited by a lack of demand and not a lack of supply. Therefore, a 25% increase in

domestic supply is readily attainable. However, coal usage faces significant environmental problems, and these problems could inhibit the nation's reliance on coal and radically increase its cost.

Electrical and thermal energy from *nuclear* resources are still viable options for the United States. By relying more on nuclear energy, valuable oil and gas stocks could continue to be displaced as electrical generation fuels. Therefore, the domestic uranium supply industry should be maintained to reduce dependence on foreign supplies. However, like coal, nuclear energy is facing significant environmental pressures, especially in the area of waste management where geoscience plays a fundamental role.

Geothermal energy is sixth on the priority list because, as an energy supply option, it is small in contribution and limited by geographical consideration. Geoscience research should continue to make contributions in evaluating this potentially large resource.

Oil Shale rounds out the list of recommendations because of its relatively high cost and environmental concerns. However, oil shale is a significant national resource, and geoscience research and technology development efforts are warranted to optimize its availability as a future liquid hydrocarbon supply.

Three important topics crosscut the research needs in oil, gas, coal, nuclear, geothermal, and oil shale energies and the basic geosciences. One such crosscutting issue is the future availability of appropriately trained *human resources*. Another involves the potential *environmental concerns* associated with the recovery and utilization of energy resources, and the ultimate disposal of energy-related wastes. Finally, this report includes the critical topic of *advanced technology* (e.g., robotics, microelectronics, supercomputers, remote sensing) as it pertains to geoscientific research and applications. Funding in these critical crosscutting areas should be commensurate with the above geoscientific research priorities. Failure to pay adequate attention to either the environmental issues or the availability of trained human resources could severely impede the country's ability to rely on its domestic energy resources. Failure to incorporate advanced technology into geoscience research, energy exploration and recovery, and waste management may result in unacceptably high costs, low productivity, and poor competitiveness internationally.

RECOMMENDATIONS

The major recommendations of this ERAB report are as follows:

- Modify DOE policy to give the highest geoscience research priority to shorter-term, lower-risk options for energy supplies upon which the nation will be primarily dependent for at least the next two decades.

- Establish in the DOE an Office of Geoscience Research (OGR) to develop and administer a strategic plan for geoscience research activities within the department, especially in oil and gas and other liquid hydrocarbon conversion options.

The OGR would develop and implement a integrated, comprehensive program covering all DOE geoscience programs to ensure that the short- and long-term geoscience research needs of the country are identified and appropriately supported. The Director of OGR should be a geoscientist with administrative and research experience in the geosciences. OGR would be responsible for the existing fundamental and discipline-oriented geoscience and environmental research projects from the Office of Energy Research, and the more technology-driven geoscience research currently in places such as the Office of Fossil Energy and the Office of Conservation and Renewable Energy. The OGR would work with the U. S. Geological Survey (USGS) to prevent unnecessary duplication, promote coordination and cooperation of geoscience research, and coordinate geoscience research with other government agencies, industry, and universities.

- Establish oil and gas research centers within each of the six major oil and gas provinces of the United States to conduct and coordinate interdisciplinary problem-oriented research in the following areas all of which mitigate the problem of domestic hydrocarbon supply: enhanced oil recovery, unconventional natural gas recovery, subtle petroleum trap exploration, and geological basin analysis.

The purpose of the university-based research centers should be to support research which could be made available to the public sector to assist in accessing more efficiently the oil and gas resources of the United States. These activities should not conflict with the traditional role of the oil and gas industry in the U.S. economic system. Regional centers would encompass the following areas of the United States: Pacific and Alaska; Rocky Mountain; Central; Eastern; Texas; Eastern and Central Gulf.

- Increase oil and gas research funding by an initial annual increment of \$50 million, primarily to support the regional research centers.

This new funding would supplement the current fossil energy research programs that would be aggregated into the OGR. This incremental funding for fossil energy should be phased up to a total of \$100 million annually by FY 90. Approximately 90% of the funding should be used to support: 1) the new regional oil and gas research centers; and 2) expanded activity in applied research by groups in the USGS, national laboratories, technology centers, universities and state organizations. The role of these DOE-supported programs should be to develop fundamental knowledge and advanced technology from research to support the development of the nation's energy resources.

Chapter 1

INTRODUCTION

The U.S. Department of Energy's (DOE's) Energy Research Advisory Board (ERAB) was formally asked to address the issues identified in a charge letter from DOE Secretary John S. Herrington to ERAB Chairman John H. Schoettler (Appendix A). Secretary Herrington asked that ERAB identify the nation's geoscience research needs relative to energy supply, recovery, and waste management; that recommendations be formulated concerning coordination and cooperation among federal agencies, industry, and universities; and that opportunities for constructive changes in DOE be identified. The ERAB was also asked to recommend a priority ranking for geoscience research topics relevant to DOE's mission to ensure an adequate supply of domestic energy at acceptable costs and environmental impacts.

In response to the Secretary's letter, the ERAB Solid Earth Science Panel (SESP) was formed in January 1986. The SESP has 11 members who together represent the disciplines of geology, geochemistry, geophysics, hydrogeology, and environmental science. The individuals were selected from universities, industry, and federal and state agencies. Members of the ERAB and SESP are listed on pages iii and v, respectively.

The SESP was asked to review the status of DOE's solid earth science programs as distinguished from ocean, surface terrestrial, and atmospheric sciences. Thus, the SESP study focused on geology, solid earth geophysics, geochemistry, and hydrogeology. The panel was also careful to make explicit differentiation between geoscience research and development and the more engineering oriented activities within organizations such as DOE's Office of Fossil Energy.

The SESP began its study by referring to the December 1985 ERAB report entitled *"Guidelines for DOE Long-Term Civilian Research and Development."* This report summarized background information and recommendations for energy supply, demand, basic energy sciences, environment, health and safety, and DOE infrastructure. The major recommendations and comments from the 1985 report, which emphasize energy security and economic stability and strength, are summarized in Appendix B Tables B.1 and B.2 of this report.

The complete SESP met in four 2-day meetings in March, June, July, and September of 1986 and heard presentations by representatives from DOE, USGS, National Science Foundation, National Academy of Sciences, U.S. State Department, industry, and universities. Members of SESP visited four national laboratories (Los Alamos, Lawrence Berkeley, Lawrence Livermore, and Sandia), three technology centers (Morgantown, Bartlesville, and Pittsburgh), and the Amoco Production Company

Research Laboratory in Tulsa. (Refer to Appendix A for details of panel meetings and meeting agendas.)

The panel also reviewed dozens of documents and reports relevant to geoscience research. Data gathering, in general, was extremely difficult because of the fragmentation of geoscience work within the DOE. The panel found that, although geoscience research program plans, scopes, and objectives often appeared robust on paper, the actual allocated financial and manpower resources were normally quite small relative to the scope of the problem being studied and the ultimate application of the geoscience knowledge or technology.

Programs included under DOE's broad definition of geosciences (oceanography, atmospheric, and geological) are financed through six or more diverse organizations whose FY 85 budgets totaled approximately \$140 million, \$61 million of which was derived from a public utilities tax for storage of high-level radioactive waste in geologic repositories.

Excluding the commercial waste management utility funds and using the more restricted definition of solid earth geosciences, (i.e., geology, geophysics, geochemistry, and subsurface hydrogeology), it appears that the DOE's geoscience budget was approximately \$45 million in FY 85 (Appendix B, Table B.3 *Geoscience Projects, FY 85 Listing, DOE/ER-0277, May 1986*). It was not clear to the ERAB panel whether or not all DOE geoscience activities were listed in this DOE summary report. However, it was the most complete reference available.

The panel also found it difficult to determine what percentage the \$45 million geoscience budget actually represents geoscience R&D work. Spot checks of various projects revealed that in many cases geoscience generally plays a subordinate, service-oriented role within DOE, rather than a central R&D focus commensurate with its importance in meeting national energy security needs.

The six DOE organizations from which FY 85 budgeting data were available include: 1) the Office of Energy Research; 2) Conservation and Renewable Energy; 3) Fossil Energy; 4) Defense Program; 5) Environmental Safety and Health; and 6) Civilian Radioactive Waste Management. Although the budget information in the DOE report (ER-0277) may not be totally complete and does not lend itself to a simple categorical breakdown, it appears that from the total of \$45 million, approximately \$36 million was spent in geothermal-related and earth crustal processes projects, slightly more than \$7 million on fossil energy, and nearly \$2 million on other geoscience areas.

Taking, for example, the \$7.4 million budget for fossil energy work reported in the DOE summary document (ER-0277), the subcategories included:

Advanced Process Technology	0.8
Enhanced Oil Recovery	2.1
Underground Coal Gasification	0.6
Oil Shale	0.3
Unconventional Gas	<u>3.6</u>
<i>Total Dollars</i>	7.4 million

The above categories are also listed in the Fossil Energy budget for FY 86 as being funded for \$37.6 million (Appendix B, Table B.4). These funds are total for science and technology projects and the actual amount spent on geoscience research is uncertain, although it is believed by ERAB to be minor.

Geoscience research within DOE generally falls into two broad categories, the discipline-oriented, fundamental research in the Office of Energy Research (OER), and the technology-driven applications work in the various DOE program offices, such as Fossil Energy. The geoscience research funded by OER was determined to be of high quality and focused principally on small, discipline-oriented, fundamental, long-term research.

On the other hand, the geoscience work within the programmatic offices, such as Fossil Energy, consisted primarily of service-oriented applications and engineering projects. This applications-oriented theme held true in unconventional gas recovery, oil shale, and enhanced oil recovery work within DOE. This was especially true within the Energy Technology Centers, which seem to have significant autonomy within DOE. Overall, short- and intermediate-term applied geoscience research and technology development are generally missing from DOE programs.

The remainder of this ERAB report is organized into the following chapters: Fossil Energy; Geothermal; Nuclear; Waste Management and Environmental Geology; Crosscutting Geoscience Topics; and Organizational Structure and Funding. In these chapters, major problems related to the nation's energy security and international competitiveness are identified. Geoscience research must play an important role in finding solutions to these problems. Designation of the organizational entities to conduct the recommended research is beyond the scope of this ERAB report. Future programs should build upon appropriate current research programs and utilize, where possible, the available research personnel and support facilities of all research groups (USGS, national laboratories, technology centers, universities, state surveys, and industry).

Chapter 2

FOSSIL ENERGY

NATURALLY OCCURRING OIL AND GAS

The major energy problem facing the United States is a shortage of domestic liquid hydrocarbons, which threatens the nation's long-term energy security and international competitiveness.

Although energy is available to the consumer from a variety of sources, crude oil, natural gas, and coal provide 90% of present usage, and patterns of consumption are projected to be similar in the year 2000 and beyond (Appendix C Figures C.1 and C.2). The only real change will be that oil and gas will diminish and coal will increase in usage. For example, the U.S. transportation system is projected to remain almost solely dependent on liquid hydrocarbons into the twenty-first century.

It is likely that U.S. dependence on foreign sources of liquid hydrocarbons will continue to increase. For example, imports accounted for only 30% of the U.S. requirements for crude oil in 1985. However, domestic oil production has been declining at the rate of more than 500,000 barrels (bbl)/day per year, and thus imports currently comprise more than 40% of U.S. oil needs. With the recent drop in worldwide oil prices, the uncertainty of future international energy prices, and the depletion of known U.S. reserves, it is anticipated that foreign imports will expand to more than 50% of U.S. requirements in the next five years.

Greater U.S. dependence on oil imports adversely affects national security, the domestic petroleum industry, the balance of trade, and national and local economies. At \$15 per barrel, imported oil currently accounts for 27.5% of the U.S. trade deficit (U.S. Department of Commerce, 1986, pp. S15-S17). Oil and gas exploration in the United States is at its lowest level since World War II. Exploration and development of oil and gas resources are directly related to the drilling activity (measured as the number of drilling rigs, or rig count), and the U.S. rig count is directly related to the price of oil and gas. The drop in prices since 1982 has resulted in a reduction in U.S. drilling activity from more than 4000 drilling rigs to approximately 900 in operation today.

The drop in oil price has, therefore, created a corresponding drop in energy exploration, lowering of production levels, loss of manpower expertise in the petroleum industry, and decrease in tax revenues and royalty payments to federal, state, and county governments. Thus, foreign governments, by their petroleum policies, are determining the price of U.S. oil and gas, the level of U.S. drilling activity related to exploration and production, and the U.S. dependency on imported oil. Most importantly, these governments are dictating the health of the U.S. oil and gas industry for years to come. Long

term investments in oil and gas projects cannot be made judiciously when the price of oil is unstable.

The major research efforts in oil and gas exploration and production historically have been conducted or sponsored by industry. However, with restructuring caused by the depression of worldwide crude oil and gas prices, industry has reduced personnel and funding for research activities by about 25 to 30% in 1986 alone. Research facilities and personnel have also been lost through corporate mergers, and research emphasis has shifted toward projects with short-term payout and low risk. For example, enhanced oil recovery research is now concentrated on relatively standard technologies, such as water and steam flooding and carbon dioxide injection.

Exploration research in older oil and gas producing basins of the continental interior has been largely eliminated in industrial research laboratories and at the industrial operations level. Exploration by the major U.S. oil and gas companies is shifting to frontier and foreign areas. Exploration in many of the important interior U.S. hydrocarbon basins is largely being left to independent operators who have little or no research capability. This trend toward a drastic reduction of industry-supported R&D in the United States is particularly ominous when one considers that R&D expenditures are usually correlated directly with industry profits of the preceding one to two years. Thus, the real impact of R&D funding reductions has not yet been felt, because the major drop in the price of oil and gas is a relatively recent phenomenon.

Under the current federal government policy that industry will take care of short- and intermediate-term R&D requirements, DOE funding support for geoscience research in the fossil energy areas has been reduced precipitously over the past several years. DOE-funded geoscience research programs in liquid and gaseous petroleum supplies are unacceptably small when the dominant role of oil and gas in supplying the energy needs of the nation and the rapid disassembly of the domestic oil and gas industry's infrastructure are considered. Further, current DOE geoscience research is not focused on the nation's highest priority needs. DOE geoscience efforts are fragmented; they have no overall coordination or strategic plan, and in most cases are only discipline or service oriented.

The Oil and Gas Resource Base

The United States has a large petroleum resource base. Whether it can be recovered on an economically competitive basis with respect to imported petroleum, and how much can be ultimately recovered, are functions of technology development through geoscience research, economic factors, and national and state government policies.

The ERAB study of energy supply, using data compiled by USGS, Energy Information Agency, Gas Research Institute, and other sources (ERAB, v.

VI, 1985), summarized the remaining total oil resource as approximately 625 billion bbl (Appendix C, Fig. C.3) and the natural gas resource-proved reserves and potential as approximately 1000 trillion cubic feet (TCF) (Appendix C, Table C.1).

However, proven reserves recoverable with today's technology and price are only 30 billion bbl of oil (4% of the estimated resource) and only about 193 TCF of gas (<20% of estimated resources). In addition, natural gas liquids contribute to the liquid resource base. *Geoscience research offers the opportunity to recover a much larger percentage of these potential energy resources.*

A large natural gas resource also exists for which conventional methods of production currently are uneconomical. This resource typically is called unconventional fossil energy, and related research has been supported by DOE under the categories of Western Tight Gas Sands, Eastern Devonian Shales, Coalbed Methane, Gas Hydrates, Gas from Deep Sources, and Geopressured Resource. For unconventional resources in the first three categories, present technology and some additional applied research are adequate to permit development, depending on the price of conventional gas resources. However, the quantification of the resource and the technology for development are inadequate for the last three unconventional resource types, which must be considered as longer term, higher risk options.

Oil and Gas Research Initiatives

The ERAB is recommending that the DOE place priority on these oil and gas research objectives:

- enhanced oil recovery
- detection of subtle stratigraphic traps
- recovery of unconventional natural gas resources
- basin analysis.

Residual oil in known hydrocarbon reservoirs is the largest U.S. oil resource, but capitalizing on this large resource has proven difficult. The general lack of success in applying enhanced oil recovery research efforts relates, in part, to a poor knowledge of internal variations of reservoirs (Petzet, 1986; DOE Report on Residual Oil Resource, 1985, GAO/RCED-86-181BR). Such internal variation in the underground environment is known as "heterogeneity," (i.e., spatial variability in physical and chemical properties in reservoir rocks that influence both the entrapment and the production of petroleum). Reservoir heterogeneity is related to geologic processes that cause vertical and lateral variation in primary or secondary porosity, permeability, and lithology or changes through diagenesis. Enhanced *integration* of sedimentology, geophysics, geochemistry, hydrogeology, petroleum and chemical engineering, geostatistics, and related basic sciences is needed for defining the origin and distribution of

heterogeneities within petroleum reservoirs and understanding their major control on fluid behavior in oil entrapment and production.

Such integration of diverse geoscience disciplines within the framework of petroleum geology models would also be a major step forward in locating petroleum-rich *subtle stratigraphic traps*; new data from known fields could help design well spacing and enhanced oil recovery projects to optimally tap this large residual oil resource. Research by the Texas Bureau of Economic Geology (*Fisher and Finley, 1986*) has demonstrated the tremendous potential of using a more integrated approach in geoscience research activities. This approach is not fully utilized in the current DOE mode of operation.

Our knowledge of reservoir heterogeneity for use in oil and gas recovery can be improved by studies such as:

- Observe continuous outcrops of reservoirs formed in known depositional environments to relate primary heterogeneity to sedimentary processes; oil saturation patterns in tar sand outcrops (exposed reservoirs) are especially useful in characterizing heterogeneity and simulating variability.
- Describe major petroleum fields, by use of drilling cores, logs, and seismic and engineering data; relate primary porosity and permeability of reservoirs to secondary patterns of diagenesis and fracturing; identify stratigraphic level of source rocks in relation to reservoir to understand migration problems.
- Formulate predictive geologic and microfacies models from the preceding research to provide a scientific basis for predicting well spacing and enhanced oil recovery potential in poorly known fields.
- Use seismic tomography, three-dimensional reflection seismology, and S-wave variations to quantify reservoir properties and predict geologic conditions between wells.
- Document relationship of geologic variables to fluid flow as described by petroleum and chemical engineers; and chemical reactions related to fluid-rock or fluid-fluid interfaces.
- Develop instrumentation to improve quantification of geologic variables.
- Develop better models relating geologic measurements to engineering factors.
- Develop a database of geologic parameters in Tertiary Oil Recovery Information System (TORIS) or other computerized systems.

- Produce mathematical modeling of reservoirs, especially fluid transport modeling, parameter estimation techniques, and inverse modeling.
- Determine horizontal drilling techniques relative to the directional properties of rocks that influence fluid flow.

Expanded research in the *basin analysis* in both better known and frontier areas will provide a fundamental database for industry use in evaluation of exploration potential and in development of exploration strategy. Research should be planned to lower exploration and development costs for hydrocarbon reserves. Future research should include both mature and frontier basins. A preliminary list of topics for which research support is needed includes:

Mature Energy Basins

- Development of more advanced technology base to aid in subsurface and surface mapping to define regional stratigraphy, sedimentology, biostratigraphy, geochronology, and geochemistry of source rocks; establishment of detailed reference sections with integration of all physical, geochemical, and geophysical properties of rock sequences; relationship of exploration concepts to sequence stratigraphy.
- Integration of reservoir heterogeneity studies in regional structure and stratigraphic framework.
- Geochemical studies related to compositional changes of rocks through time and the influence, if any, on petroleum occurrences.
- Thermal and hydrodynamic history of basins, particularly in relation to maturation of source rocks, migration, and accumulation.
- Integration of geological, geophysical, and geochemical data to improve exploration models.
- Improvement of seismic stratigraphic methods for search of subtle stratigraphic traps.
- Reevaluation, with improved geophysical logging techniques, of the reserve potential of strata behind the well casing.

Frontier Areas

- Evaluation of geotectonic setting and tectonic overprinting.
- Studies of structural evolution and related stratigraphic and depositional history related to quality of reservoirs at time of deposition, diagenetic history and secondary changes in reservoir

properties, geothermal history of basin source beds and hydrocarbon maturation, and timing and pathways of migration of petroleum.

Many of the research topics listed above are covered in the Onshore Oil and Gas and New Evolution of Sedimentary Basins programs of the USGS (Peck, 1986). This work should be expanded to include all present and future petroleum-producing provinces in the United States and to assure coverage of all topical areas related to petroleum occurrence.

All rocks contain fractures of variable spacing, scale, and permeability, and the need has been identified for a better integration of studies of fractured media with fluid flow and other geologic parameters. A few important topics are:

- Systematic study of production from fractured reservoirs (e.g., basement production), with research oriented toward discovery of new fractured fields.
- Relationship of fractures to conventional reservoir properties (permeability and porosity) in controlling fluid flow, especially in enhanced oil recovery projects.
- Fracture zones (fault zones) as major pressure barriers within basins (changes in hydrodynamic regimes, both vertical and horizontal).
- Fracture zones as major conduits for migration of petroleum.
- Relationship of major faults to local "hot spots" (are faults conduits of higher-than-normal heat flow from the subcrust?).
- Mathematical models adequately describing the scaling geometry of fracture networks that can be integrated with reservoir properties.

Additional miscellaneous research initiatives include many factors that relate to petroleum accumulations, such as liquid-to-liquid, solid-to-liquid, and solid-to-solid interactions, seals for petroleum migration paths, and the thermodynamics of expulsion of oil and associated fluids from source rocks and management of undesirable products (wastes) from petroleum production.

Finally, unacceptable environmental damage is a potential impediment to the extraction and utilization of all existing energy resources, including oil and gas. Much of the concern can be traced to lack of geoscience data, inadequate predictive understanding of earth processes, and uncertainty about environmental disruption from resource development and subsequent waste disposal.

Oil and Gas Summary Recommendations

A substantial increase in DOE funding is recommended for *integrated basic and applied geoscience research and technology development*. Such geoscience research would help U.S. industry in the discovery and recovery of liquid and gaseous hydrocarbons, thus contributing to national energy security and economic and competitive stability and strength.

The goal for the Enhanced Oil Recovery program should be the advanced geoscientific technology necessary to produce at least 100 billion bbl of oil over the next 30 to 40 years from a current U.S. resource base of 500 billion bbl of residual oil and tar sands. A similar goal for the Subtle Traps program should be an expanded knowledge base for new exploration and production to ensure success in finding and developing the potential resource of approximately 80 billion bbl of crude oil and 800 TCF of natural gas, at finding costs that are economically competitive and extraction costs that are environmentally tolerable. Finally, the goal for the Unconventional Natural Gas Resources program should be the advanced geoscientific technology to develop this large U.S. resource.

The magnitude and significance of U.S. oil and gas problems call for a new organization of effort within the DOE to ensure successful implementation of the scientific initiatives described in this report. The ERAB recommends the following organizational actions (see also Chapter 7, Organization and Funding):

- As a major mission of the new Office of Geoscience Research (see Chapter 7), the DOE should develop and administer a strategic plan to implement exploration and production research in oil and gas and liquid hydrocarbon conversion from alternate fuels.
- The DOE should review its roles in the context of programs of other government agencies, industry, and universities in applied and basic petroleum research to minimize duplication of effort. The DOE should continue to support research groups in the USGS, national laboratories, technology centers, universities, and state organizations where scientific expertise and experience exist to conduct research projects on a competitive and best performance basis.
- The DOE should establish six regional oil and gas research centers in major petroleum-producing areas of the U.S. to conduct research and to serve as an interface between university, industry, and government (federal and state) activities.

The goal of the regional oil and gas research centers and other OGR-supported activities should be to develop fundamental knowledge from research and advanced technology to support more efficient access by the private sector to the oil and gas resources of the nation. These activities

should not conflict with the traditional role of the oil and gas industry in the economic system of the United States.

The regional oil and gas research centers should:

- Conduct and plan advanced research in oil and gas geology (stratigraphy, sedimentology, structure, and hydrogeology), petroleum engineering, geophysics, and geochemistry.
- Require integrated research in the above disciplines to improve enhanced oil and gas recovery, recovery of unconventional natural gas resources, infill field drilling programs, and identification of subtle traps. Other geoscience research subjects should be supported which are consistent with the goal of the research centers.
- Support faculty and graduate student research and education to maintain a human resource pool in universities to ensure that personnel to support future research needs of industry and government will be available.
- Conduct and support research in the continental U.S., particularly in older, energy-producing basins which still contain substantial oil and gas resources. A possible subdivision of the U.S. into six regional oil and gas provinces is: Pacific and Alaska; Rocky Mountain; Central; Eastern; Texas; Eastern and Central Gulf. A possible map of these subdivisions is shown in Appendix C, Figure C.4.
- Use and improve data bases in federal and state agencies to support federal research needs and projects in older producing basins.

University-based regional research centers offer the best opportunity for cross-disciplinary programs, the promotion of strong links between research and education, and the development of support from industry and state or local governments. Although no exact prototype exists for the envisioned regional centers, DOE-supported activities through the Bartlesville Project Office at the University of Texas at Austin, Stanford University, and the National Institute of Petroleum Energy Research, are examples of research activities in Enhanced Oil Recovery research which need development on a broader and more comprehensive national scale.

Procedures used to establish the Oil and Gas Research Centers could follow the general format developed by the National Science Foundation (NSF) program for Engineering Research Centers established in 1985. Details of the procedures can be modified to fulfill the objectives of the DOE program. Details of the management and responsibility of research centers should be determined by the Director of the Office of Geoscience Research within DOE.

One of the major recommendations of the White House Science Council Panel on the *Health of U.S. Colleges and Universities (Packard-Bromley Report)* is as follows: "The Federal government should support a major initiative to establish university-based interdisciplinary, problem-oriented research and technology centers directed to problems of broad national needs and relevant to industry technology" (OSTP, 1986). Although the concept of the Oil and Gas Research Centers was developed independently of this Packard-Bromley report recommendation, the Centers are envisioned in the same context of fulfilling national needs in geoscience energy research through federal government support.

COAL

Additional utilization of the nation's coal resources, in an economically and environmentally acceptable manner, is needed in spite of the current climate of widely fluctuating energy prices.

Coal represents nearly 25% of the present U.S. energy usage. Patterns of U.S. energy consumption are projected to be similar in the year 2000 and beyond, but the amount of coal utilized annually is projected to increase from 19.4 quads (Q)* in 1985 to 29.4 Q in the year 2000. Of this amount, 22.6 Q will be dedicated to electrical energy generation, the primary conventional use of the domestic coal resource (Appendix C, Figures C.1, C.2).

In addition to its conventional use in electrical energy supply, coal should be regarded as a major alternative source of liquid hydrocarbons, either by direct coal liquefaction processes or through a gasification-to-liquid process. Research on coal by the DOE is designed to make liquefaction and gasification economically viable and to ensure that potential environmental problems can be effectively overcome, so that the resource is available if and when required.

The Coal Resource Base

Present estimates of coal reserves and resources indicate about 9,000 Q, with another 40,000 Q in deep speculative resources. These figures can be compared with present total yearly U.S. energy consumption of about 75 Q, with 19.4 Q from coal (Appendix C, Figure C.1). Currently, the use of coal in the U.S. is demand-limited and not supply-limited. The industry could expand coal production by 30 percent with relative ease. Such enhanced utilization, in an environmentally acceptable manner, of the domestic coal resource is vital to continued U.S. economic competitiveness.

It can, however, be somewhat misleading to merely survey total coal inventory figures. Coal resources are extremely variable in composition, lateral extent, thickness, chemical and physical properties, and content of

*A quad (Q) is one quadrillion (10^{15}) British thermal units (Btu) of energy.

deleterious impurities. Such variability can add significant economic risk to coal exploration, production, and utilization. These variations in coal properties are fortunately not arbitrary and random, but the result of natural geological conditions. Therefore, it is exceedingly important to understand the geological conditions during initial coal and peat formation (genesis) and the subsequent changes over geologic time (diagenesis).

An understanding of the geologic factors controlling coal formation and quality will permit the development of valid predictive methods for exploration and development. Such models, as they become more reliable, can radically decrease the economic risk of developing a resource like coal. Predictive models are also a natural mechanism for integrating diverse geoscientific knowledge and data.

The importance of controlling coal quality to improve power plant performance was summarized in papers presented at a recent research conference in Reston, Virginia. It was reported that the on-line availability (plant factor) of electrical generating units fell from 78% to 63% from 1968 to 1978, and similar problems exist today (*Heap, 1985*). The principal cause of the degradation in plant availability is the variability in coal resource quality.

Coal Research Initiatives

Research initiatives tend to fall into two broad categories. The first includes the geoscience research supporting more efficient and dependable utilization of coal for electrical power plants. This generally involves the prevention of fouling and slagging events and the control of unacceptable environmental emissions. The second category of geoscientific research involves the conversion of coal to liquid and gaseous forms. All of these uses of coal depend greatly upon the physical and chemical properties of the coal feedstock, and hence, its geological history.

Basic work on the modes of occurrence, spatial distribution, and origin of elements and minerals in coals is required. The distribution can be related to both the environments of deposition and subsequent geochemical environments. Using basic interpretations, it may be possible to predict the distribution of coal quality parameters from limited field sampling and, thus, to determine the role of mineral species in the fouling and slagging of boilers. An outcome of this research would be better understanding of the role of specific coals in the fouling and slagging process and possible remedies for more efficient power production. Short- and long-term benefits will result from improved understanding of the basic physical, geochemical, and biological processes associated with environments of deposition and subsequent changes from post-depositional geologic events.

Development of reliable coal conversion technology requires knowledge of the conversion behavior of coal and the relationship of conversion behavior to some measurable set of coal properties. Also required are answers to

such questions as the effects on performance of normal variations in organic and mineral properties of a coal from a single mine, variations in coal particle size, and of switching coals. Unscheduled coal plant shutdowns are often caused by unexpected and uncontrolled behavior of the coal feedstock. The intent would be to predict slagging and fouling behavior from the coal mineral distribution and the energy conversion process conditions. Geoscience research would be a key component of any such future predictive capability.

Design of new processes or scaling-up of an existing process could be vastly improved by the availability of good predictive capability. For example, better knowledge of the products from devolatilization (condensibles, char, and gas species) and of the secondary reactors of the condensibles are needed to design a process for producing condensable products by mild gasification. Research on fundamentals of coal-conversion behavior should emphasize the development of accurate predictive capabilities to put gasification technology on a sound geological foundation. Fundamentals of coal conversion involve coal and minerals characterization relating to the organic structure of coal and changes in inorganic mineral matter.

Research should continue on the behavior of granular solids. An improved understanding by experiments and modeling will allow improved transportation and combustion where handling of solids is important. New computational approaches and radically advanced computer technology make it possible to model mathematically the behavior of flowing granular material. This promises to convert handling of solids from an art to a science, with major payoff in the energy industries as well as in general commerce.

It is necessary to understand the mineral constituents of coal to optimize retorting and burning processes, as well as processes for the conversion of coals to liquids. Studies of the sulfur and nitrogen geochemistry of coal are required for improved conversion and utilization. Identification of chemical constituents containing these elements and of the reactions that take place during combustion and other conversion processes are needed to minimize unacceptable environmental emissions. Although there is a long history of such efforts, a new generation of technology now makes it possible to study chemical reactions and kinetics previously inaccessible. Increased understanding of the basic physical and chemical processes will facilitate significant advances in the short- and long-term availability of domestic energy.

New recovery techniques are required to utilize the vast coal resource too deep for strip-mining. Geoscience research in support of new mining methods, and of alternative recovery techniques (e.g., in situ gasification), is needed. In addition, research on geologic conditions that influence safety and environmental protection in mining should be expanded.

Basic understanding of biological agents and various reaction catalysts is required to convert coal to fuel liquids and/or to remove sulfur, nitrogen, and other unacceptable components. To be successful, procedures must be based on physical, biological, and geochemical knowledge and research. Projected studies on gene splicing in biological agents to improve both product and reaction efficiency could have long-term research implications.

An important area of research is the origin, distribution, and physical and chemical characteristics of coal components which to a large extent control the reactivity of coal as well as the quality and quantity of resulting synfuels. The United States lags behind other countries in research in this field and in organic petrography and geochemistry, in general.

The composition and thus the quality of coals has varied through geological time as a result of differences in depositional environment, stage of floral evolution, climate, and coal metamorphism. When subjected to pressure and temperature, some coals tend to generate gas, whereas other coals generate a greater amount of liquids. In Australia, for example, a close relationship has been observed between the waxy land-plant-derived crude oil (naturally occurring) and coaly sediments of the Cretaceous and Tertiary geologic periods. These observations, confirmed by researchers in other regions, suggest that coals from certain depositional environments and of a particular geologic age would be the most desirable feedstock for experimentation in coal liquefaction projects, and could pave the way for significant reduction in the cost of generating liquids from coal.

Finally, basic work on analytical and computational methods to characterize coal chemically and structurally is needed. Overall, great opportunity is present for applying modern or high-technology methods to a traditionally low-technology area. The potential benefits of applying advanced technology to the exploration, extraction, and utilization of coal cannot be overstated.

A summary of the major geoscience research categories for coal is:

- Improved prediction of coal quality (organic constituents, Btu, ash content, sulfur, and trace elements) both laterally and with depth as controlled by:
 - depositional environment and age of coal-producing organics,
 - diagenetic and postdiagenetic geological processes.
- Evaluation of coal organic constituents (macerals) as they influence liquefaction processes.

Coal Summary Recommendations

The DOE should increase its national coordination role for coal research through assistance and support of geoscience research in the USGS, state geological surveys, and DOE laboratories. Of primary importance is characterization of coal quality (physical and chemical properties) as controlled by geological conditions. The goal should be a predictive capability. Such efforts will influence future utilization of coal in electrical power generation, low-grade energy industrial processes, liquid fuel conversion (liquefaction), gasification, and deep in situ coal extraction.

OIL SHALE

Oil shale provides a large potential resource for future liquid transportation fuel. Although its use is currently not economically competitive with domestic or imported oil, research and technology development are needed to ensure oil shale's future availability should it be required.

The Oil Shale Resource Base

The oil shale resource amounts to about 4000 Q, or a potential 200-year supply of liquid hydrocarbon fuels based on the consumption of 20 Q per year. The ability of the United States to utilize economically even part of these resources would contribute significantly to energy security by reducing dependence on imported oil.

Advanced technologies must be developed with the assistance of geoscience research, based on the basic properties of oil shale and associated materials under widely varying physical and chemical conditions. This basic geologic research and characterization of the resource are the current thrust of a USGS oil shale program.

Technological problems in oil shale development are related primarily to mining, rock crushing (or rubblization), retorting, and environmental problems associated with the management of wastes in the atmosphere, on the land surface, and underground, especially as they affect groundwater. Many of the problems are similar to those described in the handling and processing of coal.

The past and present efforts of industry and government to develop a shale oil industry have identified areas of inadequate basic and technological knowledge that require new or expanded research efforts. These efforts may result in a new and economically viable technology.

Oil Shale Research Initiatives

Examples of geoscience research categories are:

- Mapping of oil shale microfacies (i.e., vertical and lateral variations in chemical and physical properties, organic content, and related mineral constituents). Geoscience data should be integrated with materials analysis and handling. Mineral constituents and their influence on retorting and burning processes, both underground and at the surface, should be characterized.
- Basic reactions in pyrolysis of oil shale kerogens to assist in the quantitative understanding of oil generation and expulsion during retorting. Results should be applied to understanding natural petroleum generation in ancient shales of lacustrine origin.
- Behavior of granular solids (crushed oil shale). Experiments and modeling with new computer technology should improve materials handling.
- Physical properties of the rock. New mining and crushing technologies and an underground rubblization process for in situ retorting should be developed.
- Environmental problems related to an oil shale industry. Regional groundwater movement should be studied to optimize use and to prevent contamination by undesirable compounds over the short- and long-term. Geological and environmental problems associated with large waste dumps should be studied (e.g., slope stabilities, water infiltration, and the movement of toxic materials in solid or dissolved form).
- Sulfur and nitrogen geochemistry of oil shale. The chemical forms containing these elements and the reactions that take place during combustion should be identified so that the atmospheric effects of emissions can be minimized.

Oil Shale Summary Recommendations

The ERAB recommends that the DOE restore stable funding for basic geologic research programs but with increased emphasis on geochemical, mineralogical and other geologic factors relating to oil shales and their quality. The goals are to create an economically competitive and environmentally acceptable technology for the long-term supply of liquid hydrocarbon fuels and to develop the viability of the oil shale resource relative to national energy security.

Chapter 3

GEOHERMAL ENERGY

More effective utilization of the earth's natural thermal energy is required to contribute to future national energy requirements.

Geothermal energy for electrical power generation has received much attention as a possible long-range alternative to fossil fuels and nuclear energy. However, geothermal resource development for electrical generation has been hampered by location, relatively high costs, environmental concerns, and supply reliability. The site-specific nature of geological conditions restrains assessment and development of geothermal resources as an electrical energy supply resource. However, geothermal's potential is not limited to electricity generation. It should also be considered as a low-grade energy resource for various industrial processes, space heating, and agriculture.

In spite of these nonelectrical uses, it is projected that geothermal energy will supply less than 5% of the country's total energy requirements by the year 2000 (Appendix C, Figure C.2). Therefore, it seems incongruent that of all the energy supply options, geothermal-related research, at \$36M in FY 85, is by far the largest component of DOE's geoscience research budget (Appendix B, Table B.3).

The Geothermal Resource Base

Geothermal includes conventional resources (dry steam and hot water) and unconventional resources (geopressured, hot-dry rock, and magma). The geothermal resource base has been geographically characterized, although only in a preliminary way for unconventional types. Because of the natural heterogeneity of geological variables and technology problems associated with field-scale resource assessment, the amount of geothermal energy economically available for development still is poorly known. Few individual geothermal systems have been explored in sufficient detail to provide an economic basis for energy development.

Geothermal Research Initiatives

For the United States to utilize the earth's natural energy in a cost-effective manner, new research knowledge and technology development are required. Theoretical and applied research are needed on the geological, hydrological, and geochemical processes controlling geothermal resources. It is also important to better understand how these processes are related to the regional geological framework. An improved understanding of such natural earth phenomena would lead to more reliable and cost-effective resource exploration, assessment, and development strategies by federal, state, and industrial entities.

One of the most important areas of needed research is on the spatial heterogeneity of geothermal reservoirs, especially in fracture-dominated thermal regimes. The costs associated with uncertainty in drill siting is a major impediment to using geothermal resources. Geophysics, geostatistics, and remote sensing technology are all promising fields for fruitful research. Improvements should be made in instrumentation as well as data collection, analysis, and display methodologies.

Second, laboratory research is required on the physical and chemical properties of rocks and fluids at elevated pressures and temperatures. In addition, testing known geothermal reservoirs is required for the long-term development of geothermal systems. This may best be done through collaborative efforts between state governments, DOE, and industry.

Third, the hot-dry rock and magma energy research projects were developed as long-term, high-risk research to evaluate the geothermal potential of these unconventional resources. Hot-dry rock research has developed concepts and technology to a stage where possible commercialization can now be evaluated by industry. However, such geothermal energy is projected to play only a minor role in future patterns of energy use. Furthermore, DOE budget constraints and the need for higher priority geoscience research to mitigate pressing energy problems require prioritization of DOE funds. For these reasons, ERAB is recommending that the hot-dry rock and magma energy demonstration projects be terminated. The results of this high quality research and the associated competent personnel should be utilized, where appropriate, in support of higher priority geoscience research.

Finally, long-range planning, which depends in part on research, is necessary for any viable geothermal industry. Such planning appears to be lacking in the DOE geothermal program. Another serious deficiency in the national geothermal energy program is the lack of a resource assessment database that goes beyond the limited regional assessments of the 1970s. In addition, it is critical that potential environmental impacts of geothermal development be well understood, especially in the management of spent geothermal fluids.

Geothermal Summary Recommendations

Fossil energy resources, though vast, are finite. Therefore, a reasonable fraction of federal energy research should be directed toward long-term renewable resources, such as geothermal energy. However, it seems inappropriate to devote a major share of the DOE geoscience research budget to geothermal energy.

ERAB recommends a shift in emphasis and decrease in funding from specific large-scale geothermal demonstration projects to more basic

research in understanding fundamental physical and chemical processes associated with geothermal regimes.

Chapter 4

NUCLEAR ENERGY SUPPLY

To help ensure national energy security, it is important to maintain a domestic supply of uranium for the nuclear power industry.

The uranium industry is deeply depressed because of cutbacks in construction of nuclear power plants and an increase in cheap, imported uranium. Yearly production has dropped from over 40 million pounds of uranium oxide in 1980 to about 10 million pounds in 1985. Imports now account for up to 50% of the United States' uranium requirements, and may increase to 60 to 70% in the 1990s. Utilizing currently available technology, the cost of domestic production of uranium from low-grade deposits is not economically competitive with high-grade, and sometimes subsidized, imports.

Starting in 1982, the drop in the price of uranium forced the closing of domestic mines and mills; the uranium mining and milling industry has now been declared nonviable by the DOE and the Nuclear Regulatory Commission (NRC). The plights of the uranium and petroleum industries in this country are similar. Their disintegration has been caused, to a significant extent, by unrestricted foreign imports at very low prices.

However, if the domestic uranium supply industry is to be resurrected, an impediment besides cost may have to be overcome. Without innovative and forward-thinking research, environmental concerns could severely impede future uranium mining and milling. Cost-effective management of byproduct fluids and tailings and restoration techniques for in situ leach fields must be developed and ready for future domestic uranium production.

The Nuclear Energy Resource Base

The United States has a large uranium oxide resource of approximately 4.1 million tons, at a forward cost of less than \$100/lb (UCRL 90820, LLNL, 1984). Geoscience knowledge and technology are essential in maintaining the domestic resource database for uranium. Annual estimates of uranium resources by the DOE's Grand Junction, Colorado Area Office are prepared from data provided by the uranium industry and government surveys. A summary of technology scenarios and resultant research needs to evaluate the uranium resource was recently prepared by the DOE Office of Nuclear Energy. As is the case for other energy supplies, the resource is finite but could be extended many-fold through the long-term development of breeder reactors and fusion-fission hybrid technologies. The United States needs a reliable domestic supply of uranium because of the uncertainty of imports in times of international crises and the

unpredictable changes in foreign-government policies on exporting uranium.

Nuclear Energy Research Initiatives

Most of the United States' uranium reserves are in sedimentary rocks, and uranium deposits are trapped by physical and chemical heterogeneities in layers similar to those found in petroleum accumulations. For these geological reasons, much of the geoscience research recommended for oil and gas (Chapter 2) also applies to uranium exploration and production. Host rock heterogeneity is a major problem in mine planning and development, and in the movement of fluids in solution mining. The objective in solving this problem is to lower costs and to make domestic uranium competitive with imports. However, the unpredictability of future resource needs poses a problem in long-term planning.

Geoscience plays a key role in the exploration, production, and waste management of uranium. In the past, geoscience research has been conducted by industry and government agencies, particularly the USGS. With reductions in federal funding, research vital to the industry has been largely eliminated, and educational programs in universities have been reduced in scope. Continued research is essential to develop new exploration and production technology. Effective and efficient DOE management should be mobilized to protect past investments in science and data. For example, due to budget problems, data from the \$300 million National Uranium Resource Evaluation program are being severely underutilized. Uranium research has been phased out at a time when information already collected by the federal government and industry could be used to build important ore-deposit models and design advanced exploration strategies.

The past and future problems in waste management from mining and milling are also targets of required research efforts as described in Chapter 5 on waste management. Uranium supply and waste management technology should be continually advanced so they will be ready when called on in the future. Research, basic or applied, rarely succeeds in a crisis environment regardless of the available budgets. Categories of necessary uranium research are:

- basin studies and rock heterogeneity of sedimentary strata for exploration, development and resource base assessment
- geology and geochemistry of uranium migration and accumulation in natural systems and application to solution mining
- advanced technology in exploration, production, and waste management

- geology and distribution of radioactive materials to help understand earth dynamics
- global resource assessment.

Nuclear Energy Summary Recommendations

The ERAB recommends that the DOE maintain a modest level of research support in the geoscience aspects of uranium supply, production, and waste management. Such efforts should be coordinated with recommended programs in oil and gas (see Chapter 2). In addition, DOE should take positive steps to protect major past investments in developing uranium supply data.

Chapter 5

GEOSCIENCE RESEARCH IN WASTE MANAGEMENT AND ENVIRONMENTAL GEOLOGY

There is inadequate knowledge about storage, mobilization and movement of energy-related wastes in surface and underground environments.

Energy sources, as they are developed and utilized, will generate waste (e.g., oil and gas wastes, coal ash, spent oil shale, spent geothermal brine, nuclear processing wastes, spent nuclear fuel, and uranium mill tailings). The DOE operates many large facilities that generate nuclear and nonnuclear (chemical) waste products; this waste must be disposed of in an environmentally acceptable way. Waste products are being generated at increasing rates by the government and industry, but waste management and disposal have been handled with varying degrees of responsibility and concern. The government and the private sector share the responsibility of ensuring that the waste by-products of energy production and utilization, and the operation of energy facilities will be managed in a safe and environmentally secure manner.

Since wastes are generally disposed in geologic media, waste management is an important application for geoscientific research and technology development. A great deal of energy and defense-related waste materials are already in the earth's environment, albeit underground. Past practices in waste management have created problems that may require remedial work, and research is needed to solve these problems and to improve on present procedures in waste disposal. Decisions concerning potential remedial actions involve large sums of money, and should not be made with insufficient data on waste material behavior in the earth's environment.

RADIOACTIVE WASTES

Radioactive wastes are generated at a variety of commercial and defense materials facilities. There are several different categories of radioactive wastes depending types and amounts of radionuclides.

Radioactive Waste Research Initiatives

Nuclear wastes are likely to be disposed of in geological media. One important long-term health and safety consideration is the potential mobilization, transformation, and transport of these waste materials by underground fluids. Development of second-generation waste forms may be one viable option for safer disposal of high-level radioactive waste. For example, highly insoluble, synthetic minerals can encapsulate radionuclides for extremely long periods of time. Basic thermochemical and kinetics data, and knowledge of conditions of processing, leachability, stability, and radiation effects, are needed for predicting the long-term

isolation (i.e., for several millennia) of radionuclides within a geological repository.

Since subsurface fluids are likely to be a key component in assessing the fate of waste materials buried underground, more intensive study is required of the flow of water and solutes in porous and/or fractured and jointed media. Such research is especially needed in unsaturated geological regimes. Basic work towards improving our understanding of flow and transport in natural systems is vital to assuring safe disposal of any waste. It is especially important that we better understand the components affecting the water balance in arid environments, and improve our predictive capabilities concerning infiltration and drainage in unsaturated domains. This understanding of fluid migration should be coupled with studies of chemical interactions in order to predict accurately the migration of chemical species, as well as dissolution and precipitation phenomena for waste materials. Studies of the fundamentals of transport processes in minerals and rock systems are needed under various temperatures, stresses, radiation conditions, fluid pressures, and chemical composition gradients. Such studies have general applicability to all energy technologies as well as to the management of waste by-products, and are critical to the development of technically defensible predictive models.

Storage of wastes in underground geological media requires development of nondestructive and nonpenetrative methods for site exploration and monitoring of the environment. Areas where nuclear waste either has already been disposed or may be disposed in the future must be examined and monitored. Improved methods of electromagnetic and acoustic imaging are vital to the confident management of nuclear waste disposal facilities.

The role of the organic constituents and biological microorganisms of natural geological systems must be better understood. Organic compounds play a role in the chemical complexation of many contaminant species, and may control transport of wastes in bulk rock and in rock fractures by creating preferential adsorption sites, such as films on natural rocks and minerals. The specific role of natural organics and microorganisms in fluid migration is not currently understood.

Utilization of data obtained from natural "experiments" can provide information on processes important in long-term repository integrity. Some natural processes that may provide critical guidelines include:

- hydration, alteration, and devitrification of volcanic glasses, such as obsidian and basaltic glass
- alpha radiation damage in natural uranium and thorium minerals, and beta damage in halite as it affects solubility, leachability, and the release of stored radiation-induced energy upon heating

- geochemistry, distribution, and movement of actinide, lanthanide, and fission-product analog elements in proximity to a natural heat source
- destruction and dissemination, as well as formation (concentration), of uranium ore deposits in sedimentary rocks
- thermomechanical responses of natural media correlates with laboratory and theoretical studies of viscoelastic properties and elastic-plastic response.

The extremely long-term hazards of nuclear wastes require predictive methods of forecasting crustal behavior over long periods. Such predictive methods demand knowledge of the frequency and timing of important natural physical, chemical, and biological processes and their impact on the waste disposal site. At present, such geoscience data are extremely limited.

Major categories of required geoscience research to support nuclear waste management are:

- fluid flow and solute transport R&D for application to saturated and unsaturated media in a representative number of heterogeneous geologic terrains
- new instrumentation and data assessment technology to increase remote sensing capabilities for surface and subsurface nondestructive probing of geologic formations
- scientifically defensible data sets against which to develop and test, and to the extent possible validate, the complex predictive models used to simulate the natural environment, and the mobilization, transport, transformation, and fate of man-induced contaminants
- second-generation disposal schemes and waste forms
- development of scale factors consistent with geological spatial heterogeneity, in order to confidently use the results of laboratory, bench, field, and pilot experiments
- tectonics and stress-strain phenomena as they relate to seismology, fracture distributions, and rock integrity.

Radioactive Waste Research Summary Recommendations

A redirection of the DOE funding is required to conduct more basic and applied geoscience research aimed at better understanding of: 1) saturated and unsaturated flow in representative types of heterogeneous geologic

environments; and 2) the natural phenomena in these environments that affect the safe encapsulation of nuclear waste over the long term. This basic and applied research would complement the ongoing application-driven programs, such as the Office of Civilian Radioactive Waste Management, and provide the nation with a continuing ability to assure the safe management of the byproducts of both nuclear energy and nuclear weapons production. The basic geoscience research results would be a necessary part of the ERAB Civilian Nuclear Panel's recommended database validation process involving the concerned parties (federal and state agencies and Indian Tribes). These data should be made available to the concerned parties through the recommended new DOE Office of Geoscience Research.

NONNUCLEAR WASTES

Examples of nonnuclear wastes include: oil and gas wastes; coal ashes and sludges; spent oil shale; geothermal brine; and various chemical processing wastes related to energy and defense activities.

Nonnuclear Waste Research Initiatives

As mentioned previously, energy sources generate various wastes that must be disposed of in an environmentally acceptable manner. Nearly all of the research areas discussed in the preceding section on nuclear wastes are also applicable to nonnuclear and mixed wastes.

However, each waste type has its own special considerations. For example, one must define the nature of spent oil shale and coal wastes and identify the specific chemical species that can be leached from them. Successful prediction of contaminant transport will require detailed understanding of the mineralogy, process chemistry, and groundwater circulation patterns in oil shale and coal beds. Another example is waste products from petroleum production, which require continual analysis for the most acceptable disposal methods. Studies should be conducted on all waste forms; contaminant mobilization, transformation, and transport; and natural traps for inorganic, organic, and biologic wastes.

Studies of natural traps for petroleum may lead to the identification of areas in the earth's crust where organic wastes can be safely stored. Synthetic clathrate minerals (e.g., zeolites) have potential for permanently storing organic solvents in rocks.

Active research should be carried out at DOE field sites where toxic pollutants or mixed wastes already exist in the ground. Methods of contaminant mobilization, transformation, and transport can all be studied in the field with improved understanding of the behavior of toxic wastes. Such research can be carried out using existing field sites at DOE installations.

Biologic agents and other advanced forms of in situ characterization and remedial action should be developed to detect and clean up low levels of organic and inorganic pollutants. As knowledge of geochemistry is also important, it is necessarily an interdisciplinary study area. Microbes are sensitive and efficient in natural systems and can be "engineered" to perform specific functions. Advanced computational and graphical analysis methods should be employed in the investigations of the earth's natural mechanisms and the interactions of man-induced pollutants into the natural system.

Examples of priority research categories are:

- studies of fluid flow in unsaturated and saturated porous and fractured/jointed rocks
- studies of physical, chemical, and biological interactions of fluids and rocks
- development of geophysical methods of monitoring flow and solute transport
- measurements of properties and dynamic processes in unsaturated (arid) domains
- studies of underground heterogeneity (spatial variability), and geophysical testing and measuring of these environments using nondestructive, high-resolution technologies
- testing and partial validation of predictive computer models using natural field sites and complex synthetic data sets.

Nonnuclear Waste Research Summary Recommendations

The DOE should expand its geoscience research and development activities to build the scientific foundation upon which predictive environmental assessments can be based. Example application areas include solid and hazardous wastes, mixed hazardous wastes and low-level nuclear wastes, coal and oil shale wastes, oil and gas wastes, and spent geothermal brines. Potential impacts of failing to implement these ERAB recommendations include:

- inability to capitalize on domestic conventional and alternative energy resources because of environmental limitations and unduly costly waste management activities.
- curtailment of currently operating DOE facilities serving the U.S. Department of Defense.

- mandated, but possibly unnecessary, costly retrieval or in situ destruction of wastes already in the ground.

Although not necessarily classified as waste management or environmental geology, geoscience research also adds to the knowledge base that provides the foundation for technology applications like underground energy storage. Examples include the Strategic Petroleum Reserve, natural gas storage, underground compressed air storage, aquifer thermal energy storage, and contemplated applications like subsurface hydrogen energy storage.

Chapter 6

CROSSCUTTING GEOSCIENCE TOPICS

Several important geoscience topics are applicable to many types of energy supply resources (i.e., fossil, geothermal, nuclear, etc.) and different energy-related waste management applications. Three of these crosscutting topics are: 1) research on basic earth crustal structures and processes; 2) development and adaptation of advanced technology (e.g., advanced computing and information management, microelectronics, robotics, remote sensing) to geoscience research and application programs; and 3) the availability of adequately trained people to support future geoscience needs in this country.

THE EARTH'S CRUSTAL STRUCTURES AND PROCESSES

Knowledge is inadequate about the origin, composition, structure, and processes of the continental crust, and the relationship of crustal structures and processes to energy resources and energy-related waste disposal.

Basic geoscience research in the DOE suffers from inadequate funding and lack of integration with other DOE programs that apply geoscience technology (e.g., Fossil Energy, Civilian Nuclear Waste Management). Both problems impair the ability of the DOE to respond to national energy needs in an effective and efficient manner.

Advances in geoscientific knowledge are vital to the utilization of the earth's resources and the disposal of wastes. Plate tectonics has, in the last two decades, provided geoscientists with a model for predicting crustal structure and behavior on a global scale. Our basic understanding, however, is still inadequate for predictions at the smaller regional and local scales normally encountered in applied geologic problems. Much more knowledge is required for understanding intraplate tectonism, basin development, basin hydrodynamics, folding and faulting, deformation and magmatism at plate boundaries, thermotectonic evolution of the crust, and intraplate seismicity.

Using the fundamentals of physics, chemistry, biology, and engineering, geologists can better understand the evolution of earth and its resources in space and time. Techniques, such as seismic reflection, refraction, and tomography, and electrical, magnetic, and gravity research, must be refined to allow us to look deeply and with greater resolution into the crust in three dimensions. Advanced analysis methods for digital terrain models also hold promise for characterizing structure and tectonics in an area. Through the use of accelerator mass spectrometers, ion probes, and similar instruments, the chemistry of earth materials and their reactions under a range of geologically realistic conditions can be assessed.

As knowledge accumulates, it becomes increasingly possible to use computer models to make predictions of structures and processes. This area has tremendous potential. Computer models, however, still require actual testing for verification and validation. The ultimate geoscience test is scientific drilling. Such drilling may be relatively shallow, or it may extend to deep high-pressure and high-temperature regimes beyond the abilities of existing technology. New developments in the technology required to drill, core, sample, and measure rocks at depth are requisite to increased understanding of the crust and crustal processes. Core, fluid, and gas samples must be recovered. Downhole devices are needed to extend measurements to as much rock around the borehole as possible. New geostatistical techniques must be developed to deal with geological spatial heterogeneity from relatively few borehole sample sites. Thus, an urgent and ongoing need exists for technological developments in the geosciences as the earth is probed more deeply and with greater precision.

Crustal Research Initiatives

The foregoing are large tasks that DOE cannot undertake alone. Fortunately, a network of federal agencies, national laboratories, and universities provide support for both small programs and large comprehensive national and international efforts in the solid earth sciences. The DOE must seek increased involvement in basic science programs so that its own efforts can be magnified. It should also design means to ensure that its own widely varied earth science efforts (e.g., those in fossil fuels) are coordinated to avoid wasted research opportunities.

An area of basic geoscience research in which the DOE has initiated excellent and important activities is in developing geologic models dealing with thermal regimes and testing these models through drilling. The DOE can make important contributions to advances in fundamental understanding in this field. To take full advantage of all opportunities, however, DOE should consider coordinating its own activities in drilling, whether inside or outside Basic Energy Sciences (BES), in a timely way that permits more scientific utilization of drilled holes. At the same time, BES should adhere to its basic geoscience objectives, which may require considerable freedom to explore fundamental problems.

The present policy of concentrating the BES drilling program on "thermal regimes" is too narrow, and a broader focus of testing crustal processes in general should be developed. Present policies essentially restrict the drilling program to regions of high heat flow in the far western United States, and exclude equally worthwhile and perhaps higher priority geoscience research on other topics and in areas located east of the Rockies. If DOE were to interact more broadly and more fully with the National Scientific Drilling Program operated for the National Science Foundation and the USGS by Deep Observation and Sampling of the Earth's Continental Crust, Inc. (DOSECC), a more vigorous and broader

program could be developed. For example, by combining efforts and coordinating planning, economies could be effected through the joint funding of a single drilling and engineering group, rather than duplication of these efforts by each organization.

The BES basic geoscience program must also seek broader interaction with the university community. University research should be done through a competitive grant program allowing access to the research work of a broad range of university programs. Cooperative studies in the geosciences between universities and national laboratories should be expanded to all of the laboratories. Interactions between universities and national laboratories in the geological sciences must be expanded because the DOE needs access to the diverse research capability of the entire geoscience community. Such interactive, long-term support is necessary to provide stability to a fluctuating profession in which a severe shortage of geoscience personnel is expected to develop in the near future.

A summary of research categories include:

- improved understanding of the behavior of subsurface organic and inorganic fluids in rocks
- three-dimensional characterization of the internal properties and structures of rock bodies
- in situ measurement in high-pressure and high-temperature environments in deep boreholes
- modeling crustal structures and processes
- testing crustal models through scientific drilling
- exploring the range of hydrocarbon generation in time and space.

Crustal Research Summary Recommendations

Substantially increased funding support is recommended for basic geoscience research related to the structures and processes within the earth's crust. The goal is to stimulate new approaches to DOE geoscience programs, including all crustal regimes pertinent to energy. Development of fundamental data is necessary for applied programs. The DOE effort in structures and processes should include areas in which cooperation between national laboratories and other research institutions can be leveraged into greater collaborative efforts. The DOE should cooperate with others in its drilling program, and perhaps coordinate its efforts in continental scientific drilling with the USGS and NSF, which already operate jointly through DOSECC. The DOE should continue to expand its support for university research programs, and develop a competitive process of selection that encourages new university groups to work with

the DOE and its laboratories. This process is important in mitigating the shortage of broadly trained geoscience personnel that the panel believes will develop in the near and intermediate future.

ADVANCED TECHNOLOGY DEVELOPMENT AND IMPLEMENTATION

The United States has reduced funding for the development and adaptation of advanced technological tools and the methods required for more cost-competitive and environmentally sound energy exploration and development.

In the past, advances in energy technology have been the product of efforts by industry, the government, and universities, either singly or cooperatively, with industry conducting most of the research. Reductions in government funding, and in particular cutbacks in research and exploration by petroleum and mining companies, have created a cloud of uncertainty regarding development of the advanced technology required to conduct more sophisticated energy exploration, production, and waste management efforts. In 1985, an already depressed oil industry spent \$700 million in geoscience-related petroleum research, while the federal government, including DOE, USGS, and NSF, spent approximately \$21 million in geoscience-related petroleum research. Thus, federal government expenditures were only 3% of industry's level of spending. The petroleum industry expects to reduce research by one-third in 1986, continuing the drastic downward trend in geoscience research in this country.

Advanced Technology Research Initiatives

The following section identifies some areas where the federal government should play a leading role in funding advanced technology development and adaptation to the geosciences. Many have been listed because of their recognized immediate importance to the nation's oil and gas energy needs. However, technological areas for focused development must be identified for expanded research in all areas of energy problems. The topics selected here include remote sensing, artificial intelligence systems, advanced drilling systems, electrical and electromagnetic technology, supercomputing, biotechnology and geosphere-biosphere interactions, advanced seismic applications, surface geochemistry exploration, and advanced well evaluation methods.

Airborne Remote Sensing and Satellite Mapping and Measurement

Airborne and satellite remote-sensing survey systems provide a rapid and relatively inexpensive method for exploration, resource evaluation, and waste-management activity assessment. Unfortunately, civilian photographic aerial survey systems have not evolved significantly over the past decade. Minor advances have been made only in large-scale format cameras and film resolution and sensitivity. Major opportunities exist for

significant technology breakthroughs in the areas of digital airborne systems, multichannel spectroscopy, and quantitative remote sensing. New engineering developments related to charge-couple-device technology provide for major advances in spectral coverage and resolution and array type scanning devices. Large-scale data management and display is also a critical area, especially in the integration of diverse geophysical and geological data sets with remote sensing data.

Areas for future technical developments include:

- use of higher resolution multichannel scanners to support quantitative assessment of vegetation, geochemistry, water balances, thermal variations, geological structure, etc.
- development of synthetic aperture radar satellite systems
- direct/indirect hydrocarbon airborne scanners
- improved image-processing and complementary data set integration and display capabilities.

Artificial Intelligence (Knowledge-based) Systems

Artificial intelligence (AI), or computer-based expert systems, is not a new technology. It has been in relatively widespread use for more than 15 years. The approaches used to guide reasoning by AI systems are intended to reduce the amount of time required searching for solutions, given all the potential answers. AI programs have already been developed for well log interpretation and mineral exploration. Opportunities exist for AI applications in a variety of geoscience technology areas, for example:

- seismic data processing assistance
- seismic stratigraphic interpretation
- "play and prospect" evaluation
- well log evaluation and correlation
- conceptual model development
- "smart and friendly" user interfaces for computer programs

Advanced Drilling Systems

Well drilling is one of the largest costs in exploration, development, geoscience research, and waste management programs. The high cost of drilling adversely affects a wide range of geoscience programs as well as oil and gas field operations, ranging from deep, expensive wildcat wells in hostile environments, to standard in-fill development wells, to multiple shallow shotholes for seismic spreads. Future drilling needs will require that standard wildcat wells be drilled to greater depths (greater than 30,000 ft.) and be placed in deepwater areas to fully exploit our domestic hydrocarbon resources. In field development situations, horizontal drain

holes will need to be drilled accurately to exploit fractured reservoirs and thin hydrocarbon columns more efficiently.

Most future oil and gas discoveries onshore in the conterminous United States will be from subtle geological traps (*DOE Guidelines, Vol. 6, p. 37, and Myer and Fleming, 1983*). To find and develop these traps, industry needs to be able to drill a larger number of wells more rapidly and less expensively.

Additional technological needs related to drilling include:

- dependable measurement-while-drilling systems
- advanced high-temperature mud systems
- improved well-stimulation techniques
- less-expensive casing design systems
- improved cementing techniques.

Electrical and Electromagnetic Technology

Improved electrical exploration methods could provide detailed images of the geoelectric structure and stratigraphy of oil and gas traps and of regions susceptible to contamination. Under appropriate conditions, oil/water contacts and geochemical alteration chimneys associated with hydrocarbon reservoirs could be detected. In areas yielding pool seismic data, improved electrical techniques could be used to define structural and stratigraphic traps.

Supercomputing

Present research in numerical modeling of earth structures is focused on developing advanced finite-element method and discrete-element method computer codes capable of modeling large deformations, heat transport, and fluid flow in both continuous and discontinuous geological intervals. Theoretical work, code complexity, and large scientific computers have evolved to the point where it is conceivable to define problems and obtain solutions for "real world" geological problems. Basic research on constitutive theory and computational modeling can provide quantitative insight and models for a variety of theoretical and applied problems, such as:

- integrated subsidence, deformation, and fluid flow basin models
- compressive and extensional fault styles
- three-dimensional stratigraphic correlation interpolation models
- coupled thermomechanical, hydrological, and geochemical models.

Biotechnology and Geosphere - Biosphere Interactions

New instrumentation and technologies are required for research on possible geosphere-biosphere interactions at hundreds of meters below the

earth's surface. As the human need for potable groundwater and the volume of extracted groundwater both increase the probability of groundwater contamination will inevitably rise. The impact of waste facilities sited at or near the surface and the interaction of contaminants with moving groundwater takes on critical, and in some cases life-threatening, importance. Development of the technology needed to mitigate groundwater contamination is in the formative stage. The DOE is encouraged to continue its new initiative to develop information about microorganisms living on the surface and down to hundreds and perhaps thousands of meters. Opportunities exist on a global scale for fundamental breakthroughs in this area. Regions most susceptible to waste contamination are in areas of large and deep aquifers lying beneath many of the nation's large population centers. Biotechnological solutions to prevent or mitigate deep aquifer contamination will depend on a sound database.

Advanced Seismic Applications

The capabilities of the seismic method have been significantly improved with recent advances in vertical seismic profiling, three-dimensional surveys, full-wave field seismology, and seismic tomography. Despite these improvements, the seismic method as currently practiced does not approach the full potential capabilities of the technique. Areas where improved seismic technology is required include:

- imaging of low-relief subtle structures and stratigraphic traps
- seismic tomography to characterize reservoir heterogeneities
- direct detection and mapping of oil/water contacts
- direct detection and mapping of natural gas occurrences
- monitoring enhanced oil recovery processes
- accurate techniques for determining lithologies and porosities
- accurate measurement of pore fluid types and concentrations
- accurate delineation of complex structural traps in overthrust terrains
- siting of nuclear power plants
- waste management
- monitoring of fluid-flow fronts.

In addition, the detonation of nuclear explosives at the Nevada Test Site should be used as a seismic source to study deep geologic structure. These sources have been used by the Soviet Union to study the deep crust and upper mantle. The DOE should foster the use of these seismic sources by the seismology community because they hold the promise of providing greater resolution of deep structure than conventional sources.

Surface Geochemistry Exploration

Surface geochemical techniques provide a relatively cheap means of evaluating the hydrocarbon potential of large areas quickly and

inexpensively. Basic research is required to better understand the processes that govern the upward migration of hydrocarbon gases and fluids, the spatial and temporal variability of hydrocarbon microseepage, and chemical interactions between seeping hydrocarbons and common surface materials. Bacteria that use seeping hydrocarbons as a natural feedstock play a key role in producing geochemical anomalies in the near-surface environment; however, bacterial processes responsible for chemical alteration of surface materials are poorly understood at the present time. Two critical areas for future research are: 1) long-term studies of hydrocarbon microseepage rates in different geological settings and their relationship to environmental parameters, such as tidal stress, barometric pressure, antecedent rainfall, and atmospheric humidity; and 2) microbiological studies of bacterial processes in areas subjected to long-term microseepage. Research in these areas could eventually lead to predictive models that could forecast seepage-induced geochemical anomalies in different geological provinces.

Advanced Well Evaluation

Future evaluation of well bores will require advances in wire-line and remote-logging tools to provide accurate values of rock and fluid formation properties. With the advent of improved high-speed miniaturized computer systems, much of the digital log data will be reduced in real time for more rapid on-site well evaluations. New logging systems need to be developed for more accurate determination of:

- rock matrix compositions
- sedimentary structures and primary directional properties
- porosity and pore structure networks
- matrix and interstitial permeability
- in situ stress for preferred fracture propagation
- reservoir characteristics behind the casings
- natural and artificially stimulated fractured sets
- oil and gas saturations with a downhole sniffer
- ionic concentrations in formation fluids.

Advanced Technology Summary Recommendations

Creation of new tools and refinement of existing ones in the geological sciences is fundamental to all areas of DOE concern. Therefore, ERAB recommends that more advanced technology be funded, where applicable, within all geoscience research and development programs. The application of advanced technologies to geoscientific research has unlimited potential to increase the efficiency, decrease the costs, and decrease the environmental impacts of energy supply and production. New tools and methodologies have particular applications in programs in fossil energy, waste management, geothermal and nuclear resources, and in basic research in crustal processes.

HUMAN RESOURCES SUPPLY AND DEMAND

The United States appears to be at risk concerning the supply of well-trained and experienced geoscientists needed to address future energy supply and waste management challenges. Although the problem may affect all aspects of the geosciences, it is particularly acute and of immediate national importance in the petroleum and mining industries. Therefore, this report uses petroleum geoscientists as an example of the problem in human resources.

In the past ten years, there has been a sharp increase, followed by an equally steep decline, in the nation's demand for geologists, geophysicists, and geochemists. This represents the cyclic hiring history of the petroleum and mining industries. The current boom and bust cycle, with a shorter period and much greater amplitude than former cycles, has been triggered by global overproduction of crude oil, OPEC market manipulations, and mergers of major U.S. companies. These factors have resulted in significant cuts in exploration, production, and technical staff. Reductions by major companies have led to additional staff declines among smaller independent operators and related service companies.

Adding to the uncertainty in the petroleum industry are the questions posed by the recently passed tax legislation and the future viability of the domestic petroleum industry infrastructure. Reductions in the petroleum industry alone have led to unparalleled, abrupt declines in the number of undergraduate geoscience majors. It is expected that graduate student populations will begin to decline over the next three years if present market conditions prevail. Reductions in student populations extended over time will result in faculty reductions as well, which will ultimately result in insufficient numbers of well-trained geoscientists to meet the next energy crisis.

An unpredictable future for geoscientists and the volatility of hiring in recent years put all recent attempts at estimating present and future human resources into disarray. The national spectrum of human geoscience resources has never been inventoried accurately. The primary need in human resource evaluations is stable funding for statistical and demographic planning efforts already in place through the American Geological Institute. Presently available information, however, indicates that the petroleum industry employed about 60,000 geoscientists before forced lay-offs of 10,000 to 15,000. With early retirements and other separations, an estimated 25 to 30% of all geoscientists with petroleum geology training are presently unemployed or underemployed. Another 60,000 to 70,000 geoscientists are employed in unrelated areas. However, these individuals could not be considered as future human resources in petroleum geology for a variety of reasons (e.g., lack of current training). The present status of laid-off geoscientists is mixed. Some of those released in the past year are seeking employment opportunities in geoscience outside the petroleum industry, whereas others are moving to new careers

out of geoscience. Many geoscientists are seeking advanced degrees in other fields of science, whereas some are waiting out the down-turn in part-time, petroleum-related consulting.

A consequence of a cyclic, high-amplitude employment pattern is that a down cycle might become so prolonged that the formerly robust U.S. petroleum industry will suffer long-term damage. The reservoir of domestic human talent could be drained away before global energy needs revive enough to stimulate the job market. Without an experienced and competent domestic human reservoir in petroleum geology, the United States may suffer impaired national security and loss of strength caused by a shifting technology base. The United States has been the leader in petroleum geoscience, occupying a position of technical superiority in drilling, exploration, and research. At issue is the real possibility of a growing dependence on foreign technical personnel and energy resources, an increase in high labor and training costs, a loss of technological competitiveness, and a decrease in energy and defense security.

Human Resources Summary Recommendations

A resolution of the cyclic employment dilemma in the petroleum industry must begin with the universities. Students must accommodate their interest in geoscience with broader academic training and double majors in such areas as computer science, chemistry, engineering, physics, mathematics, biology, and business. There should be an increased emphasis in multidisciplinary education with a focus in geoscience. Additional training in petroleum and reservoir engineering will be required as emphasis changes from exploration to exploitation.

Critically needed by the profession is an accurate inventory of geoscientists. Where possible, employers should provide knowledgeable estimates of future needs for geoscientists. Educational and training profiles of both practicing and recently laid-off geoscientists must be reviewed. Continuously updated forecasts for future employment are required, and, if possible, models of future economic and geopolitical forecasting should be constructed. It is necessary that government and industry needs be made readily available to universities so that enrollments in universities can be synchronized with projected needs.

The DOE's responsibilities in stabilizing human resources should be increased to foster national energy security and competitiveness. Interaction with industry in geoscience research should be aggressively pursued. More research support should be provided to stimulate existing departments to improve geological programs that are addressing basic research. In addition, more cooperative ventures between the national laboratories and universities should be considered by the DOE. These efforts should take the form of expanded programs in laboratories where geoscience is now funded, and development of new programs in national laboratories where geoscience efforts have been minimal or nonexistent.

DOE should assume a responsible national role to preserve scientific and technical expertise in the geosciences. Categories of responsibility are assessing human resources, retaining a critical mass of geoscience research experts in universities and government, and providing institutional support to energy industries by encouraging a national policy commensurate with the country's energy needs.

Chapter 7

ORGANIZATIONAL STRUCTURE AND FUNDING

The geosciences are of critical importance to the DOE, especially in the areas of energy supply, environmental concerns, and waste management. Geosciences must play a central role in the search for solutions to U.S. energy problems. Unfortunately, geoscience research and technology development is extremely fragmented and dispersed throughout a minimum of six DOE offices, including the Offices of Energy Research, Conservation and Renewable Energy, Fossil Energy, Defense Programs, Environmental Safety and Health, and Civilian Radioactive Waste Management. As a result of this fragmentation, geoscientific work is generally of a service or applications type and is typically underfunded. Furthermore, what geoscience R&D currently exists is not well integrated across the multitude of DOE offices and programs. Consequently, little or no strategic planning is done and limited cross-fertilization takes place; these might have been able to at least leverage the productivity associated with the limited budgets.

Within the DOE, the activities of many technical disciplines (e.g., materials, chemistry, high-energy physics, computational sciences, etc.) are championed by high-level administration officials. Typically, these officials are trained and experienced in their respective fields. No such advocate for geosciences appears to exist within DOE. Given the importance of geosciences this seems inappropriate.

The U.S. energy problems call for a new organization within DOE to assure implementation of the geoscience initiatives described in this report and to conduct the strategic planning and prioritization required for future efficient and productive operation. Therefore, ERAB recommends the following:

- Establish in FY 87 a high-level DOE Office of Geoscience Research (OGR).
- Integrate existing DOE geoscience research projects into OGR where appropriate.
- Use more geoscientists in the DOE management structure, especially in program areas where geoscience is required in a service or technology applications mode.
- Define the role of OGR in the overall national energy research picture to avoid duplicating efforts and to promote coordination and cooperation among USGS, other government agencies, industry, and universities.

- Establish six regional oil and gas research centers as described in Chapter 2 on Fossil Energy; organizational plans should be completed by the director of OGR in FY 87.
- Have ERAB review periodically both program structure and progress after initiation of OGR and report its findings to the Secretary of Energy.

The OGR should be charged with the authority to develop and administer strategic plans to ensure that the geoscience research needs of the energy industry and DOE programs are identified and appropriately supported. The goal is to develop a unified comprehensive mission at both the planning and programmatic level. The Director of OGR should be a geoscientist/administrator with extensive research background in the geosciences.

Potential benefits accrued by creating the OGR include: 1) a vehicle for strategic planning; 2) a focal point for communicating application or technology needs as identified by other DOE offices, other government agencies, and industry; 3) a single clearing house for geoscience research results that can be transferred to others; 4) a more efficient means of communicating; 5) an improved method of applying R&D results from one program area to another; 6) an improved coordination and cooperation with other government agencies, especially the Department of Interior; 7) a better transfer of advanced technology from other disciplines; and 8) an organization that can serve as a strong advocate for the geoscience needs of the DOE.

The following existing DOE groups serve only as *examples* of a potential OGR composition. The OGR *could* initially be composed of existing geoscience groups listed as follows (*Geoscience Projects, FY 1985 Listing, DOE/ER-0277*):

- Energy Research
 - BES Geosciences
 - BES Carbon Dioxide Research
 - OHER Physical and Technological Research Division
 - OHER Ecological Research Division
- Fossil Energy
 - Natural Gas
 - Unconventional Gas Recovery
 - Oil Shale and Tar Sands
 - Enhanced Oil Recovery
 - Underground Coal Gasification
 - Advanced Technology

- Conservation and Renewable Energy
 - Geohydrothermal Resources
 - Geopressured Resources
 - Brine Injection Technology
 - Reservoir Technology
 - Caldera Reservoir
 - Hot-Dry Rock
 - Magma Resources.

Although the subject of this report is DOE civilian geoscience research, it must be noted that several high-quality geoscience research programs are funded under Defense Programs. Further consideration of the potential synergistic benefit from the interaction between the civilian and defense programs is compelling. There are also several application-oriented geoscience programs involved with nuclear and nonnuclear waste management. These should also be considered for inclusion in the OGR. However, because of the special utility tax funding status of the Office of Commercial Nuclear Waste Management, it does not seem appropriate that the geoscience portion of this program be considered. The aforementioned programs are listed only as examples. Detailed delineation of what existing geoscience programs might be aggregated into the OGR is beyond the scope of this report.

A major theme of this ERAB report is that the geoscience efforts within the federal government in general, and specifically the DOE, are inadequate. Therefore, the OGR should include expanded and new programs as well, especially in the area of oil and gas research. The six new regional oil and gas research centers discussed in Chapter 2 should become a major part of the OGR funding.

Because of high priority needs in oil and gas research, an initial annual funding increment of \$50 million is recommended, to be phased up to \$100 million annually by FY 90. The new funding would be a supplement to the current fossil-energy research programs, which would be consolidated into the OGR. Approximately ninety percent of the funding should be used to support: 1) the new regional geoscience research centers; and, 2) expanded activity in applied research by groups in the USGS, national laboratories, technology centers, universities and state organizations, where expertise should be utilized to achieve the new DOE policy objectives. The role of these DOE-supported programs should be to develop fundamental knowledge and advanced technology from research to support the private sector. These activities should not conflict with the traditional role of the oil and gas industry in the U.S. economic system. It is anticipated that facilities to accommodate the regional centers and other expanded activities are available at universities and federal laboratories. Therefore, the funding would be primarily used for labor and specialized equipment, and that

much of the actual research would be done on a technically competitive contract basis.

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GLOSSARY

acid precipitation - precipitation abnormally high in acids (sulfuric and nitric) as a result of man's activities

acoustic imaging - a method of graphically describing the earth's subsurface, using the travel time of sound waves

biostratigraphy - characterizing rock by its contained fossils

caldera - a circular volcanic depression whose diameter is many times greater than the diameter of the volcanic vent

calthrate - chemical complexes in which molecules of one substance are completely enclosed within the crystal structure of another

Cretaceous period - a geologic age occurring from 65 to 135 million years ago, when flowering plants rapidly expanded and dinosaurs became extinct

devitrification - the breakup of glassy rocks into definite minerals, usually crystalline quartz and feldspar

devolatilization - the removal of volatiles from a material

diagenesis - the process of chemical and physical alteration in geological materials

drilling cores - cylinders of soil or rock extracted from a well

drilling log - the record of a well drilling, containing information such as formations penetrated, drilling progress, depths of water, oil, gas or other minerals, and materials used to drill

electromagnetic imaging - a method of graphically describing the earth's subsurface using electromagnetic waves

fracturing - a method of increasing the fluid flow potential of geological strata near a well by pumping in fluid and sand under high pressure

gas hydrates - a gaseous compound formed by the union of water and some other substance, with the water being retained in its molecular state

geochronology - a system of dating to relate time and the history of the earth

geopressured resource - resources typically from depths of more than a mile or two under the earth's surface; characterized by abnormally high pressure and temperature

geothermal energy - the earth's internal energy, available as heated rocks or water

hydrocarbon - a chemical compound containing only the elements hydrogen and carbon

in situ - taking place where the subject material is originally from

kerogen - a bituminous material in oil shale; yields oil upon heating

lithology - the physical characteristics of a rock

lacustrine - produced by or formed in a lake

magma - molten rock within the earth

microfacies - the microscopic features of a rock

oil shale - a sedimentary rock containing kerogen, from which oil can be obtained

permeability - the capacity of a rock for transmitting a fluid

porosity - the ratio of the total volume of interstices or holes in a rock to the total rock volume

pyrolysis - chemical changes caused by heat

quad - a unit of heat energy equal to 10^{15} btu

scaling law - a law stating that two quantities are proportional at certain orders of magnitude, used to calculate the value of one of the quantities at another order of magnitude

radionuclide - a radioactive atomic nucleus

slagging - the formation of a vitreous mass left as a residue by smelting of a material

S-wave - a seismic bodywave propagated by a shearing motion of the material, so that there is oscillation perpendicular to the direction of propagation

supercomputer - a computer that is among the largest and fastest at the time

synfuels - hydrocarbon fuels derived from fossil energy deposits such as coal, oil shale, or tar sand

tar sand - a sand with the interstices filled with asphalt that remains after the escape of the lighter fractions of crude oil

Tertiary period - a geologic age occurring from 1 to 70 million years ago, marked by extensive mountain range formation and the rise of mammals

viscoelastic - a viscous material that also exhibits certain plastic properties, such as the ability to store the energy of deformation

ACRONYMS

BES - Basic Energy Sciences

DOE - Department of Energy

DOSECC - Deep Observation and Sampling of the Earth's Continental Crust, Inc.

EOR - Enhanced Oil Recovery

ERAB - Energy Research Advisory Board

ESB - Evolution of Sedimentary Basins

FY - Fiscal Year

NSF - National Science Foundation

OER - Office of Energy Research

OGR - Office of Geoscience Research

OHER - Office of Health and Environmental Research

R&D - Research and Development

SESP - Solid Earth Science Panel

TCF - Trillion Cubic Feet

TORIS - Tertiary Oil Recovery Information System

USGS - U.S. Geological Survey

APPENDIX A

DEPARTMENT OF ENERGY CHARGE LETTER AND SOLID EARTH SCIENCES PANEL ACTIVITIES

THE SECRETARY OF ENERGY
WASHINGTON, D.C. 20585

December 27, 1985

Mr. John Schoettler
Chairman
Energy Research Advisory Board
11855 East Daly Circle
Parker, CO 80134

Dear Mr. Schoettler:

Improved understanding of the solid earth can make an important contribution to the Nation's energy security, stability and strength and to our environmental well-being. For the foreseeable future, the energy needs of the Nation and the world will be met primarily by resources drawn from the earth. Oil, gas, coal, oil shale, uranium and geothermal resources all have a role to play. Not only are these resources extracted from the earth, but the byproducts of their conversion to useful energy are often returned there. Knowledge of the history, properties, structure and processes of the solid earth should improve our ability to identify energy resources, extract them efficiently and dispose of their byproducts acceptably.

The Department of Energy (DOE) has many research and development programs involving the solid earth sciences, including such topics as basic research on continental structure, modeling enhanced oil recovery and underground migration of chemicals. Also, some of the unclassified information associated with geophysics related to DOE weapons responsibilities might be more broadly useful. Other Federal agencies support related research, as do the energy industries. For the DOE programs to be effective, they must focus on the highest priority topics relevant to our mission. I would like the Energy Research Advisory Board to review this area.

In particular, the review should examine:

- o The short and long term earth science needs of the energy industries, the needs of DOE programs and the current R&D efforts.
- o The arrangements for coordination and cooperation with industry, universities, and other agencies.
- o The opportunities for changes in DOE program emphasis.

This study should help to ensure that our R&D investments in this area are appropriate in terms of both the proper role of government and our future energy needs. The Office of Energy Research will provide staff assistance for this important task, which I hope can be completed by November 1986.

Yours, truly,

A handwritten signature in dark ink, appearing to read "John S. Herrington". The signature is stylized with a large, looped initial "J" and a long, sweeping underline that extends across the name.

John S. Herrington

Meeting 1

SOLID EARTH SCIENCE PANEL: ERAB
 Forrestal Building
 Washington, DC
 March 18/19, 1986
 Room 8E-089

TUESDAY, March 18

8:30 a.m.	Coffee in Anteroom	
9:00	Introduction and Briefing on Mission of ERAB and Past Studies	John Schoettler, ERAB Chairman
	DOE and the National Labs	Joel Snow, ERAB Acting Exec. Secty.
	Administrative Items	Bill Woodard, Panel Secty.
9:15	Overview of Current Earth Sciences Programs in DOE	Jim Coleman, DOE
	• Basic vs. Applied Research Programs (Definition)	
	• Organizational Framework for Programs	
	• Other Committees or Councils Serving in an Advisory Role to DOE	
	DOE PROGRAMS IN SOLID EARTH SCIENCE	
9:35	a. Fossil Energy	Douglas Uthus, DOE
10:30	BREAK	
10:45	b. Conservation, Renewables & Geothermal	John (Ted) Mock, DOE
11:45	LUNCH	
12:45 p.m.	c. National Laboratories	William Luth, Sandia
1:45	d. Office of Energy Research	George Kolstad, DOE
2:30	BREAK	
2:45	e. Radioactive Waste Management	Ben Rusche, Director, Office of Civilian Radioactive Waste Management
3:45	SUMMARY DISCUSSION	
4:30	ADJOURN	

March 19
Room 4a-110

WEDNESDAY, March 19

ISSUES AND ACTIVITIES OF OTHER FEDERAL AGENCIES IN SOLID EARTH SCIENCES
(ENERGY RELATED SUBJECTS)

8:30 a.m.	U.S. Geological Survey a. All Areas of Funding from DOE b. Programs Being Cut or Reduced c. International Programs d. Potential for Joint USGS/DOE	Raymond Watts, Acting Asst. Director for Research
9:30	National Science Foundation	James Hays, Div. Dir. Division of Earth Sci.
10:30	BREAK	
10:50	Other Federal Agencies National Academy of Sciences	Joseph Berg, Staff Dir. Board on Earth Sci.
	Department of State a. Policy Issues and Energy Security b. Geoscience Funding in International Programs	Don Jamerson, Prin. Dep. Dir., Off. of Science & Tech. Prog.
12:20 p.m.	LUNCH	
1:20	Discussion for Future Directions: Industry, Academic, and Government needs for Earth Scientists in the Long and Short Term (What is "short" and "long"?) a. Present and past status of supply of earth scientists. b. Future predictions. c. Recommendations for industry, academia, and Government. d. Status of cooperative programs.	
1:50	Review of Meeting, discussion of Agenda Items for Next Meeting	
3:00	ADJOURN	

Meeting 2

SOLID EARTH SCIENCE PANEL: ERAB
 Sandia Labs, Albuquerque, New Mexico
 June 2/3, 1986

MONDAY, June 2

8:30 a.m.	Introductory Comments	R. Weimer, Chairman, SESP J. Schoettler, Ex. Officio, SESP
8:45	Status Report on DOE Geoscience Working Group	L. McGinnis, Tech. Adv. SESP
9:00	Overview of Geoscience Program: Morgantown Research Center (20 minute presentation with 10 minute discussion)	C. Komar and W. Gwilliam, Geologists Morgantown Energy Technology Center
9:30	Summary of Congressional Testimony (10 minute presentation with 20 minute discussion)	C. Mankin, Director Oklahoma Geological Survey
10:15	State Government Activities General Statement on Past, Present, Future Activities	
	a) Coal and Uranium (35 minute presentation with discussion)	F. Kottowski, Director New Mexico Bureau of Mines and Mineral Res.
	b) Geothermal, Oil Shale, Coal (35 minute presentation with discussion)	G. Atwood, State Geologist Utah Geological and Mineral Survey
	c) Oil, Gas, Coal (20 minute presentation with discussion)	C. Mankin, Director Oklahoma Geological Survey
11:45	LUNCH	
1:00 p.m.	Status of Industry Research (30 minutes each with discussion)	
	a) CHEVRON	L. Bonham, Panel Member
	b) ARCO	M. Milling, Panel Member
	c) Marathon	F. Poettman, Professor Co. School of Mines
	d) Golden and Land Oil Company	C. Land
3:00	BREAK	
3:20	Status of Continental Scientific Drilling	F. Stehli, Vice Chairman, SESP
3:50	General Panel Discussion: Open Topics	R. Weimer, Chairman, SESP
4:30	ADJOURN	

TUESDAY, June 3

8:00 a.m.	University Programs in Energy Research in the Solid Earth Sciences (30 minutes each with discussion)	
	a) Basin Research Institute Coastal Studies Institute	J. Coleman, Director LSU Geosciences Geology Dept., LSU
	b) Houston Area Research Center (HARC), Geotechnology Research Institute	M. Talwani, Director
	c) Oklahoma Energy Institute	F. Stehli, Vice Chairman, SESP
	d) Exploration Geoscience Inst. (10 minutes) Colorado School of Mines	R. Weimer, Chairman, SESP
9:40	BREAK	
10:00	Studies of AGI Study on Geoscience Manpower	M. Milling, Panel Member
	Academic Enrollment Trends	M. Milling, Panel Member W. Dickinson, Panel Member R. Weimer, Chairman, SESP
10:30	General Discussion on Manpower Problems, Academic Enrollments, Professional Dislocations, etc.	
11:00	General Discussion of the Effect of Economic Climate on Energy Research; Summary of Resource Base	
12:00 p.m.	LUNCH	
1:00	Overview of Sandia Labs	I. Welber, President Sandia National Labs.
	Geoscience Review of Sandia Labs Programs	W. Luth, Manager Geosciences Department, Sandia National Labs
5:00	ADJOURN	

Meeting 3

SOLID EARTH SCIENCES PANEL: ERAB
 Forrestal Building, 4A 110
 Washington, DC
 July 28/29, 1986
 Room 4A-110

MONDAY, July 28

8:30 a.m.	Introductory Comments	R. Weimer
9:00	Security Issues and Petroleum Supply	Daniel P. Serwer, Director Office of Energy Consumer Country Affairs, Department of State
9:45	BREAK	
10:20	Coal Liquefaction	J. Batchelor, DOE
11:00	Earth Science Related Research in OHER-DOE	H. McCammon, Director Ecological Research Div.
11:30	1) Review and Discussion of Geoscience Research Documents FY 85	
	2) Funding and Organizational Structure of Programs Within DOE	
	3) Procedures Within DOE for Prioriti- zation of Geoscience Research Activities	
12:00 p.m.	LUNCH	
1:00	Discussion of Contents and Recommenda- tions of SESP Report	
5:00	ADJOURN	

TUESDAY, July 29

8:30 a.m.	Introductory Comments	
8:45	Morgantown Energy Technology Center (METC) Research in EOR, Oil Shale and Liquids from Coal or Gas	A. Pitrolo, Director Morgantown Energy Technology Center
9:40	Oil and Energy Crises of the Future	D.E. Kash, Professor Sci. and Public Policy Univ. of Oklahoma
10:15	BREAK	
10:30	Continuation of Panel Discussion on Contents and Recommendations of Report	
11:45	LUNCH	
1:00 p.m.	Continuation of Panel Discussion on Contents and Recommendations of Report	
3:00	Place and Agenda for Next Meeting	
3:20	ADJOURN	

Arrangements are being made for a visit by Panel members to METC on Wednesday, July 30.

Meeting 4

SOLID EARTH SCIENCE PANEL: ERAB
Solar Energy Research Institute
Golden, Colorado
September 15/16, 1986
Room 17/3A

MONDAY, September 15

9:00 a.m.	Discussion of Panel Report	
11:00	National Coal Research	Jack Medlin, Asst. Chief Geologist, East. Region, USGS
12:00 p.m.	LUNCH	
1:00	Discussion of Panel Report	
5:00	ADJOURN	

TUESDAY, September 16

9:00 a.m.	Discussion of Panel Report	
11:00	Fossil Energy Program Overview	Marvin Singer, Dir. Advanced Technology Programs, Office of Fossil Energy, DOE
12:00 p.m.	LUNCH	
1:00	Discussion of Panel Report	
5:00	ADJOURN	

ADDITIONAL SITE VISITS

Apr-14	Lawrence Berkeley (Weimer, Milling, Schoettler, McGinnis)
Apr-15	Lawrence Livermore (Weimer, Milling, Schoettler, McGinnis)
Jun-2/3	Sandia (Meeting 2) (all SESP Panelists)
Jun-04	Los Alamos (SESP Panel)
Jul-21	Bartlesville Energy Technology Center (Weimer, Hanshaw, Luth, Schock, Domenico, McGinnis)
Jul-22	AMOCO Research Center (Weimer, Hanshaw, Mitchell [for Milling], Domenico, McGinnis)
Jul-30	Morgantown Energy Technology Center (SESP Panel)
Jul-31	Pittsburgh Energy Technology Center (Weimer and McGinnis)

APPENDIX B

SUMMARY OF ERAB RECOMMENDATIONS FOR DOE LONG-TERM CIVILIAN R&D PROGRAMS

APPENDIX B

SUMMARY OF ERAB RECOMMENDATIONS FOR DOE LONG-TERM CIVILIAN R&D PROGRAMS

This appendix contains a summary of ERAB recommendations and comments contained in the report "Guidelines for DOE Long Term Civilian Research and Development" (Vol. 1, Overview and Summary, 1985). General recommendations to the Department of Energy are reproduced in Table B.1. Recommendations on Energy Supply Issues are listed in Table B.2.

Expenditures on DOE Geoscience programs are listed in Table B.3 taken from the Office of Energy Research report "Geoscience Projects, FY 1985 Listing (1986)." A break-down of expenditures for Fossil Energy programs is listed in Table B.4. These data are extracted from the Fossil Energy Budget listing for FY 1986.

TABLE B.1
SUMMARY OF MAJOR RECOMMENDATIONS FOR DOE LONG-TERM CIVILIAN R&D PROGRAM

Primary National Objectives	Important Relevant Activities/ Technologies (DOE Role Varies)
<ul style="list-style-type: none"> REDUCE U.S. LONG-TERM DEPENDENCE ON FOREIGN OIL <p>Primary Driving Forces: Economic and National Security</p>	<ul style="list-style-type: none"> New Sources of Domestic Oil and Gas Enhanced Oil Recovery Geosciences Research Demand Reductions in Buildings and Industry Fuel Switching in Industry and Transportation Synthetic Fuels
<ul style="list-style-type: none"> ASSURE AN ADEQUATE SUPPLY OF ECONOMICAL, SAFE AND ENVIRONMENTALLY ACCEPTABLE ELECTRIC POWER <p>Primary Driving Forces: Economic, National Security, and Environmental</p>	<ul style="list-style-type: none"> Clean Use of Coal Nuclear Safety and Waste Disposal Environment and Health Impacts Fusion Photovoltaics Alternate Nuclear Reactors Including Breeders Advanced Research Projects
<ul style="list-style-type: none"> CONTINUE THE DEVELOPMENT OF A STRONG NATIONAL BASIC SCIENCE BASE <p>Primary Driving Force: Scientific</p>	<ul style="list-style-type: none"> Basic Energy Sciences <ul style="list-style-type: none"> Materials Chemistry Geosciences Engineering Mathematics Nuclear Biological Health and Environmental Research High Energy Physics Nuclear Physics Nuclear Medicine

Program Implementation	Required DOE Actions
<ul style="list-style-type: none"> DRAMATICALLY UPGRADE DOE'S RESEARCH AND DEVELOPMENT MANAGEMENT CAPABILITIES <p>Primary Driving Force: Economic</p>	<ul style="list-style-type: none"> Reorganize Stabilize Implement Strategic Planning Intensify Meaningful Industry Interactions Upgrade Staff Quality Terminate Weak Programs Improve Management Procedures for the National Labs

TABLE B.2
COMMENTS ON R&D PROGRAMS RELATED TO KEY SUPPLY ISSUES

Issue	Related R&D Programs	Probability of Success	Federal Role
• LIQUID FUELS SUPPLY	• Improve enhanced oil recovery (EOR)	Technical: Good Economic: Varied	EOR is primarily in private sector domain. Scaled-up DOE geosciences research would help and is recommended.
	• Demonstrate synfuels and biofuels technologies	Technical: Good Economic: Difficult	Synfuels depend on government support.
• NATURAL GAS SUPPLY	• Increase development of unconventional gas	Same as above	Private sector (GRI) will pursue near-term unconventional gas.
	• Demonstrate synthetic gas technology	Same as above	High risk sources, such as geopressed zone methane and synthetic gas, require government support.
• CLEAN COAL COMBUSTION	• R&D and demonstration of a diverse set of technologies for both retrofit and new plants	Good	Mainly to give leadership and some financial support to private industry programs by EPRI and others.
• RENEWABLE ENERGY	• R&D on diverse set of technologies	Technical: Most are assured Economic: Difficult	Certain technologies warrant substantial DOE support. All are high risk.
• NUCLEAR FISSION	• R&D on safety and geo-technical emplacement of wastes	Good	Lead role on waste disposal and supporting role on safety.

TABLE B.2 (CONTINUED)
COMMENTS ON R&D PROGRAMS RELATED TO KEY SUPPLY ISSUES

Issue	Related R&D Programs	Probability of Success	Federal Role
• BREEDER/FUSION	• R&D on breeder components and possible new approaches	Varied	DOE is dominant in both breeder and fusion R&D.
	• Projects on magnetic confinement and inertial fusion	Undetermined	
• TRANSMISSION AND DISTRIBUTION	• R&D on overhead and underground transmission, health effects, resistance to EMP, etc.	Varied	DOE to share cost with private sector.
• ENVIRONMENTAL CONSTRAINTS ON ELECTRIC POWER SUPPLY	• R&D on environmental impacts, Good emission standards, toxics, control technologies, and reliability/operability/costs aspects of new emission control options		Federal lead role appears mandatory. EPA and DOE must be involved in this area.
	• Studies on optimum integration of new technologies	Good	

TABLE B.3
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***

*-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: Data from Geoscience Projects, FY 1985 Listing, DOE/ER-0277, 176p.

TABLE B.4
FY 86 FOSSIL ENERGY SUMMARY (\$ in thousands)

	Bartlesville Proj. Off.	Grand Forks Proj. Off.	Laramie Prof. Off.	Morgantown Energy Tech C.	Pittsburgh Energy Tech C.	DOE-OPS	Nat. Labs	Fossil Energy Headquarters	Total *
Adv. Res. & Tech.		1038		4851	11170	145	13552	3093	33849
Coal	502	4727	1782	62367	53381	836	12381	2102	138078
Fuel Cells				28623		3517	1723	194	34057
Heat Engines		445		11844				25	12314
Magnetohydrodynamics					7687	18866	970	194	27717
Uncon Gas				3475			4476	552	8503
Adv. Proc. Tech.	3210	10	320	668			1049	266	5523
EOR	6212		1058	1379		964	1209	632	11454
Oil Shale			5450	1261			4985	440	12136
Totals	9924	6220	8610	114468	72238	24328	40345	7498	283631

*If items under management (53156), capital equipment (6197), liquid gas spill (1732), Strategic Petroleum Reserve (148395), and NPR (168845) are included the total is 661956.

APPENDIX C

ENERGY SOURCES AND USES

APPENDIX C

ENERGY SOURCES AND USES

Any evaluation of DOE research expenditures must consider the overall U.S. energy usage, present and future, and energy resource availability. U.S. energy usage for 1985 and projections to the year 2000 are shown on Figures C.1 and C.2. The reference is from Lawrence Livermore National Laboratory.

The resource base from which future energy supplies may be obtained was described in the ERAB report on Supply (*Volume VI of the Guidelines for DOE Long Term Civilian Research and Development, 1985*). The U.S. resource base for oil, gas and coal, shown as Figure C.3 and Tables C.1- C.5 are taken from articles in ERAB Report by Cook, Linden, and Reichl. An example of U.S. oil and gas producing regions is shown in Figure C.4.

Source of the data used in the construction of the charts shown a Figure C.1 and C.2 is the Department of Energy's *1985 Annual Energy Review, May 1986 and The National Energy Policy Plan Projections to 2010, December 1985*. The balance between energy supplied and energy consumed by the U.S. economy is not perfect for all fuels due to rounding procedures. "Nonfuel" end-use consists of energy sources that are not used to produce heat, e.g., asphalt, petrochemicals, carbon black, waxes, etc. The division between "useful" and "rejected" energy is dependent on assumed efficiencies of conversion processes. For residential/commercial end-uses a 75% efficiency was assumed, which is an average between space heating (60%) and other electrical uses (90%). Eighty percent efficiency was assumed for industrial uses and 25% in the transportation sector, the approximate efficiency of the internal combustion engine.

The charts for the sake of consistency record net hydroelectric and geothermal energy based on kilowatt-hour generated. The total of 94 quads (1015) for 1985 is the DOE total which includes gross amounts and is several quads higher than the input and output shown in the chart. Only net amounts are included in both the 99-quad total and the chart for the year 2000.

U.S. Energy Flow – 1985

Net Primary Resource Consumption 74 Quads

I. Borg / C. Briggs
Revised 9/86

FIGURE C.1

U.S. Energy Flow - 2000

Net Primary Resource Consumption 99 Quads

FIGURE C.2

U.S. Oil Reserves Position (Source: Extracted from Cook, 1985,
as Revised from USGS Circ. 860, 1980)

FIGURE C.3

FIGURE C.4 EXAMPLE OF SUBDIVISION OF U.S. INTO SIX OIL AND GAS-PRODUCING PROVINCES

TABLE C.1
CURRENT ESTIMATES OF REMAINING RECOVERABLE CONTINENTAL U.S.
NATURAL GAS (TRILLION CUBIC FEET)

Estimate	<u>New Fields</u>		<u>Old Fields</u>		Total Potential	1981 Proved Reserves ^a
	Onshore	Offshore	Onshore	Offshore		
<hr/> <u>Lower-48 Resources</u> <hr/>						
USGS ^b	390.2	102.4	132.1	39.8	664.5	169
Potential Gas Committee ^c	442 ^d	116	151 ^d	33	742	169
<hr/> <u>Alaskan Resources</u> <hr/>						
USGS ^b	36.6	64.6 ^e	4.4	1.2 ^f	106.8	33
Potential Gas Committee ^c	44	82	6	2	134	33
<hr/> <u>Approximate Total Remaining Recoverable Resources --</u> <u>Proved Reserves and Potential^g</u> <hr/>						
	<u>Onshore</u>		<u>Offshore</u>		<u>Total</u>	
USGS ^b	724.6		248.4		973.0	
Potential Gas Committee ^c	805		273		1078	

^a Energy Information Administration (EIA) proved reserves data is as of Dec. 31, 1981.

^b The U.S. Geological Survey (USGS) estimates reflect the data of the 1980-1981 time period. Onshore drilling depth of 0-30,000 ft; offshore lower-48 water depth of 0-2500 m. USGS Circular 860 (G. Dolton et al.) 1981.

^c The Potential Gas Committee (PGC) estimates are as of Dec. 31, 1982. Onshore drilling depth of 0-30,000 ft except Alaskan Old Fields: 0-15,000 ft; offshore water depth of 0-1,000 m except Alaskan Old Fields: 0-200 m. Potential Gas Committee, Potential Supply of Natural Gas in the U.S. as of December 31, 1982, June 1983.

^d Onshore lower-48 potential resources by depth (Tcf):

<u>Depth (ft)</u>	<u>New Fields</u>	<u>Old Fields</u>
0-15,000	216	103
Over 15,000	226	48
Total	442	151

^e Water depth of 0-2400 m.

^f Water depth of 0-200 m.

^g Total Remaining Recoverable Resources are defined to be the sum of proved reserves and potential resources.

Linden (1985)

TABLE C.2
CURRENT ESTIMATES OF IN-PLACE AND RECOVERABLE TIGHT SANDS
U.S. NATURAL GAS RESOURCES

Estimate	Gas Price (1982 \$/1000 cf)			Gas In-Place	Total Gas Recoverable
	\$2.50	\$5.00	\$9.00		
	(TCF) *	(TCF)	(TCF)	(TCF)	(TCF)
GRI Estimates **				950	640
• Present Technology	100	240	310	-	-
• Advanced Technology					
• Geological and Geophysical	140	270	330	-	-
• Plus Fracture Design and Diagnostics	210	350	440	-	-
• Plus Real-Time Diagnostics and Control	250	410	510	-	-
NPC Estimates ***				924	608
• Base Technology	200	320	400	-	-
• Advanced Technology	280	470	590	-	-

*
TCF is Trillion Cubic Feet

**
The National Petroleum Council (NPC) resource estimates were the basis for GRI's analysis. Differences in total gas recoverable and gas-in-place involve the correction of gas compressibility factors used by the NPC made in the development of the Tight Gas Analysis System (TGAS: by Lewin & Associates). After closely replicating the NPC results, TGAS was used to develop the GRI estimates based on different assumptions on advanced technology. NPC estimates were updated to reflect changes in various production cost components.

Source: National Petroleum Council, Unconventional Gas Sources, Vol. V, "Tight Gas Reservoirs," 1980.

Source (Linden, 1985)

TABLE C.3
CURRENT ESTIMATES OF IN-PLACE AND RECOVERABLE DEVONIAN SHALES,
NATURAL GAS, AND COAL SEAM METHANE RESOURCES IN THE LOWER 48 STATES

Estimate	Gas Price (1982 \$/Mcf)*			Total Gas Recoverable	Gas In-Place
	\$2.50	\$5.00	\$9.00		
	(TCF)	(TCF)	(TCF)	(TCF)	(TCF)
Devonian Shales Gas (Appalachian Basin Only)				50	225-1861**
• Traditional Technology	3	11	17	-	-
• Advanced Technology	12	27	39	-	-
Coal Seam Methane				N/A \$	398
• Traditional Technology †	3	20	38	-	-

*

Based on National Petroleum Council studies (1980) of each resource. Gas prices based on recoverable producer costs in 1979 dollars plus required return on investment. Well drilling costs today are roughly equivalent to 1979 levels.

**

Lower estimate includes black shales only. Higher estimate includes grey shales.

\$

N/A = data not available.

†

No advanced technology case provided.

Source: National Petroleum Council, Unconventional Gas Sources, Vol. II, "Coal Seams," and Vol. III, "Devonian Shale," 1980.

Linden (1985)

TABLE C.4
NATIONAL COAL ASSOCIATION FORECAST OF U.S. COAL CONSUMPTION
(10⁶ tons/yr)

Coal Consumption	1985	1995	10-yr growth (%)
Electrical Utilities	633-642	752-881	19-37
Metallurgical	48-50	47-52	0-4
Industrial, etc.	76-86	100-145	30-68
	<u>757-778</u>	<u>899-1078</u>	<u>19-39</u>
Export	<u>81-111</u>	<u>113-157</u>	<u>39-41</u>
Total	838-889	1012-1235	20-39

TABLE C.5
DEMONSTRATED RESERVE BASE OF COAL IN THE U.S. (10⁹ tons)

Area	Anthracite	Bituminous	Subbituminous	Lignite	Total
East of Mississippi	7.2	219.8	-	1.1	228.1
Underground	7.1	180.4	-	-	187.5
Surface	0.1	39.4	-	1.1	40.6
West of Mississippi	0.1	35.8	181.5	44.0	261.4
Underground	0.1	26.7	118.8	-	145.6
Surface	-	9.1	62.7	44.0	115.8
U.S. Total	7.3	255.6	181.5	45.1	489.5
Underground	7.2	207.1	118.8	-	333.1
Surface	0.1	48.5	62.7	45.1	156.4

Source: Energy Information Administration, Coal Production, 1983, DOE/EIA-0188, U.S. Department of Energy (1983).

Reichl (1985)